Presentation to

California Carbon Capture and Storage Review Panel Meeting

August 18, 2010

Presentation Outline

Saline Aquifer Storage Overview

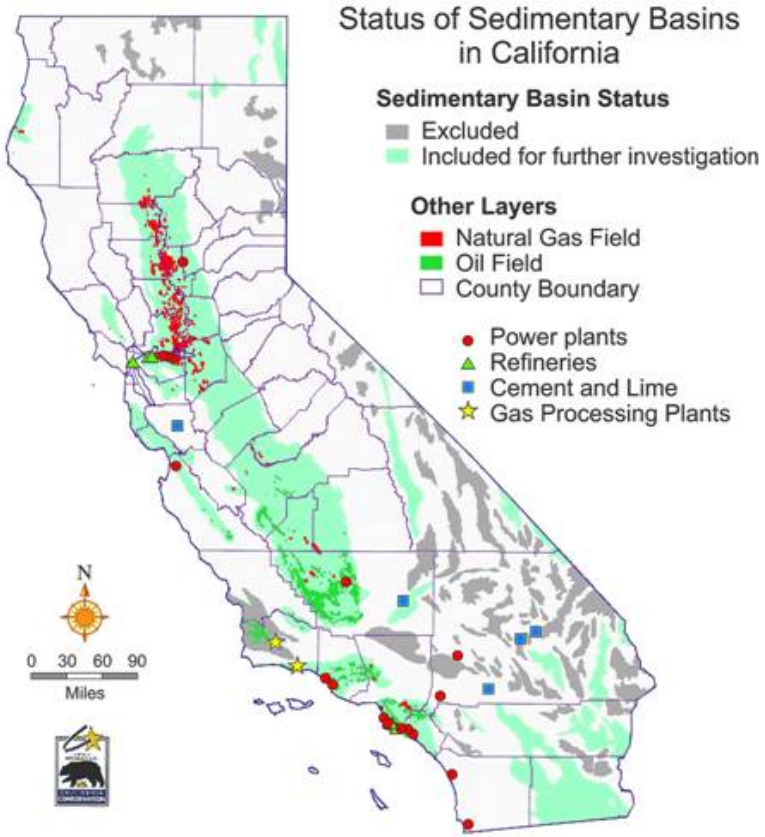
- Motivation and Opportunities in California
- Advantages and Disadvantages Relative to Oilfield Storage

Reservoir Characterization and Safe Injection Operations

- Assessing Storage Capacity
- Assessing Sealing Characteristics
- Assessing and Mitigating Risks
- Appropriate Operating Parameters and Monitoring

Sample Opportunities in San Joaquin Basin and LA Basin

Discussion



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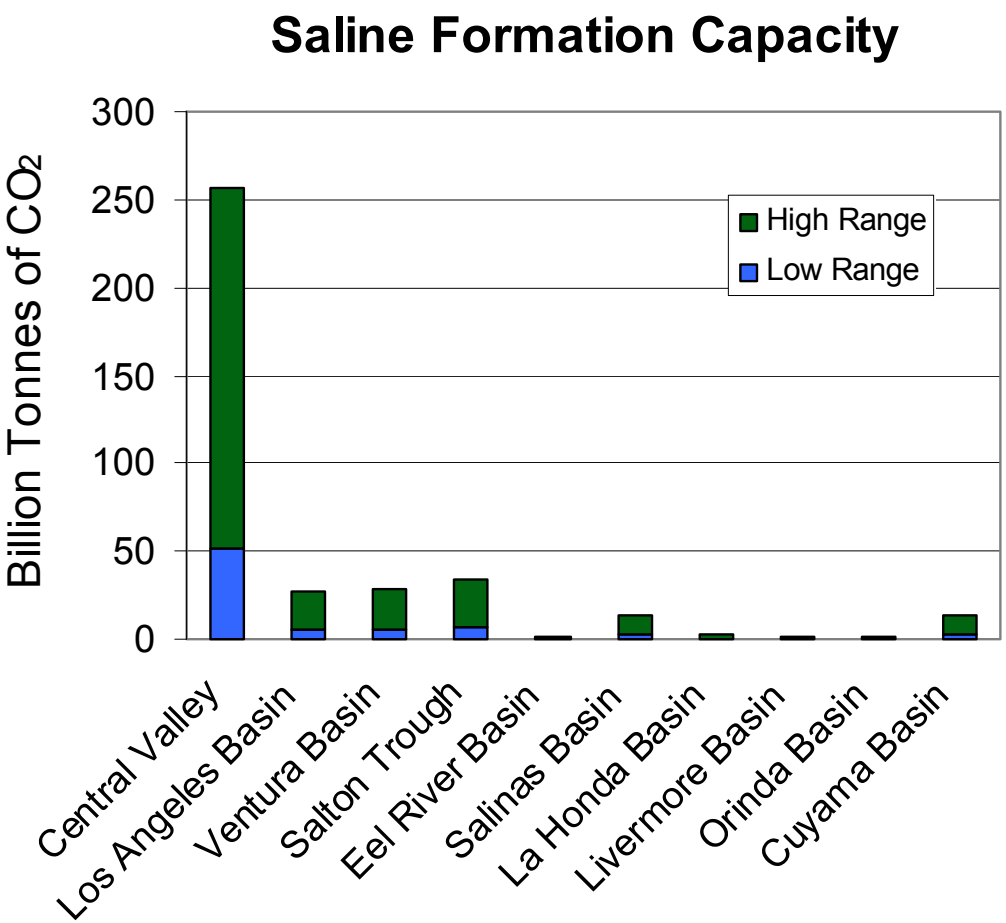


Estimated CO_2 storage capacities for ten largest sedimentary basins in California

Advantages Relative to EOR or Storage in Depleted O&G Fields:

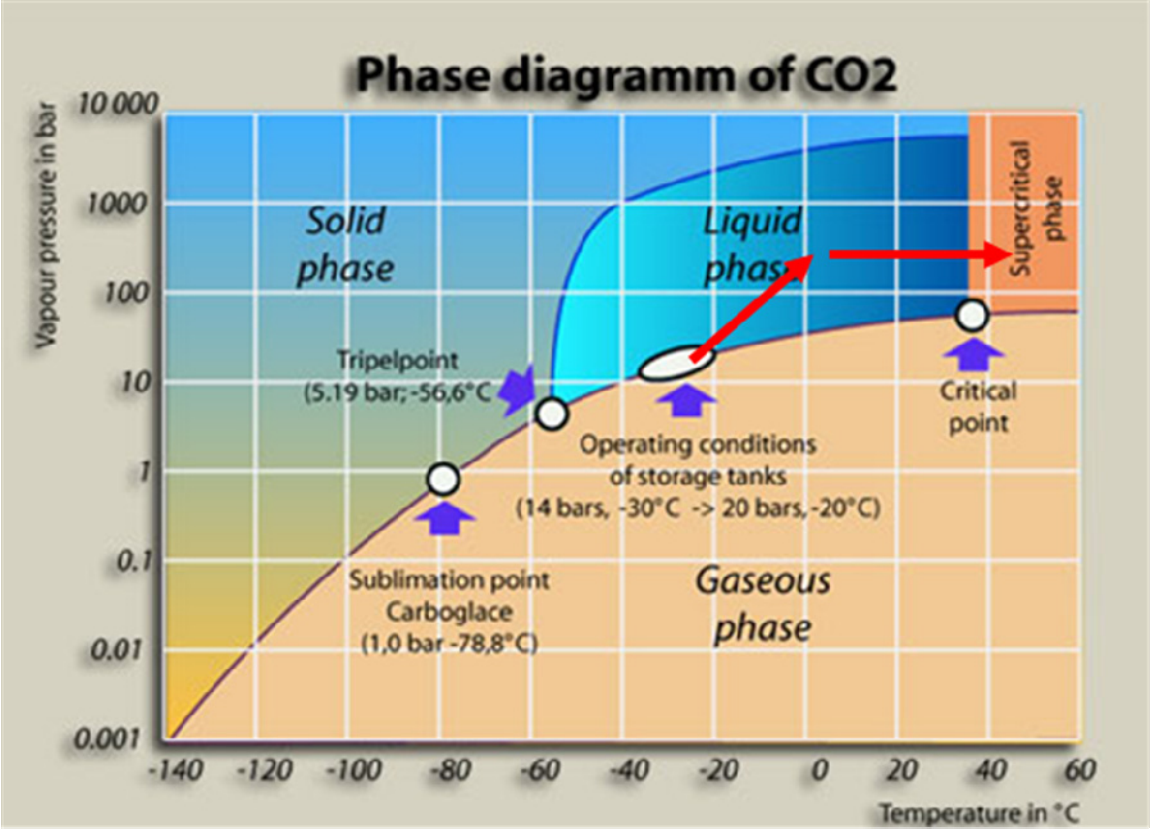
1. Geographically much more pervasive throughout California
2. Much higher storage capacity
3. Fewer old/existing wells resulting in lower leakage risk
4. Limited impact on existing O&G production
5. Longer term operation relative to EOR (less likely to produce/cycle CO2)

Disadvantages Relative to EOR or Storage in Depleted O&G Fields:

1. Limited geologic data requires more extensive characterization
2. Limited economic incentive (relative to EOR)
3. Generally requires greater reliance on solubility trapping
4. Less common, fewer analogs, more challenging public outreach

CO2 storage in saline aquifers (and depleted O&G fields) requires EPA underground injection permit (Class I, Class V, or Class VI)

CO2 injection for enhanced oil recovery requires CA DOGGR injection permit (Class II)

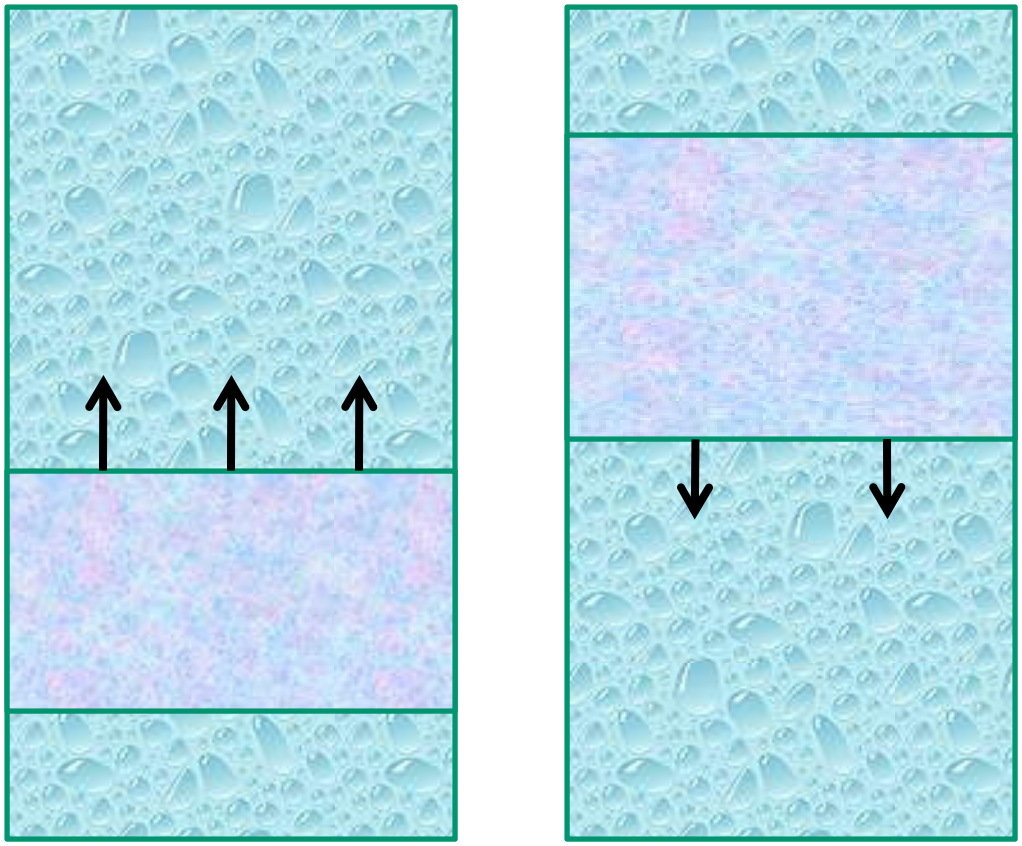


(100bar = 1450psi)

After injection in the subsurface, the CO_2 will become trapped within the pore space of the rock formation through three primary storage mechanisms:

- **Structural storage;** (requires appropriate geology)
- **Solubility storage; and,** (requires sufficient time)
- **Mineral storage**. (requires appropriate lithology/chemistry and sufficient time

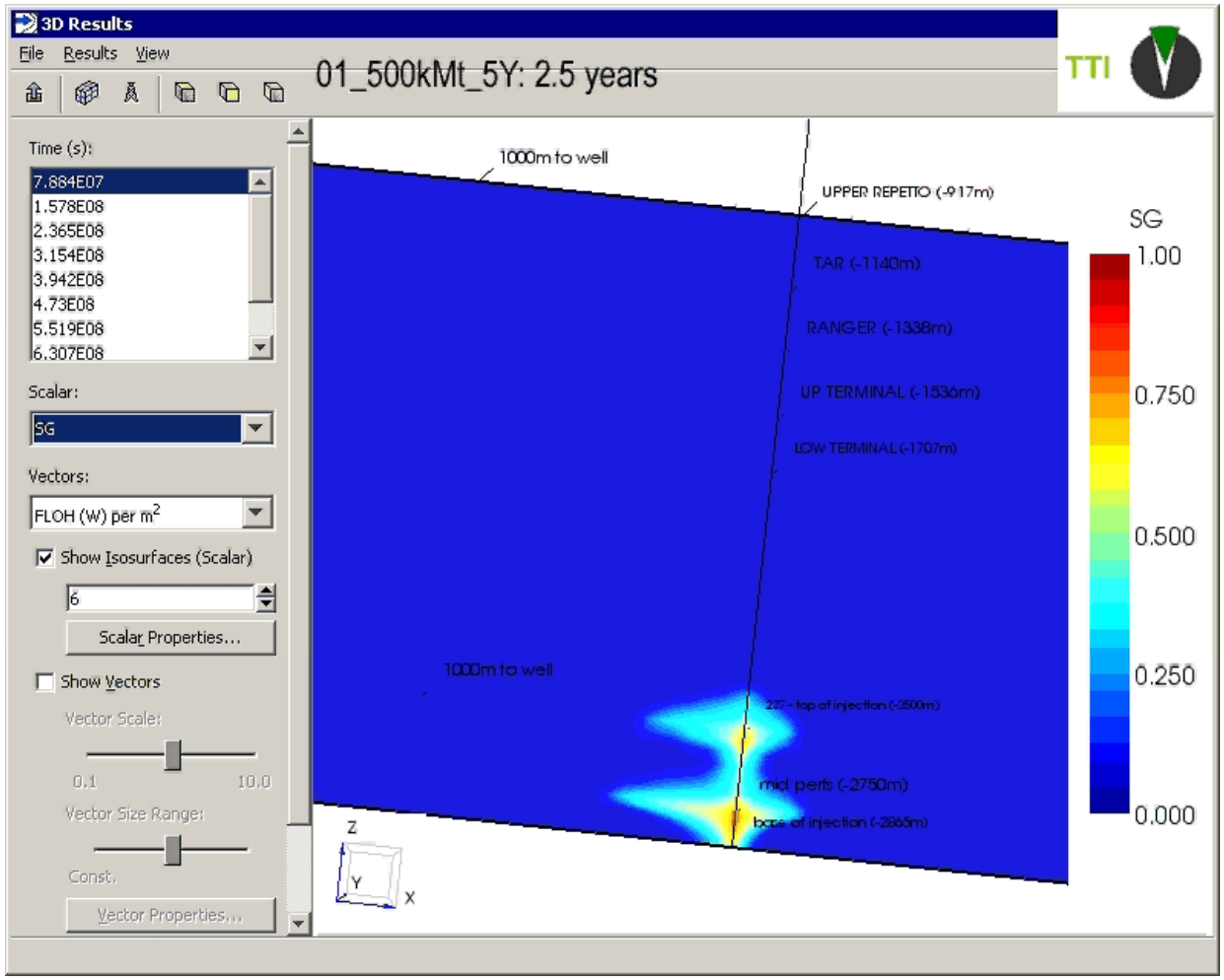
Supercritical CO2 less dense than formation water and will rise due to buoyancy



CO2 Saturated water slightly more dense than formation water, and will eventually drop over time

Several Years Time

Movie – Simulation 01 – Gas Saturation



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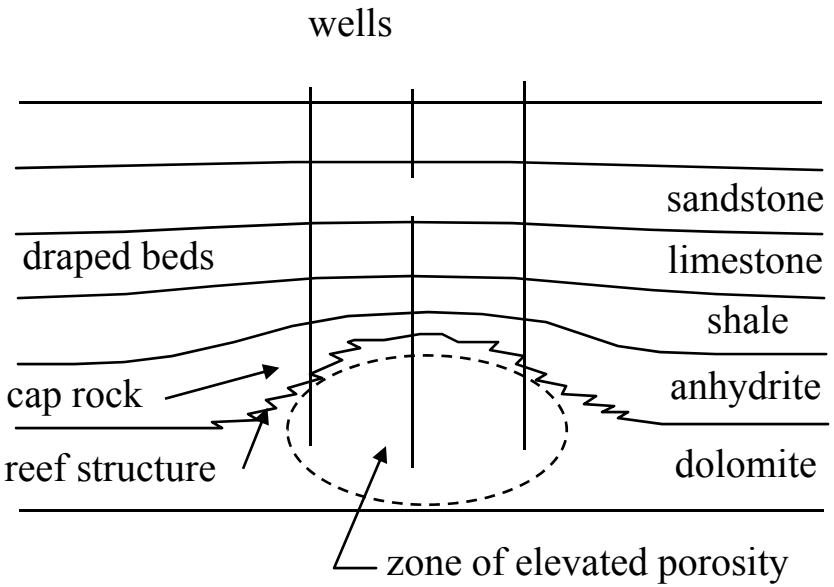
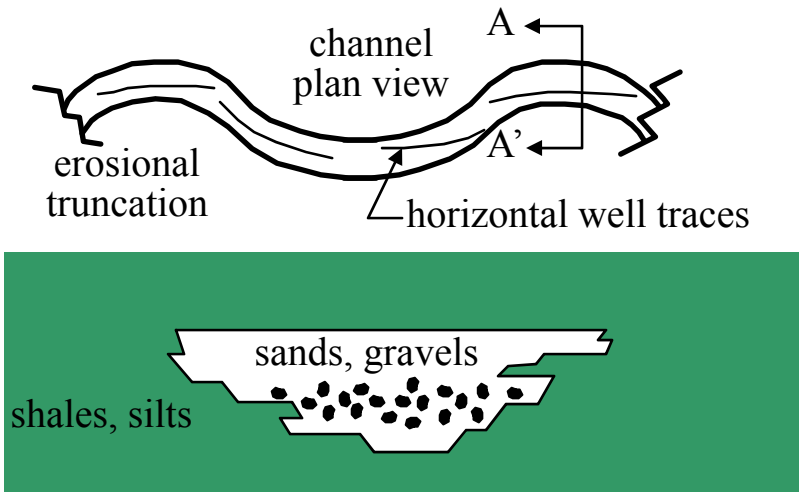
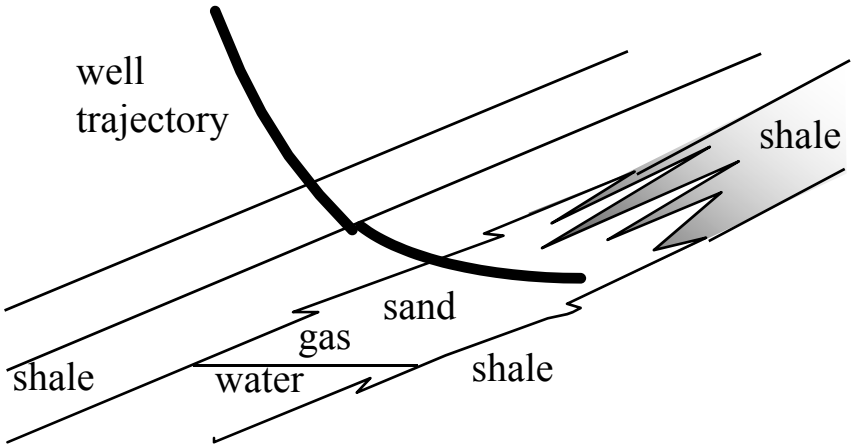


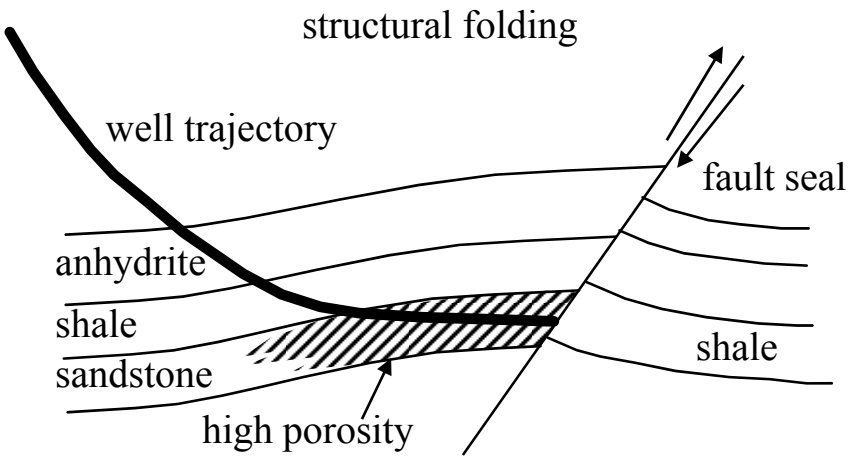
a. Carbonate reef with closure for gas storage



b. Channel sand of limited length

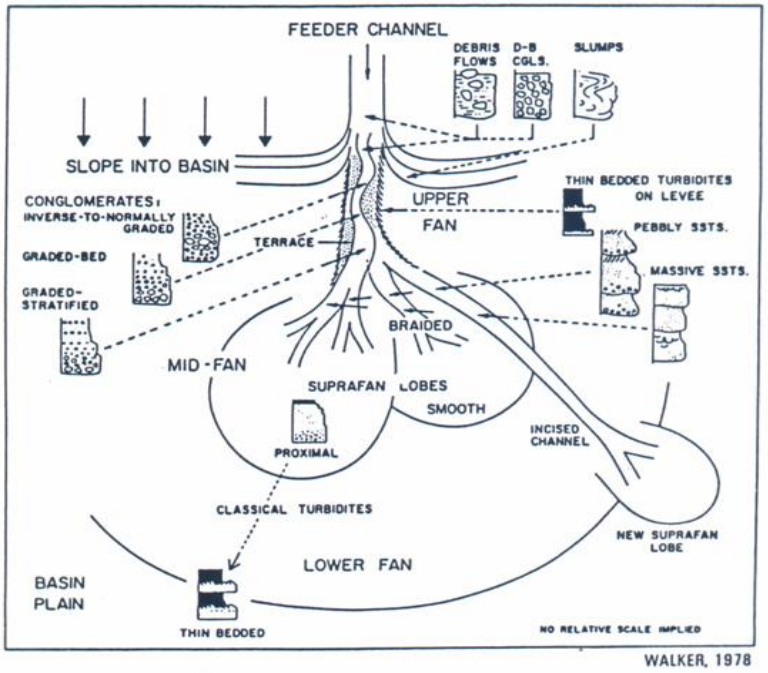


c. Stratigraphic trap for gas storage development



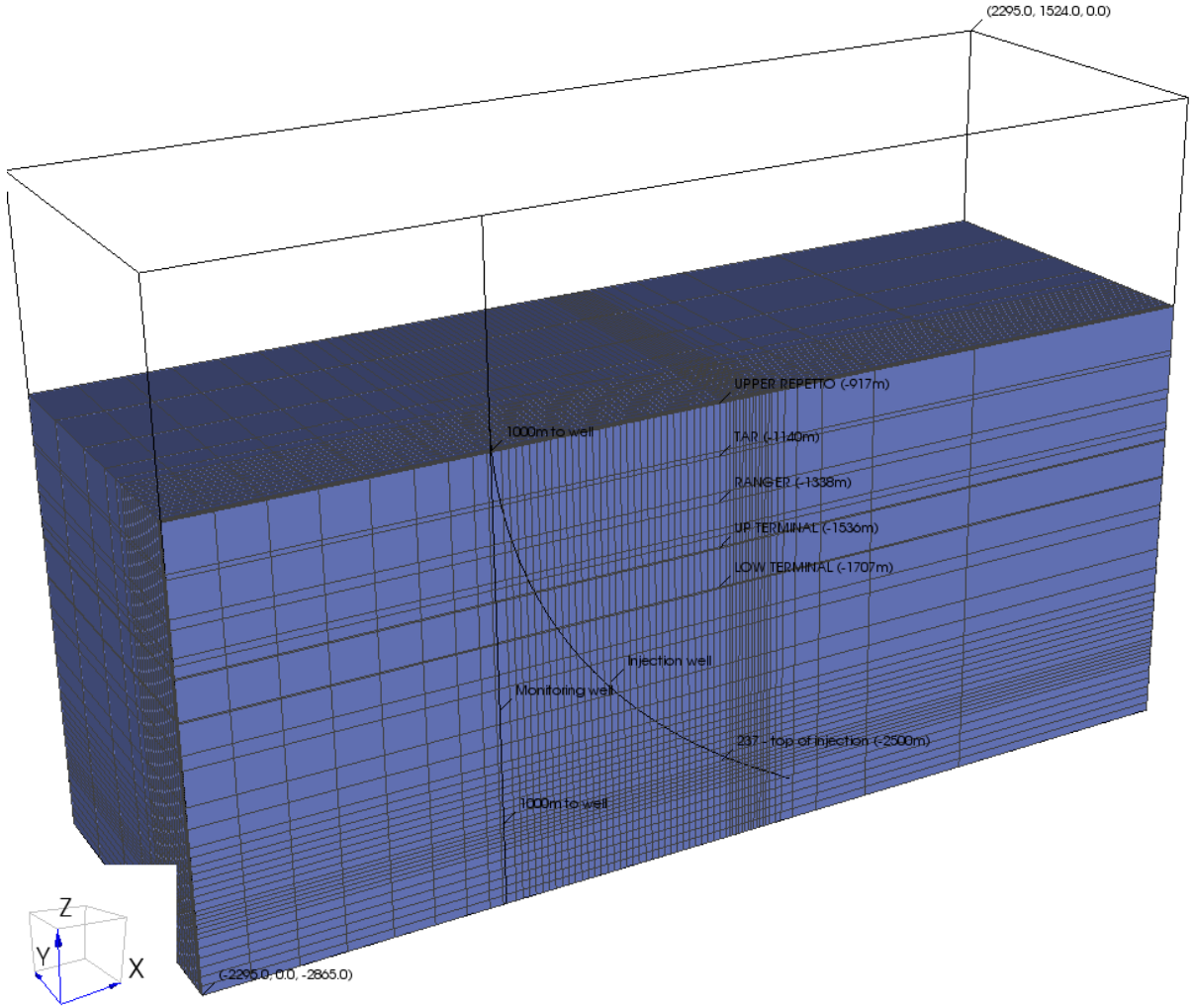
d. Isolated zones of high porosity for storage

Optimum Storage Zones Located Beneath Alternating Seals (shale layers) and Sinks (sand layers)



Map and cross-section of typical turbidite deposition
(Henderson, 1987)

Two well model for dipping injection



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07

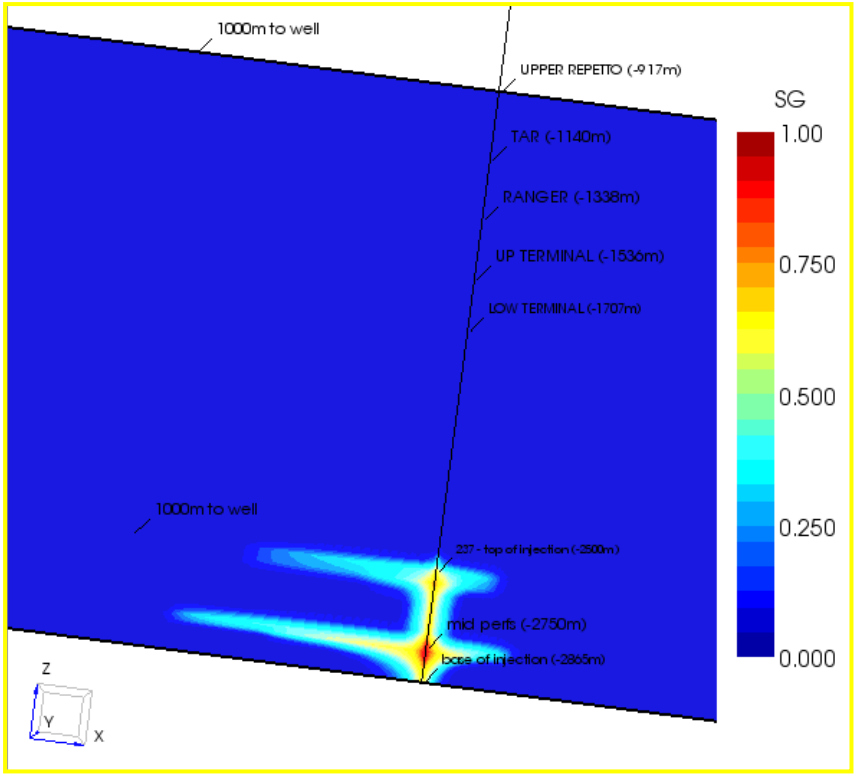
Gas saturation

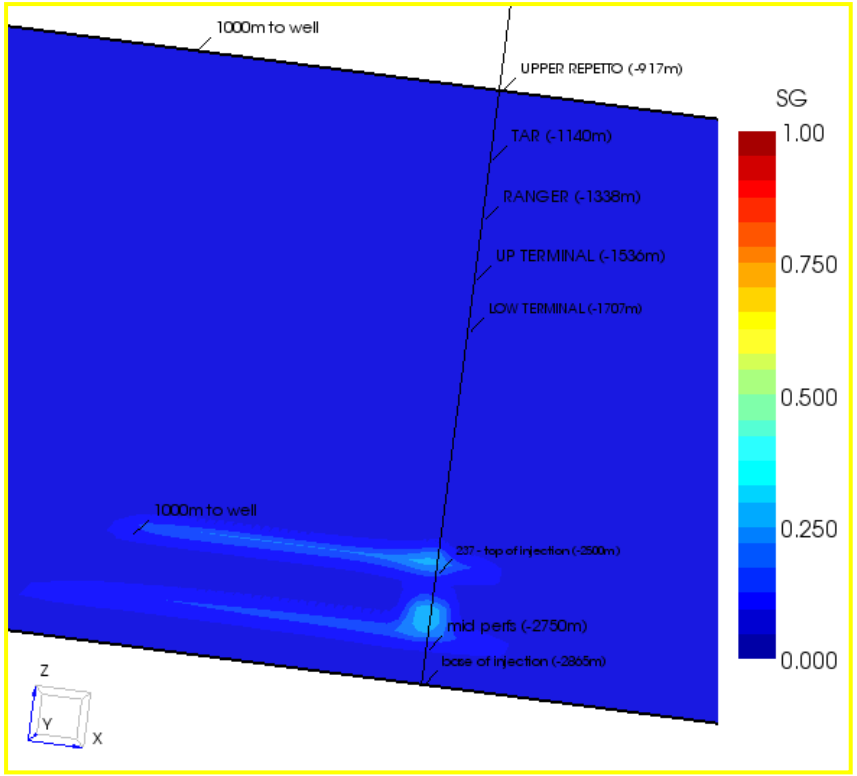
Injection Rate: 1MM mt/yr

Injection Duration: 5 years

Shale permeability: 1mD

Salt: 3%





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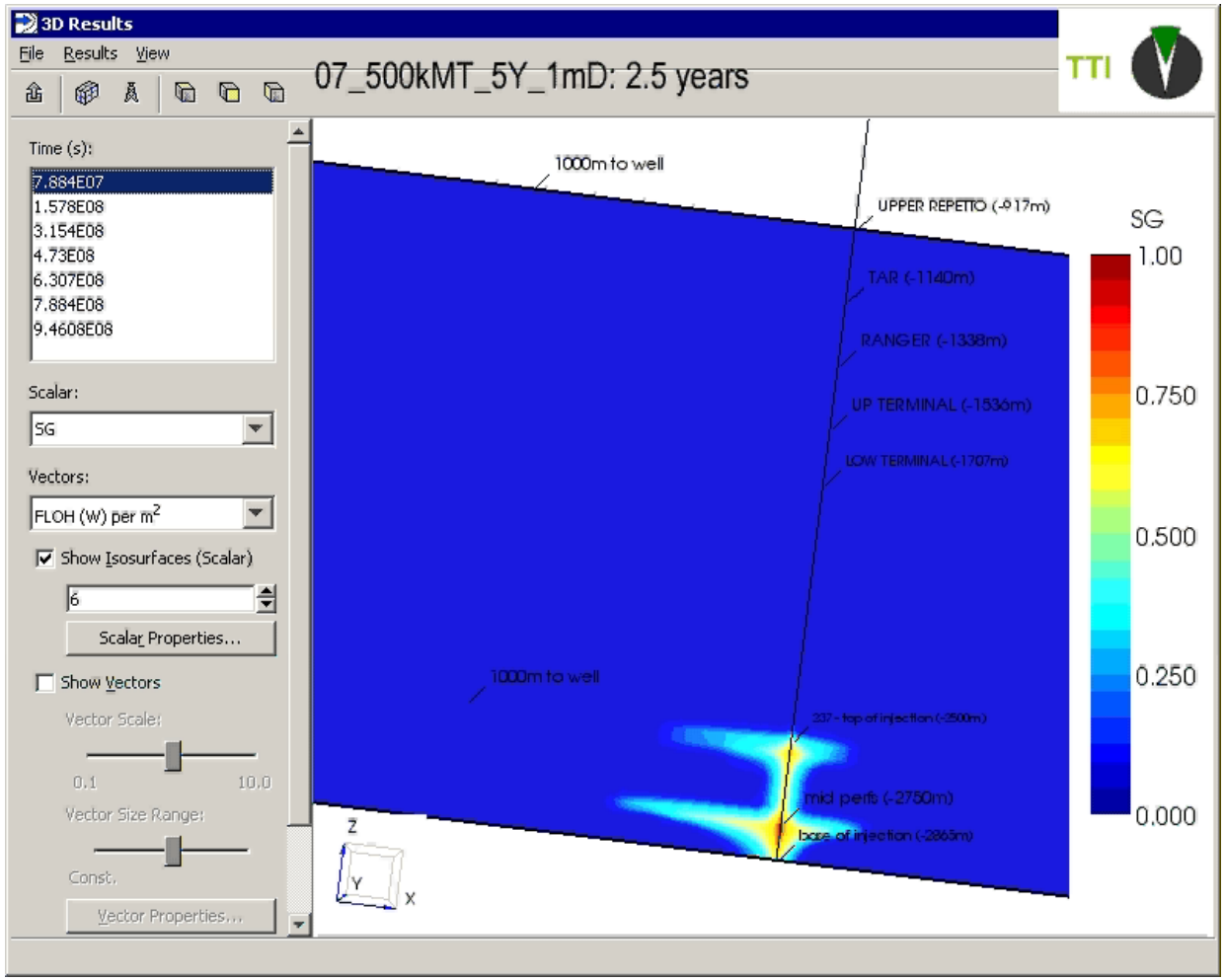
T = 5 years	T = 30 years

Movie – Simulation 07 – Gas Saturation



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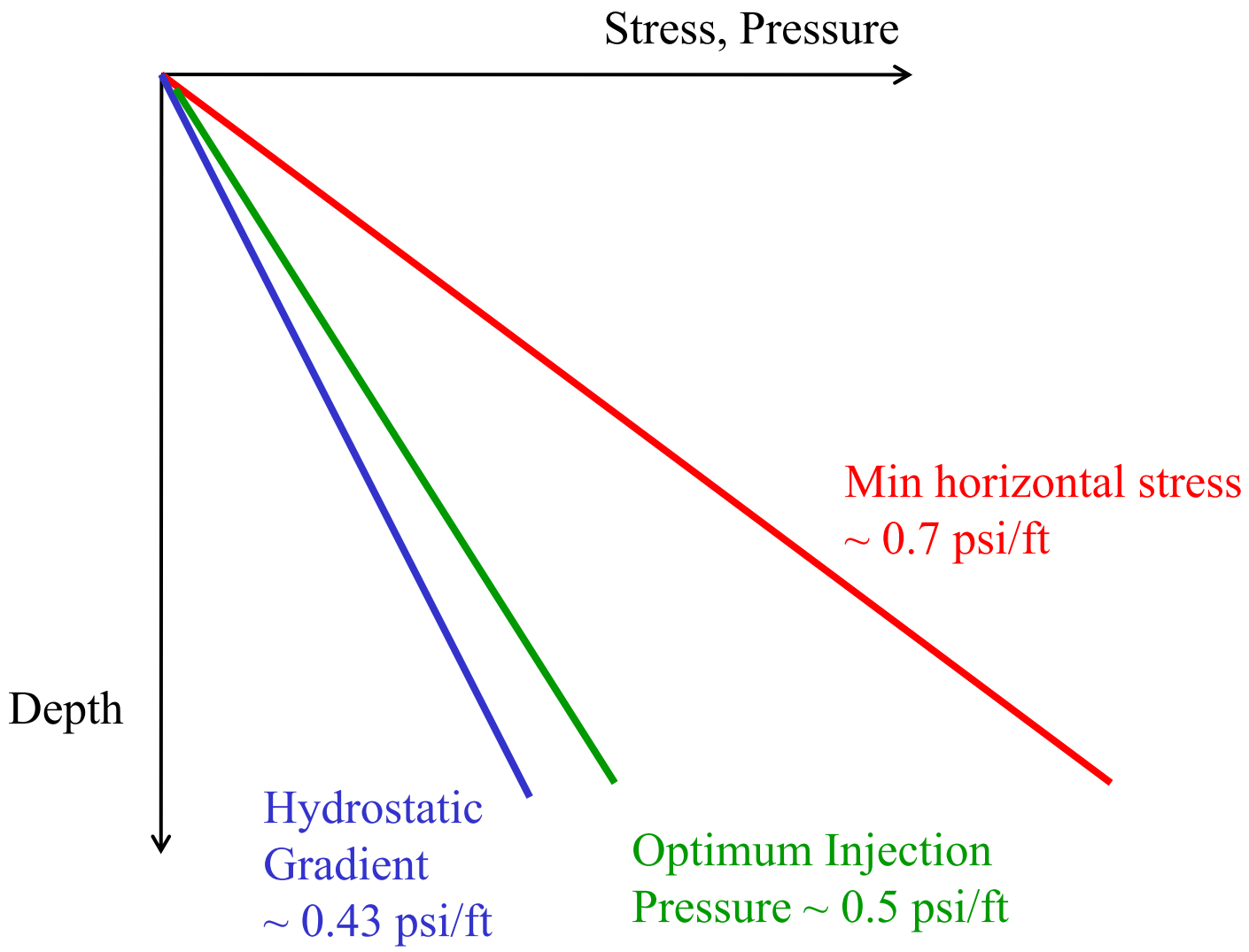
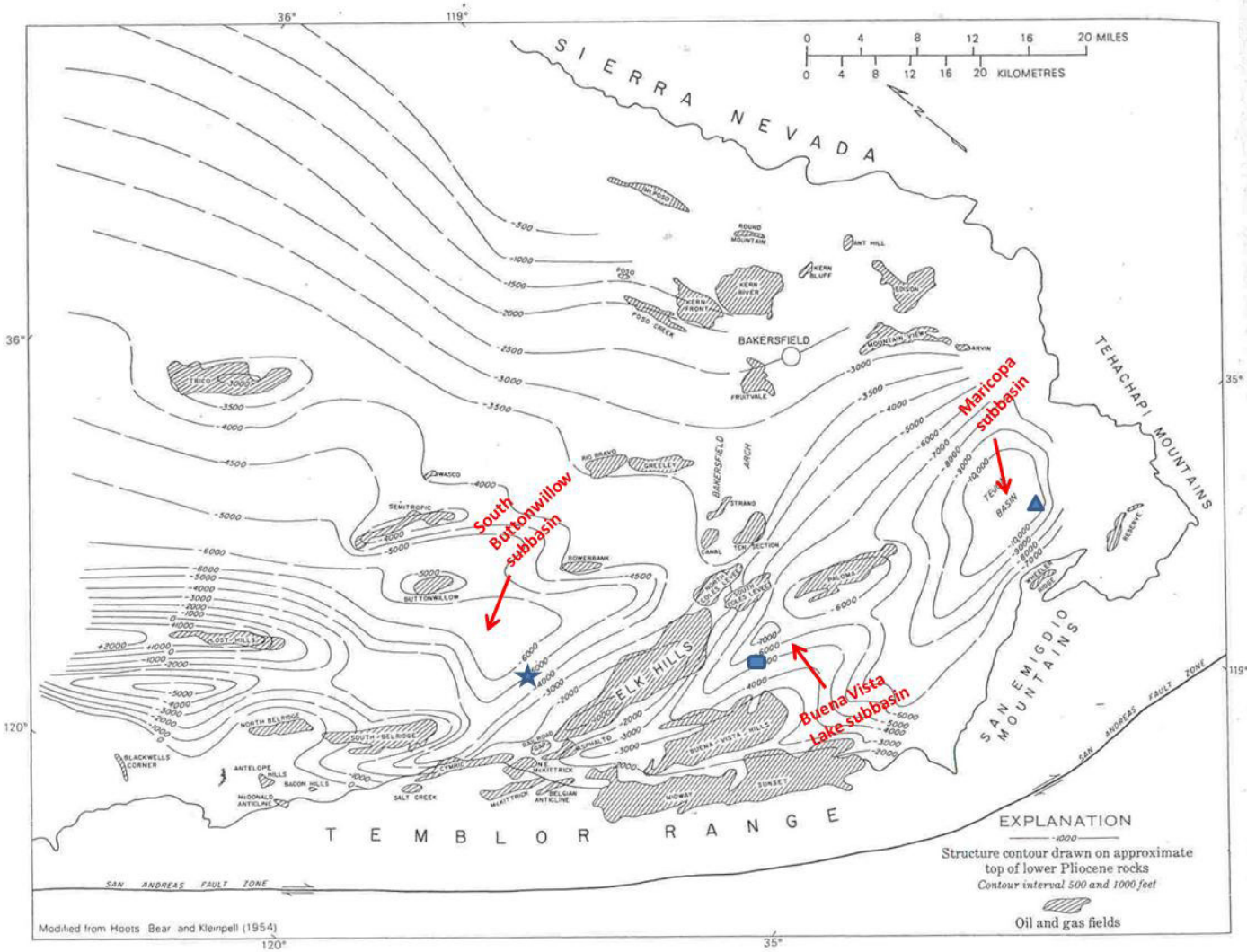
Ideal Geology for Storage of CO2 in Saline Aquifers (in order of effectiveness)

1. Well Defined Effective Structural Trap

2. Multiple Alternating Sand-Shale Sequences

3. Thick, Deep Storage Interval (bottom injection)


Stress, Pressure
Depth
Min horizontal stress
~ 0.7 psi/ft
Hydrostatic
Gradient
~ 0.43 psi/ft
Optimum Injection
Pressure ~ 0.5 psi/ft



Saline Sub-basins in Southern San Joaquin Valley

Maricopa Sub-basin

Formation / Zone	Depth (ft)	Thickness (ft)	Area (E6 ft2)	Porosity (%)	Pore Vol (ft3)	Pore Vol (m3)	Liq CO2 (1000 kg)	1000 kg at 5% Saturation
Etchegoin	9200	150	1449	27%	5.87E+10	1.64E+09	7.62E+08	3.81E+07
L Fruitvale/Reserve Zone	10900	100	2453	29%	7.11E+10	1.99E+09	9.24E+08	4.62E+07
Vedder	12500	100	2244	22%	4.94E+10	1.38E+09	6.41E+08	3.21E+07
							TOTAL	1.16E+08

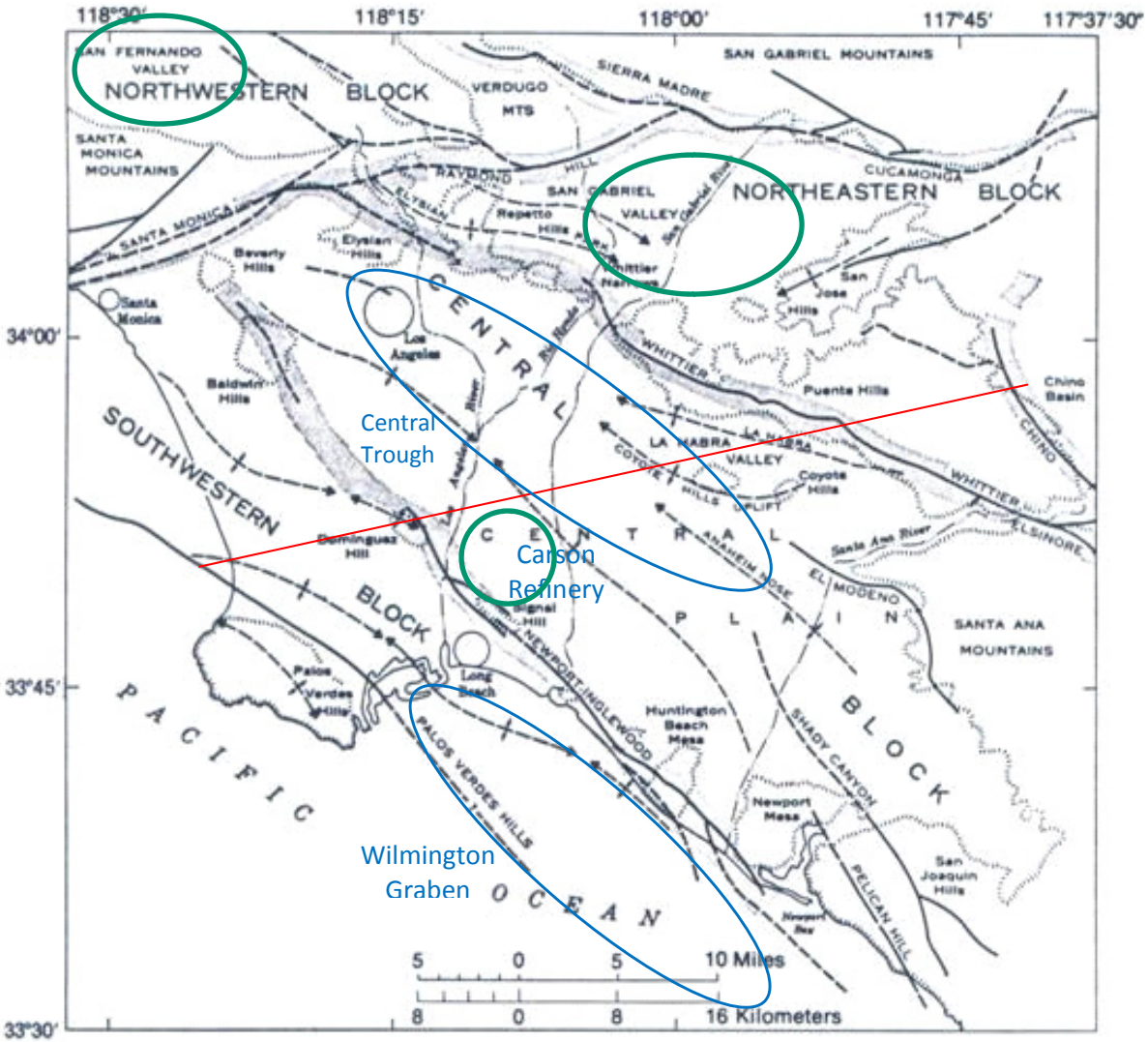
Buena Vista Lake Sub-basin

Formation / Zone	Depth (ft)	Thickness (ft)	Area (E6 ft2)	Porosity (%)	Pore Vol (ft3)	Pore Vol (m3)	Liq CO2 (1000 kg)	1000 kg at 5% Saturation
San Joaquin	6080	130	33.5	30%	1.31E+09	3.66E+07	1.70E+07	8.49E+05
Monterey	12800	600	63	21%	7.94E+09	2.22E+08	1.03E+08	5.16E+06
							TOTAL	6.01E+06

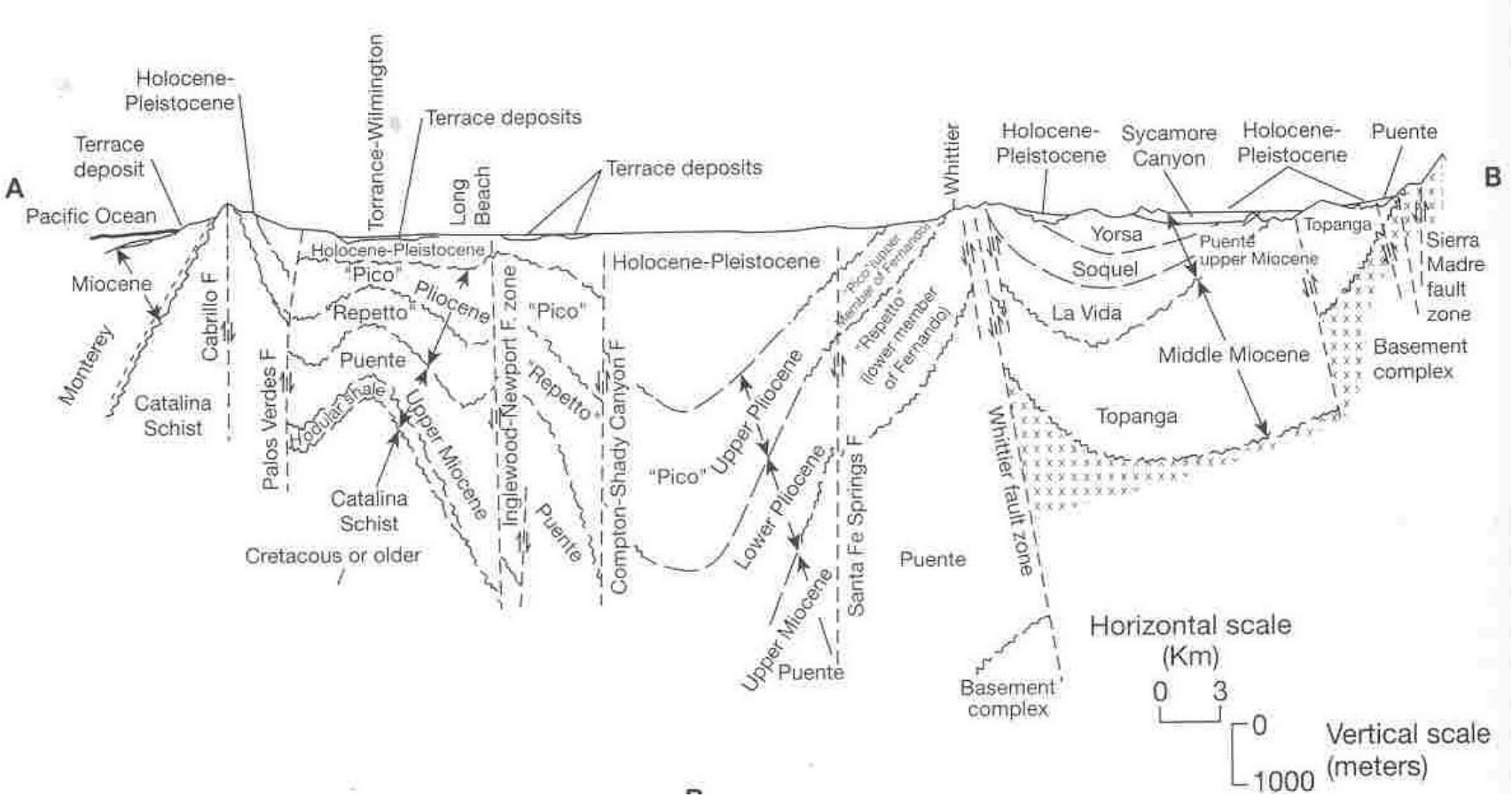
South Buttonwillow Sub-basin

Formation / Zone	Depth (ft)	Thicknes s (ft)	Area (E6 ft2)	Porosit y (%)	Pore Vol (ft3)	Pore Vol (m3)	Liq CO2 (1000 kg)	1000 kg at 5% Saturation
Monterey	13100	400	1449	21%	1.22E+11	3.41E+09	1.58E+09	7.91E+07
							TOTAL	7.91E+07

Sample Saline Reservoir Storage Capacity Estimates for Southern San Joaquin Valley

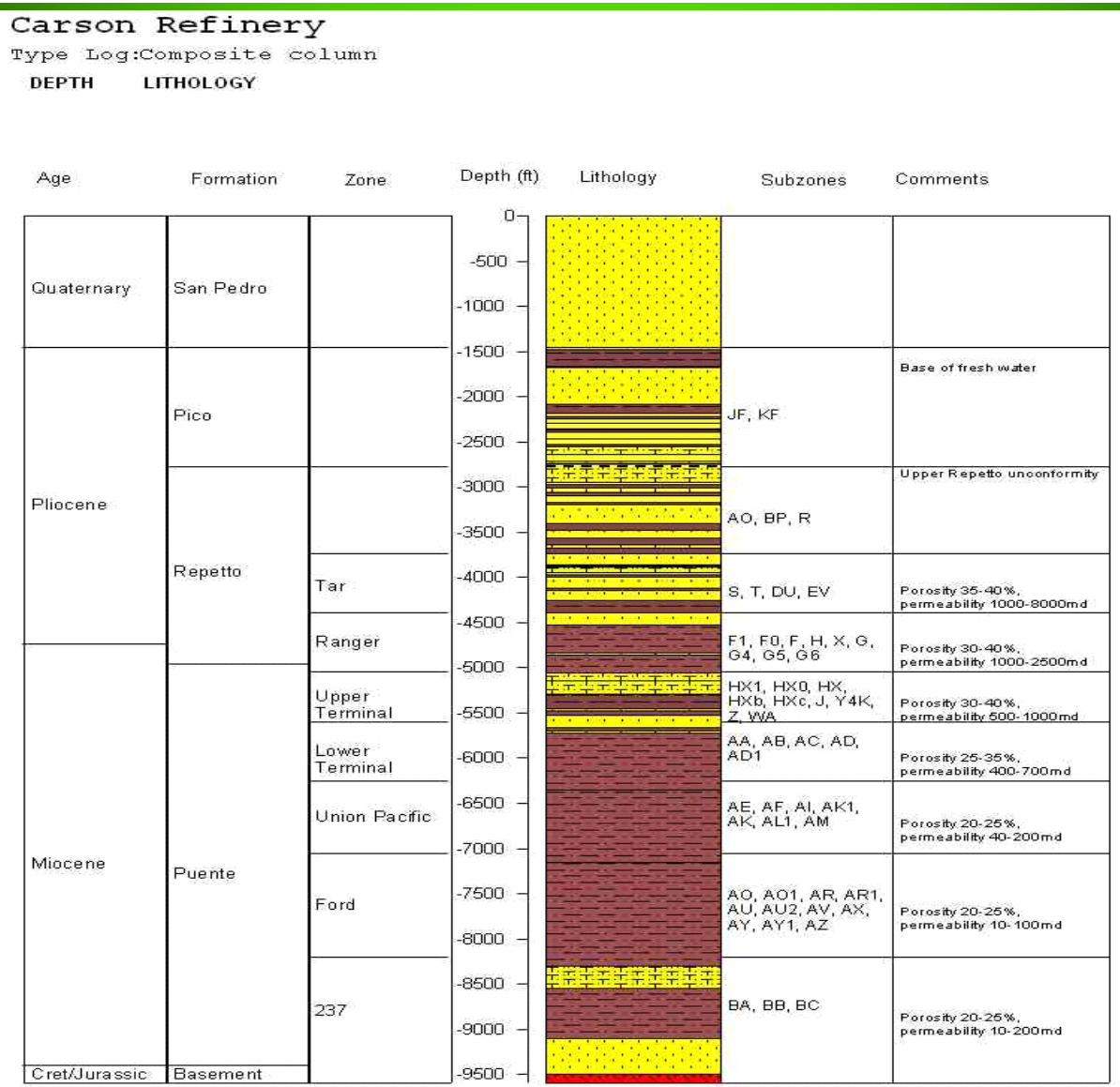


Saline Sub-basins in Los Angeles County


A
B
Holocene-Pleistocene
Terrace deposit
Pacific Ocean
Miocene
Monterey
Catalina Schist
Cabrillo F
Palos Verdes F
Torrance-Wilmington
Terrace deposits
Long Beach
Holocene-Pleistocene
"Pico"
"Repetto"
Pliocene
Puente
Nodular shale
Upper Miocene
Catalina Schist
Cretacous or older
Inglewood-Newport F. zone
"Pico"
"Repetto"
Puente
Compton-Shady Canyon F
Terrace deposits
Holocene-Pleistocene
"Pico" Upper Pliocene
Lower Pliocene
Upper Miocene
Puente
Pico (upper member of Fernando)
"Repetto" (lower member of Fernando)
Santa Fe Springs F
Puente
Whittier
Whittier fault zone
Basement complex
Holocene-Pleistocene
Sycamore Canyon
Holocene-Pleistocene
Puente
Yorsa
Soquel
La Vida
Puente upper Miocene
Middle Miocene
Topanga
Topanga
Sierra Madre fault zone
Basement complex
Horizontal scale (Km)
0 3
0
1000
Vertical scale (meters)

Area	Potential Pore Vol (ft3)	Potential Pore Vol (m3)	Capacity (1000 kg at 5% saturation)	Depth (ft)
Carson	6.67×10^{10}	1.87×10^{9}	4.34×10^{7}	6250 - 9000
Wilmington Graben	3.13×10^{11}	8.75×10^{9}	2.03×10^{8}	7000
Central Trough	7.74×10^{11}	2.17×10^{10}	5.03×10^{8}	15000 - 20000
San Gabriel Valley	1.80×10^{11}	5.04×10^{9}	1.17×10^{8}	7000 - 9500
San Fernando Valley	8.45×10^{10}	2.36×10^{9}	3.29×10^{7}	3000

Sample Saline Reservoir Storage Capacity Estimates for Los Angeles Basin


Carson Refinery
Type Log:Composite column
DEPTH
LITHOLOGY
Age
Formation
Zone
Depth (ft)
Lithology
Subzones
Comments
Quaternary
San Pedro
Pliocene
Pico
Repetto
Miocene
Puente
Cret/Jurassic
Basement
Tar
Ranger
Upper Terminal
Lower Terminal
Union Pacific
Ford
237
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
-5500
-6000
-6500
-7000
-7500
-8000
-8500
-9000
-9500
JF, KF
AO, BP, R
S, T, DU, EV
F1, F0, F, H, X, G, G4, G5, G6
HX1, HX0, HX, HXb, HXc, J, Y4K, Z, WA
AA, AB, AC, AD, AD1
AE, AF, AI, AK1, AK, AL1, AM
AO, AO1, AR, AR1, AU, AU2, AV, AX, AY, AY1, AZ
BA, BB, BC
Base of fresh water
Upper Repetto unconformity
Porosity 35-40%, permeability 1000-8000md
Porosity 30-40%, permeability 1000-2500md
Porosity 30-40%, permeability 500-1000md
Porosity 25-35%, permeability 400-700md
Porosity 20-25%, permeability 40-200md
Porosity 20-25%, permeability 10-100md
Porosity 20-25%, permeability 10-200md

CO2 Injection and Storage in Saline Aquifers

By Michael S. Bruno, PhD, PE
Terralog Technologies USA, Inc.

TTI

The Los Angeles Basin presents a unique combination of great need and great opportunity for large scale geologic storage of CO2.

In part due to its significant population, and in part due to its historical and geologic setting as one of the most prolific oil and gas producing basins in the United States, the region is home to more than a dozen major power plants and oil refineries which produce more than 5 million metric tons of fossil fuel related CO2 emissions each year.

Furthermore, there are several natural gas storage reservoir in the basin, providing analogs and empirical evidence of long-term safe storage

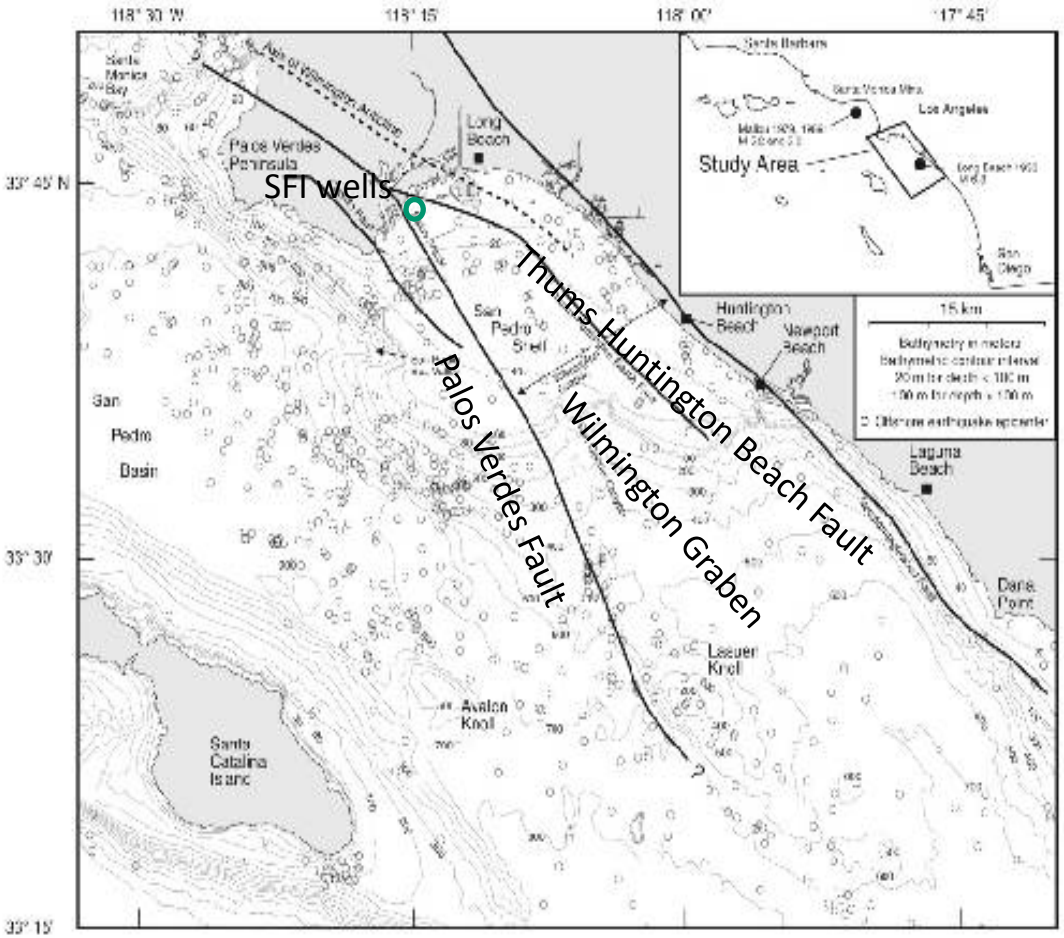
CO2 Injection and Storage in Saline Aquifers

By Michael S. Bruno, PhD, PE
Terralog Technologies USA, Inc.

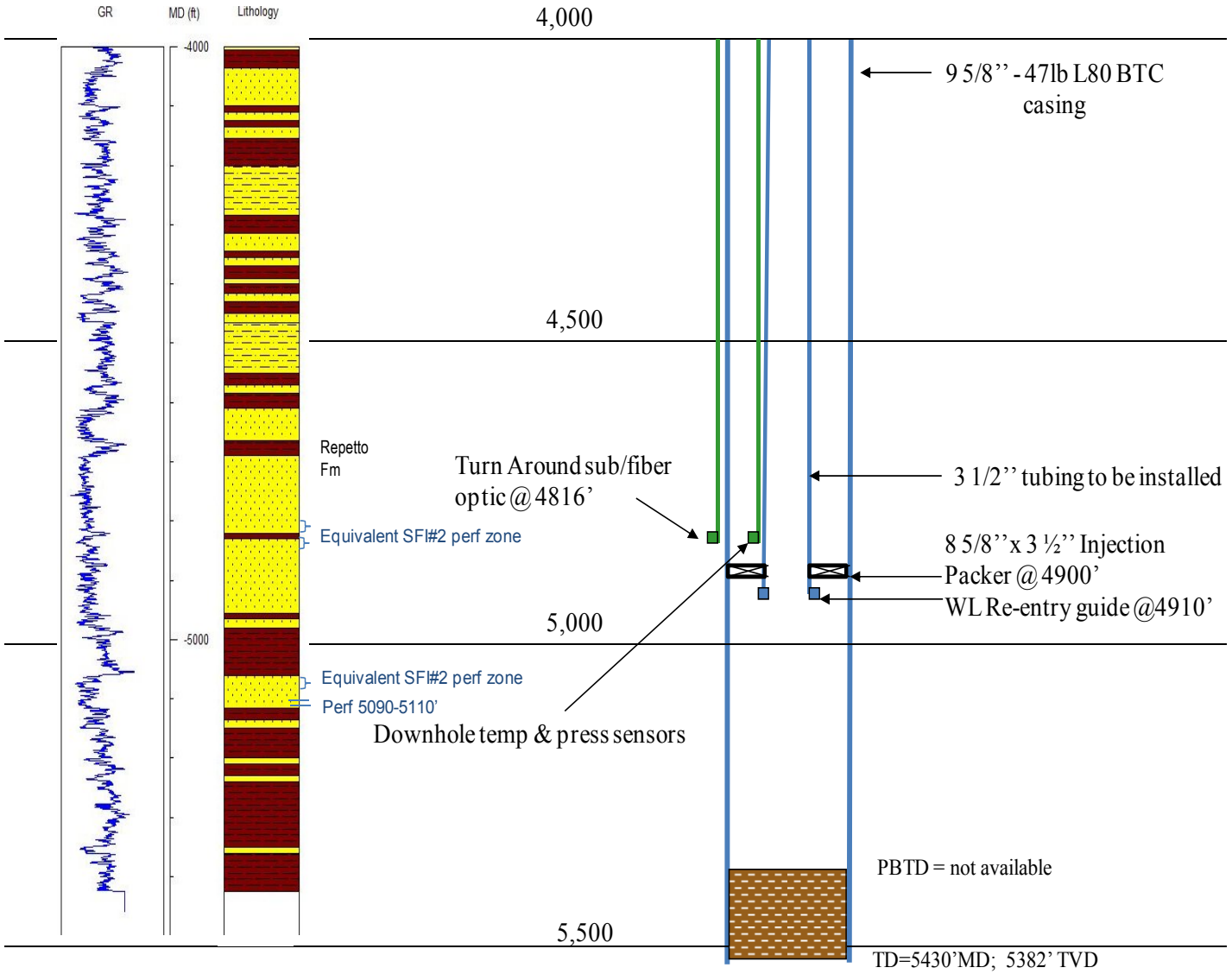
TTI

More than 3000 feet thickness of Pliocene and Miocene formations are present in the large Wilmington Graben directly offshore the Los Angeles and Long Beach Harbor area, at appropriate depth for CO2 sequestration (about 3000 to 7000 ft).

This zone is easily accessible yet geologically isolated from the nearby Wilmington Oilfield and onshore area, reducing communication risk and public risk.



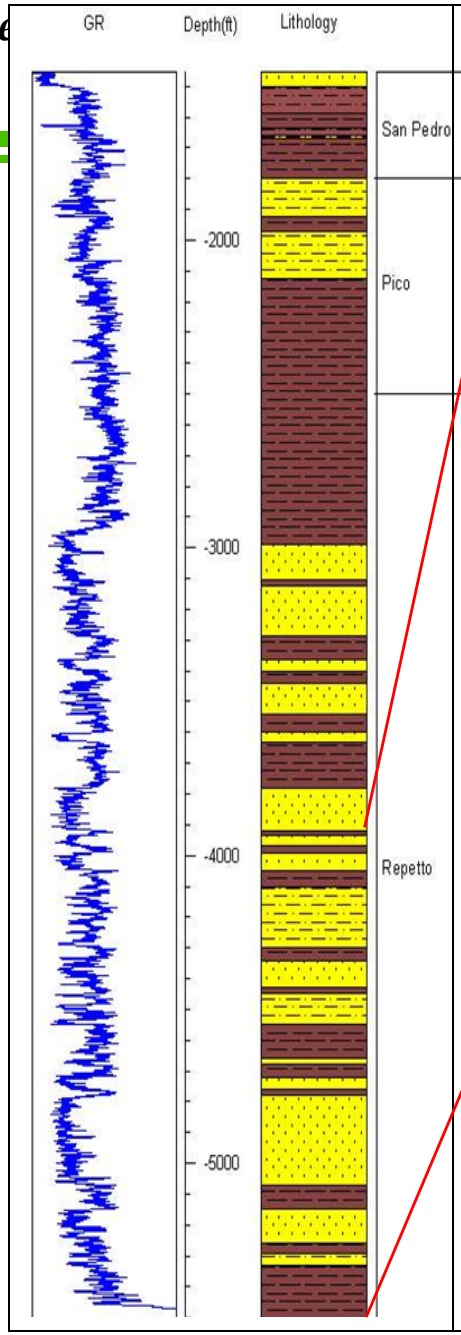
North Graben Stratigraphy - DOE Project Formation Evaluation and Test Well #1



CO2 Injection and Storage

By Michael S. Bruno, PhD, PE
Terralog Technologies USA, Inc.

North Graben Stratigraphy - CLA Demonstration Project Test Well



Top from sea level [m]	Bottom from sea level [m]	Thickness [m]	
1183	1187	5	SHALE
1187	1198	11	SAND
1198	1204	6	SHALE
1204	1222	18	SAND
1222	1237	15	SHALE
1237	1241	3	SILT
1241	1270	30	SILT
1270	1298	28	SILT
1298	1311	12	SHALE
1311	1317	6	SAND
1317	1329	12	SAND
1329	1338	9	SAND
1338	1344	6	SHALE
1344	1375	30	SILT
1375	1390	15	SHALE
1390	1408	18	SHALE
1408	1414	6	SILT
1414	1426	12	SHALE
1426	1439	12	SAND
1439	1445	6	SHALE
1445	1533	88	SAND
1533	1558	24	SHALE
1558	1575	17	SAND
1575	1600	26	SHALE
1600	1612	12	SILT
1612	1666	53	SHALE

Summary and Discussion:

1. Significant Saline Aquifer Storage Capacity in California
2. Significant Storage Capacity Within LA Basin (near industrial sources)
3. Most require further characterization and evaluation
4. Limited commercial incentive for CO2 storage in saline aquifer (particularly for intermediate scale projects)
5. Current regulatory regime complex, but not insurmountable
6. To date there have been no large-scale saline injection projects in California, and none currently in regulatory queue
7. Incentives should be developed for intermediate scale project (100,000 to 500,000 tons/yr) to demonstrate and evaluate the technology prior to larger scale operations.