Characterization of Pliocene and Miocene Formations in the Wilmington Graben, Offshore Los Angeles, for Large-Scale Geologic Storage of CO_2*

William E. Childers[1]

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Abstract

The Los Angeles Basin presents a unique and special combination of high need and significant opportunity for large-scale geologic storage of CO_2. Terralog Technologies USA, Inc. was selected by the Department of Energy to manage a research project with the objective to characterize Pliocene and Miocene sediments within the Wilmington Graben, located offshore Los Angeles, for high-volume CO_2 sequestration. These sediments are suspected to span more than 5000 feet of vertical interval, with an estimated capacity to store more than 50 million metric tons of CO_2.

The Wilmington Graben is situated between the Palos Verdes and the THUMS-Huntington Beach faults, both of which act as sealing faults. While geologically isolated from the onshore area, thus reducing migration and communication risks, the graben remains easily accessible via directional drilling from the existing onshore oil and gas infrastructure. These Pliocene and Miocene sediments, primarily saline aquifers, have not been fully characterized.

To accurately evaluate and quantify sediments within the Wilmington Graben, we have drilled the first of 3 characterization wells. A complete suite of wireline logs, core samples and reservoir data were acquired as a result. We have also mapped the Wilmington Graben, using previously drilled well logs and seismic data, new and old. A CO_2 gas migration model has begun simulating the injection of 1 million metric ton per year of CO_2. In addition, we have identified the top industrial sources of CO_2 emissions in the Los Angeles Basin. To complement this effort, potential geologic sinks and pipeline infrastructure for transporting CO_2 from sources to sinks are also being identified.

Website

Southern California Carbon Sequestration Research Consortium (SoCalCarb): Web accessed 24 May 2012. www.socalcarb.org

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Terralog Technologies USA, Inc

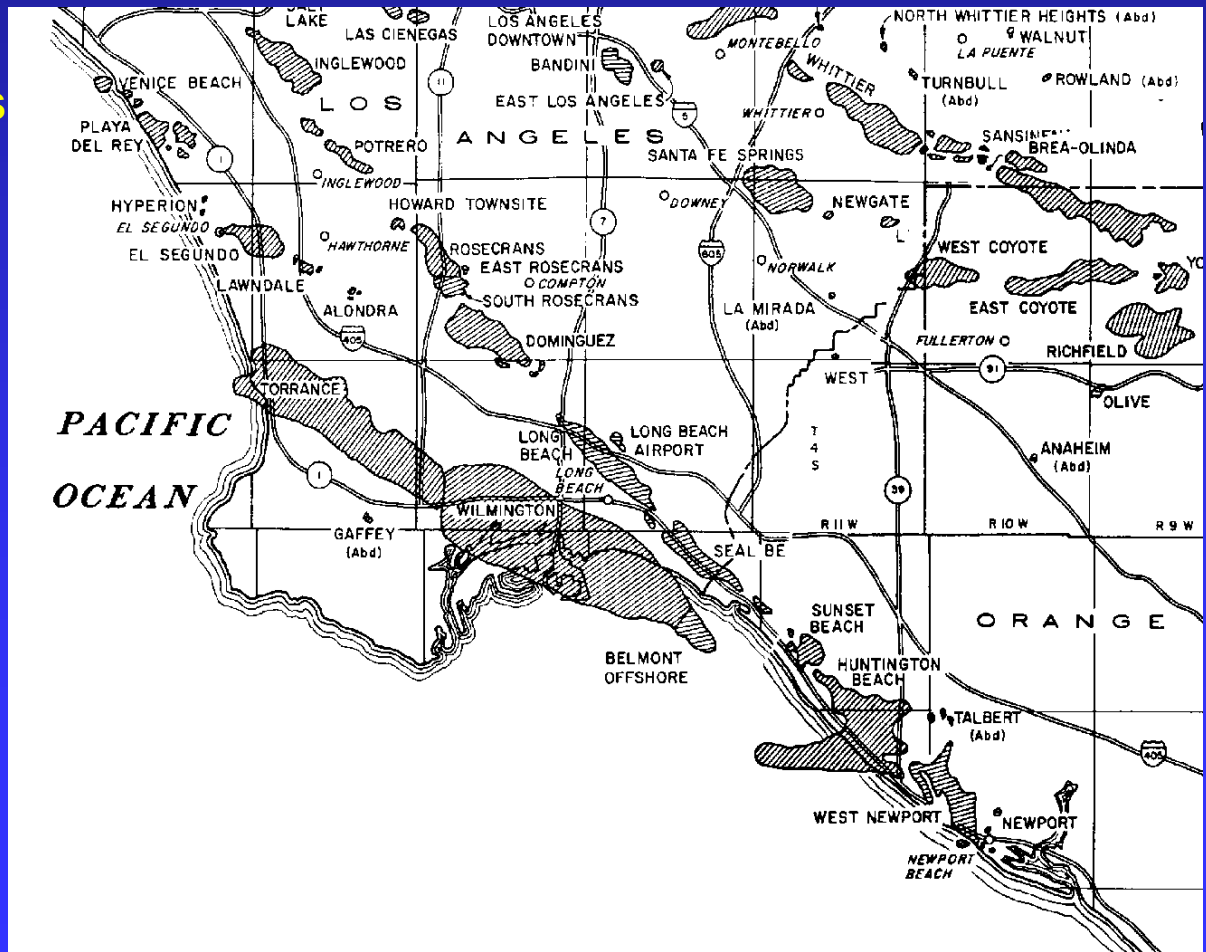
1. Project Background and Motivation
2. Project Plan, Status and Accomplishments
3. Next Steps

Los Angeles Basin and Wilmington Graben

- Prolific oil & gas producing basins; Thick sediments.
- Home to numerous large power plants, oil refineries which produce more than 5 MMT of CO_2 emissions each year
- Precedence for gas storage throughout basin
- Significant need and opportunity for large-scale geologic storage of CO_2

Los Angeles Basin Geology

- Contains massive sand & shale interbeds within the Pliocene and Miocene
- Provides excellent traps for oil & gas
- Contains several billion-barrel oil fields, e.g., Wilmington Oil Field (> 2 billion barrels produced to date)
- Contains 6 large-scale underground gas storage fields in the same age sediments (Operated by So Cal Gas Co. for over 50 years).
- Demonstrated both the storage potential & security of these formations for CO_2 sequestration if properly characterized and selected.

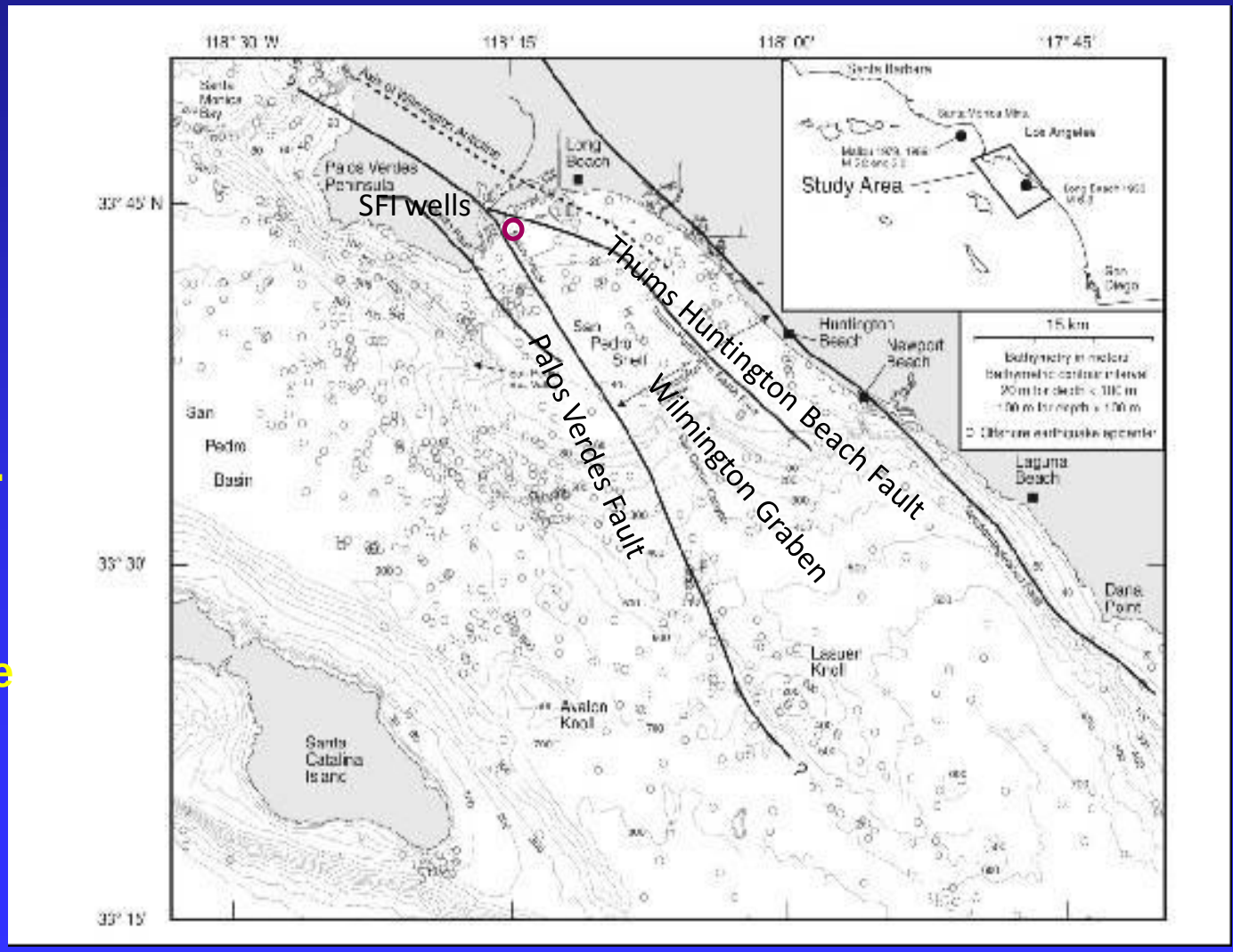


Why Wilmington Graben

- It is impractical to site a large-scale CO_2 storage project onshore beneath LA due to large population & complex land ownership.

- >3000ft thick of the same Pliocene and Miocene sediments are present in the Wilmington Graben, at approx. 3000-7000ft depth for CO_2 sequestration.

- This zone is easily accessible but geologically isolated from the nearby Wilmington Oilfield and the onshore area, thereby reducing communication and public risks.



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Efforts to Better Characterize Pliocene & Miocene for high-volume CO_2 Storage include

TTI

1) Improved evaluation and interpretation of existing 2D and 3D seismic data;

2) Acquisition and interpretation of additional 2D seismic lines;

3) Detailed log evaluation of existing exploration wells in the area;

4) Drilling and coring three new evaluation wells into the Graben (Pliocene and Miocene) and/or on the landward side of the THUMS-HB fault

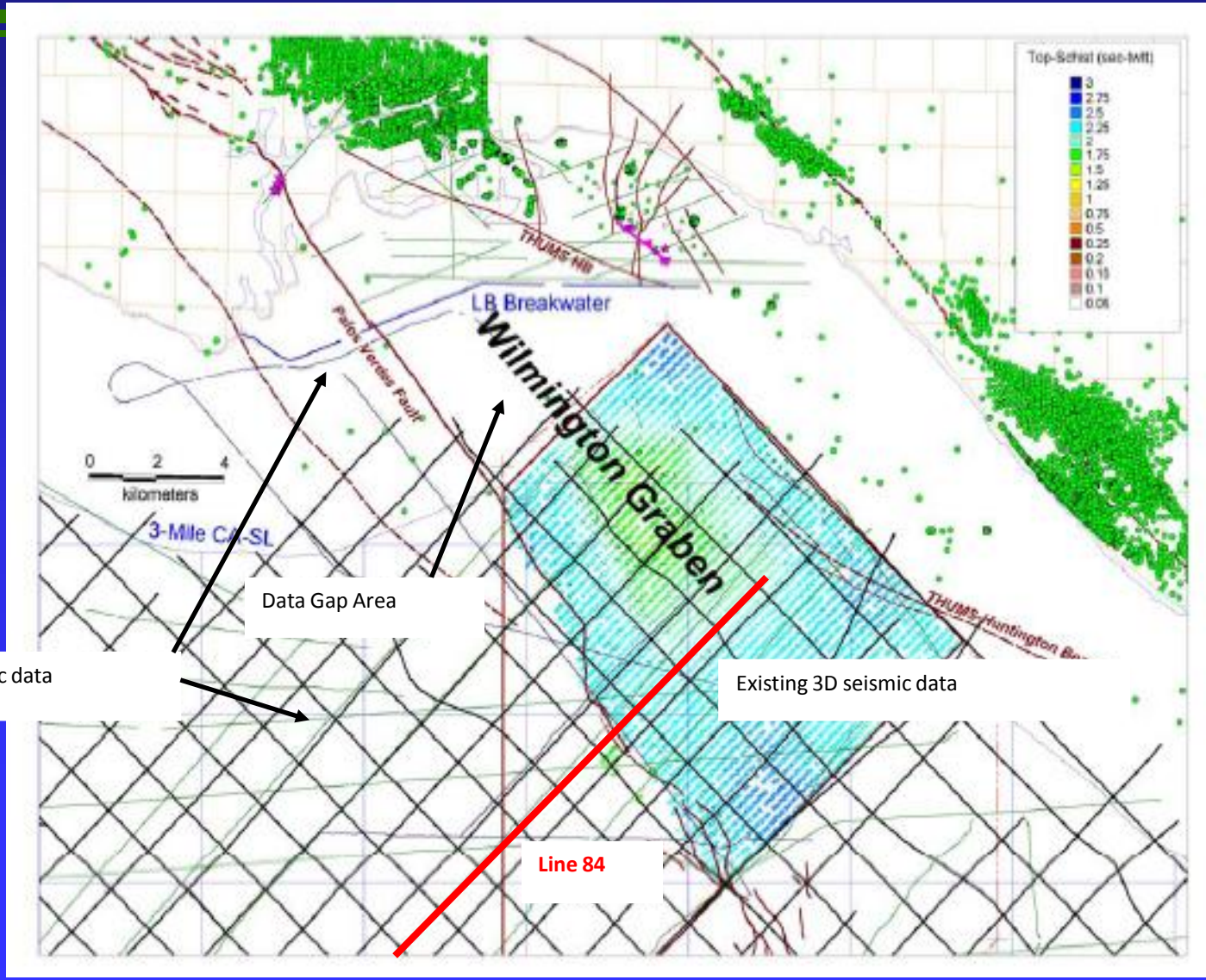
5) Development of 3D geologic models, geomechanical models, and CO_2 injection and migration models for the region.

6) Analysis of industrial sources (top 20 in the LA Basin)

7) Engineering study of existing and new pipeline systems to transport CO_2 from significant local sources to sequestration sites (transport infrastructure study)

8) Risk analysis (include well integrity, induced and natural seismicity)

Existing 2D and 3D Seismic Data Prior to Project



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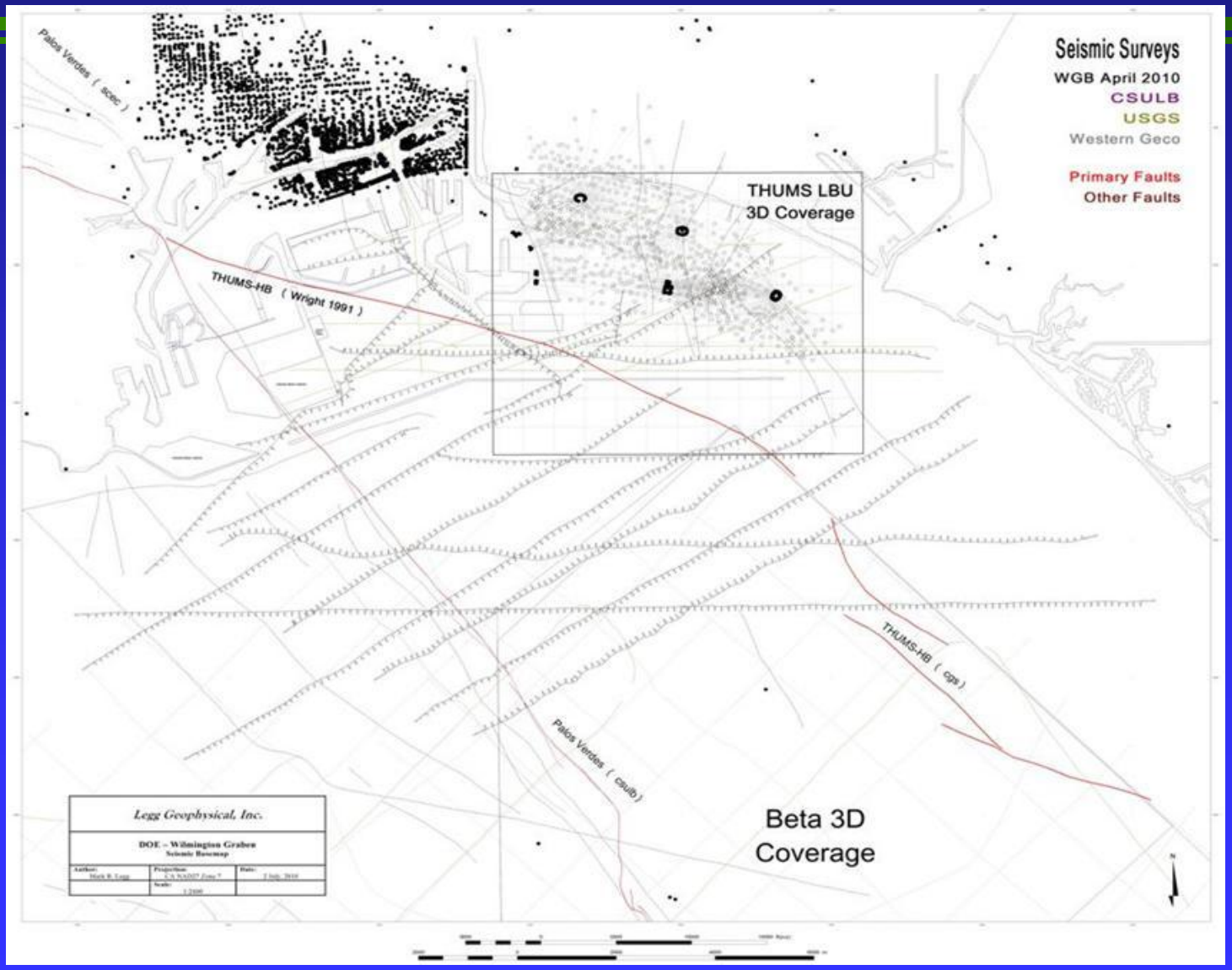
Shot Point Map for 175km of New Seismic Lines



California State University, Long Beach provided the Seismic Boat and Equipment

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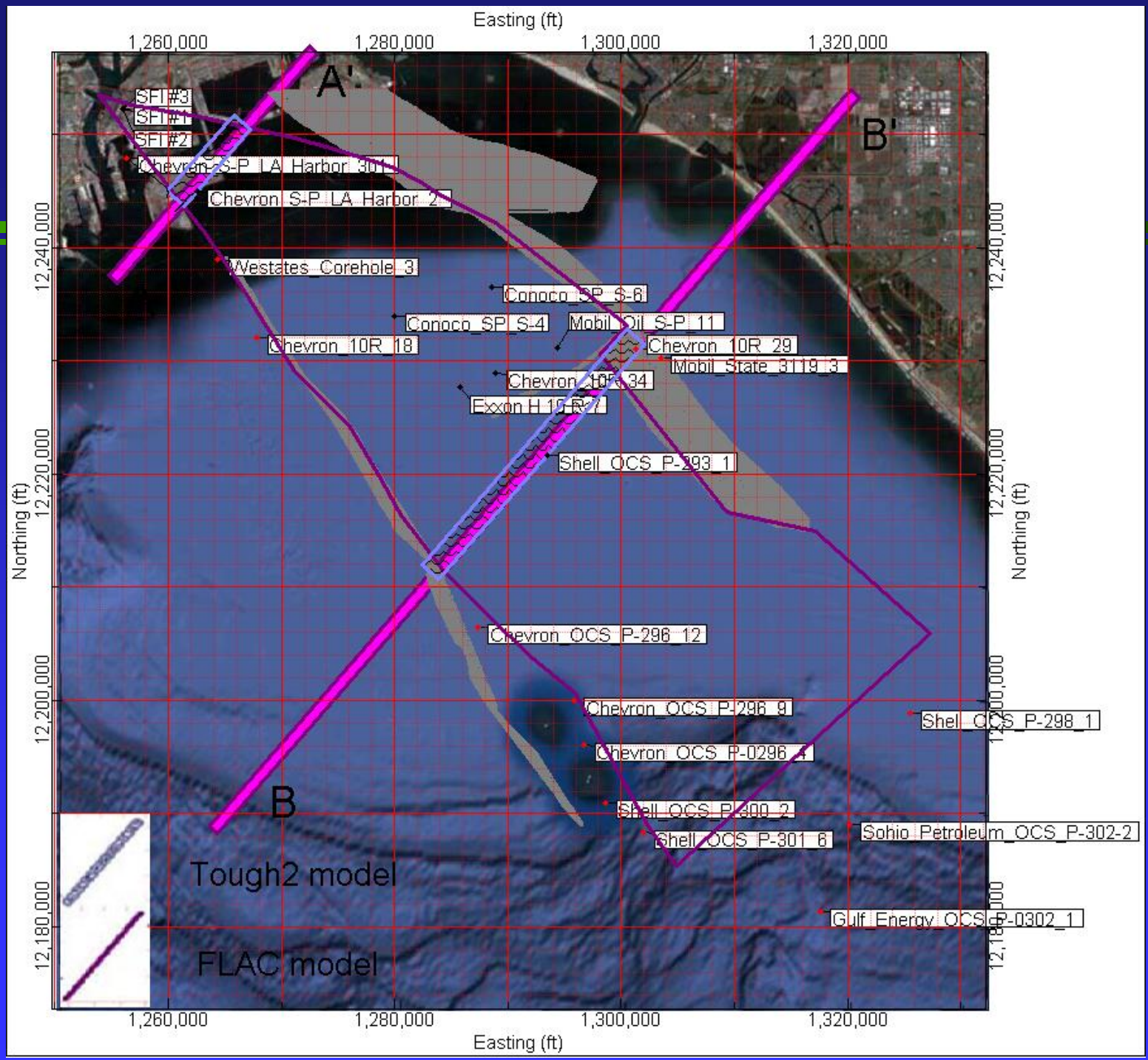
Exploratory Well Locations



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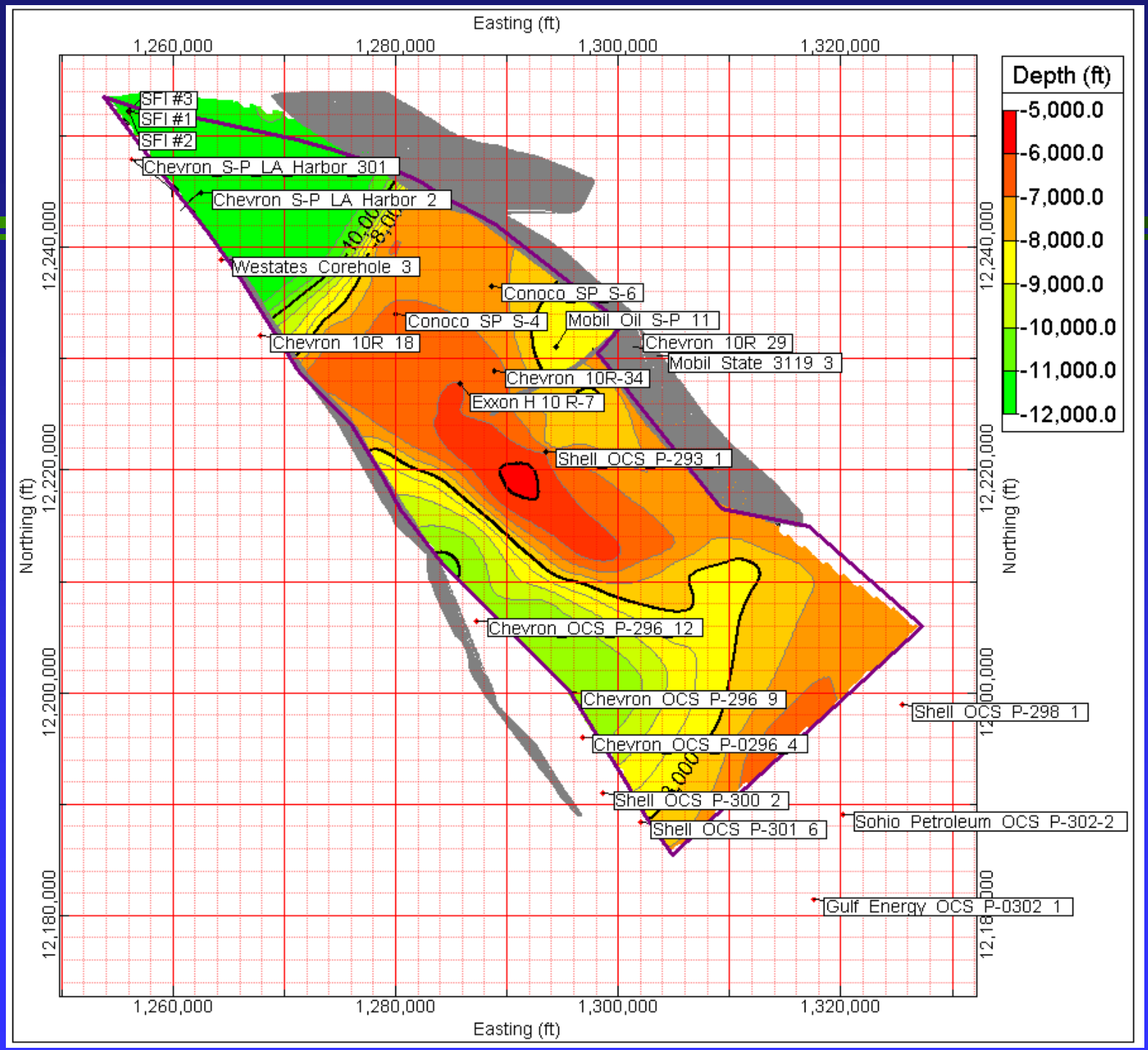
Catalina Schist, Top Basement structure map



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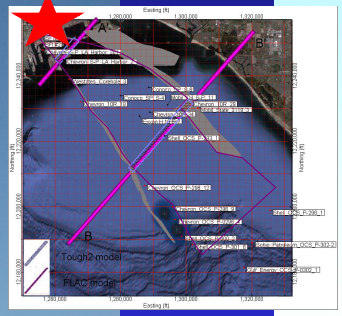

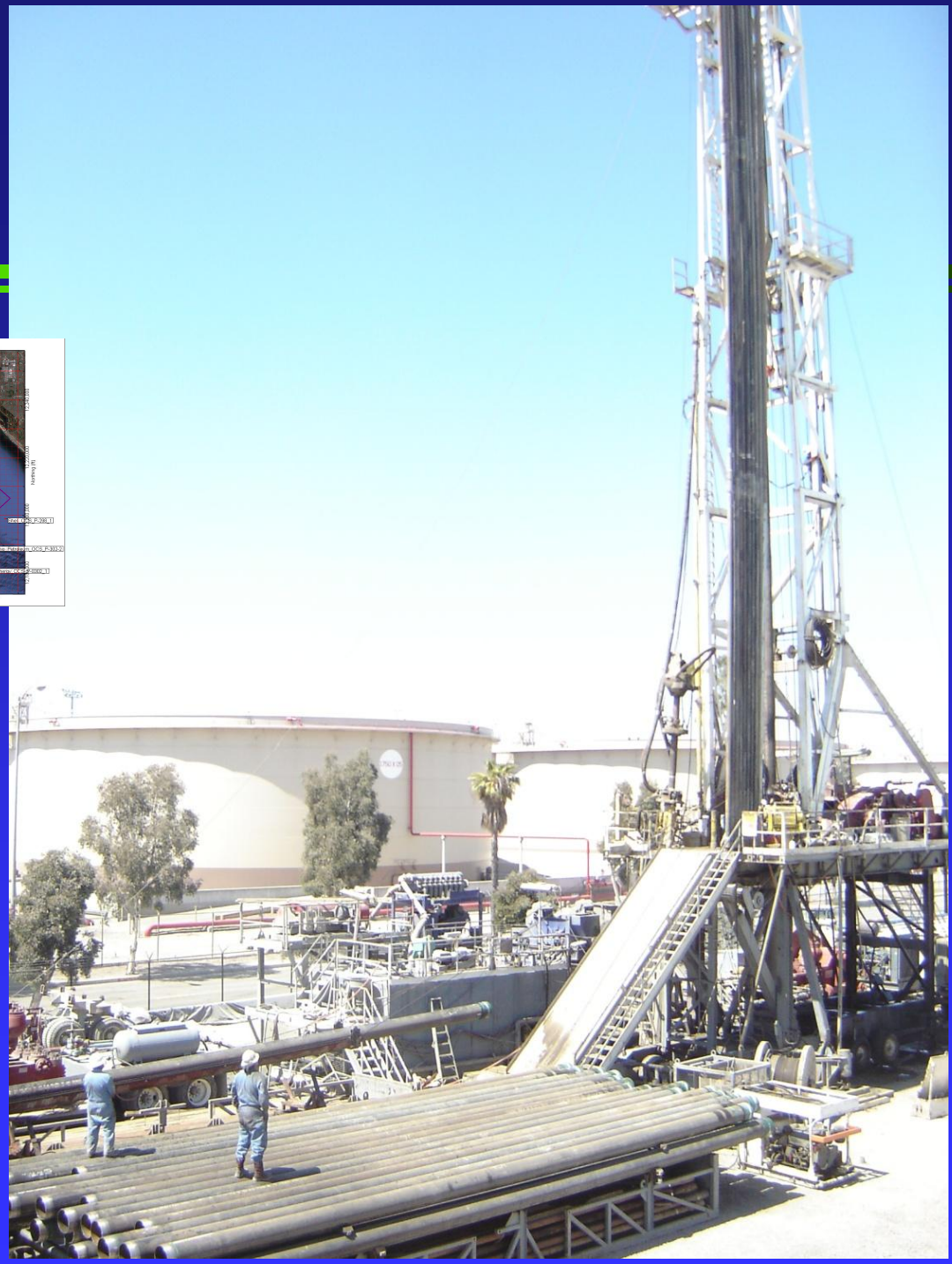

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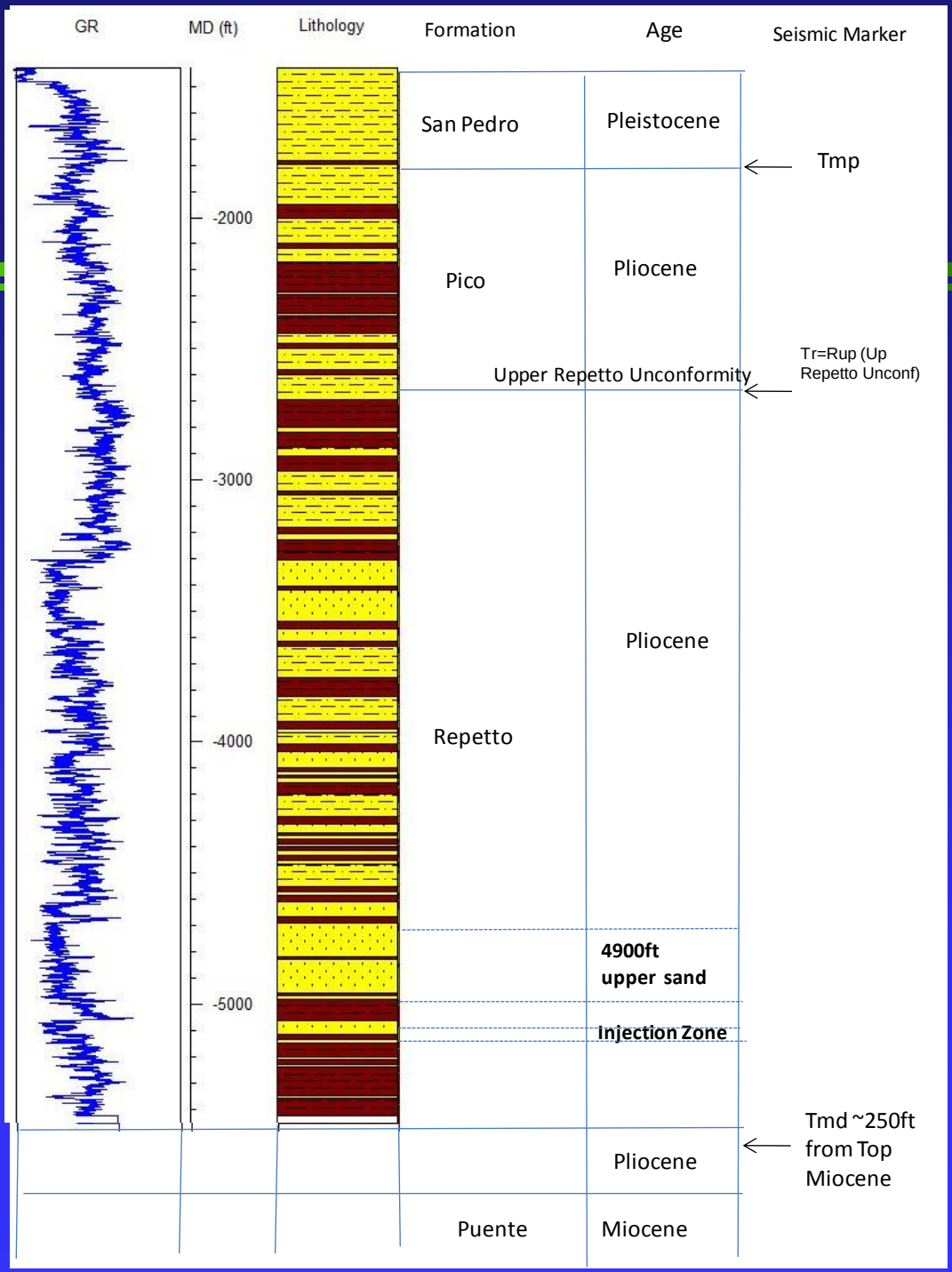
DOE#1 Well Stratigraphic Column – Characterizes Pliocene Interval, Pico & Repetto Formations



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Northern Wilmington Graben Pliocene Characterization from DOE#1 Well

- Recovered 29 SWC and 9.5ft conventional core
- Correlated lithology with SFI#1 and SFI#2 wells
- Well TD in Pliocene based on micropaleontology correlation from SFI#2 well

•Sand porosities	24-31%
•Sand permeabilities	50-353md
•Shale porosities	23-29%
•Shale permeabilities	<1-2md
•Pliocene gross sand thickness	3000-3500ft

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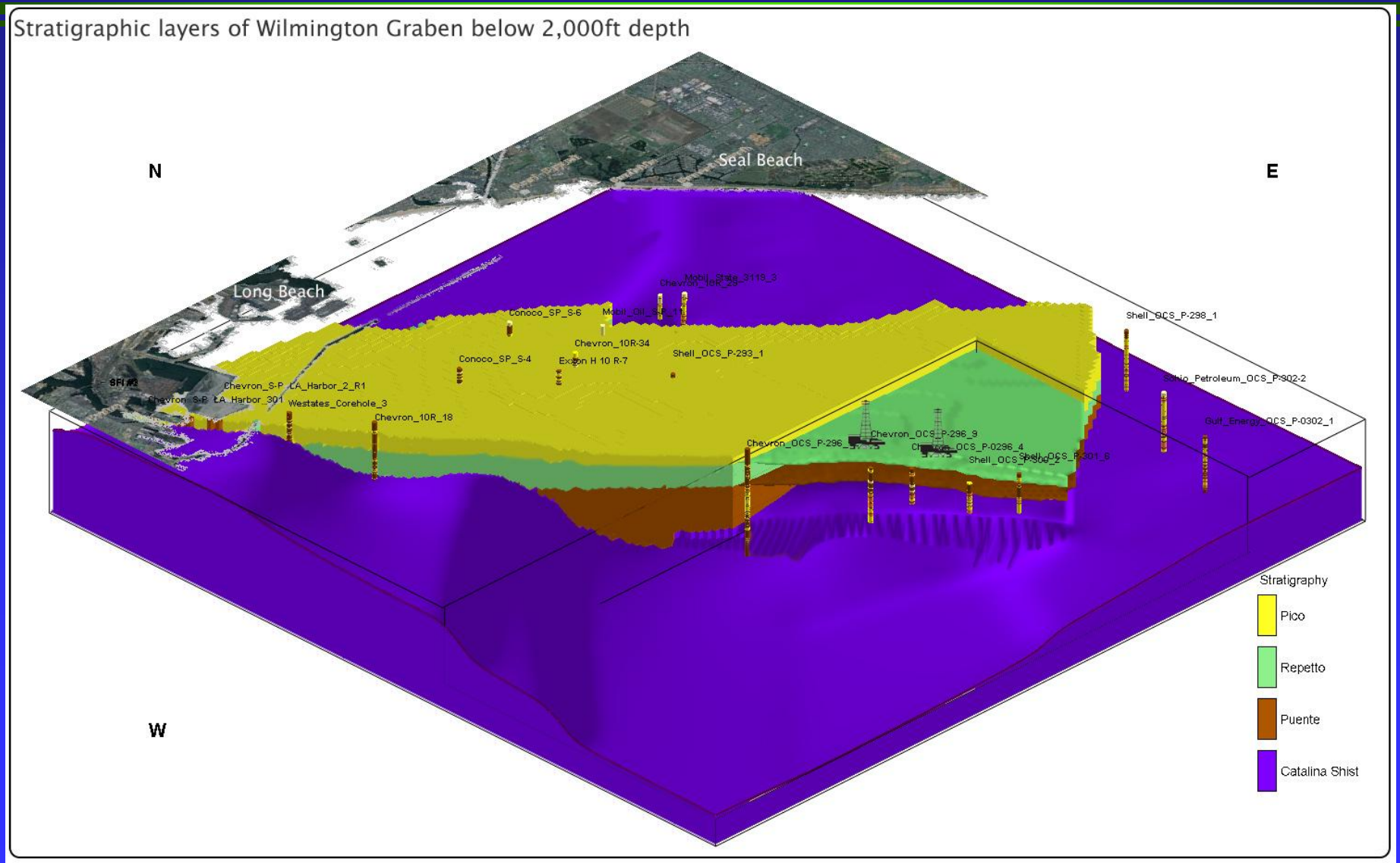
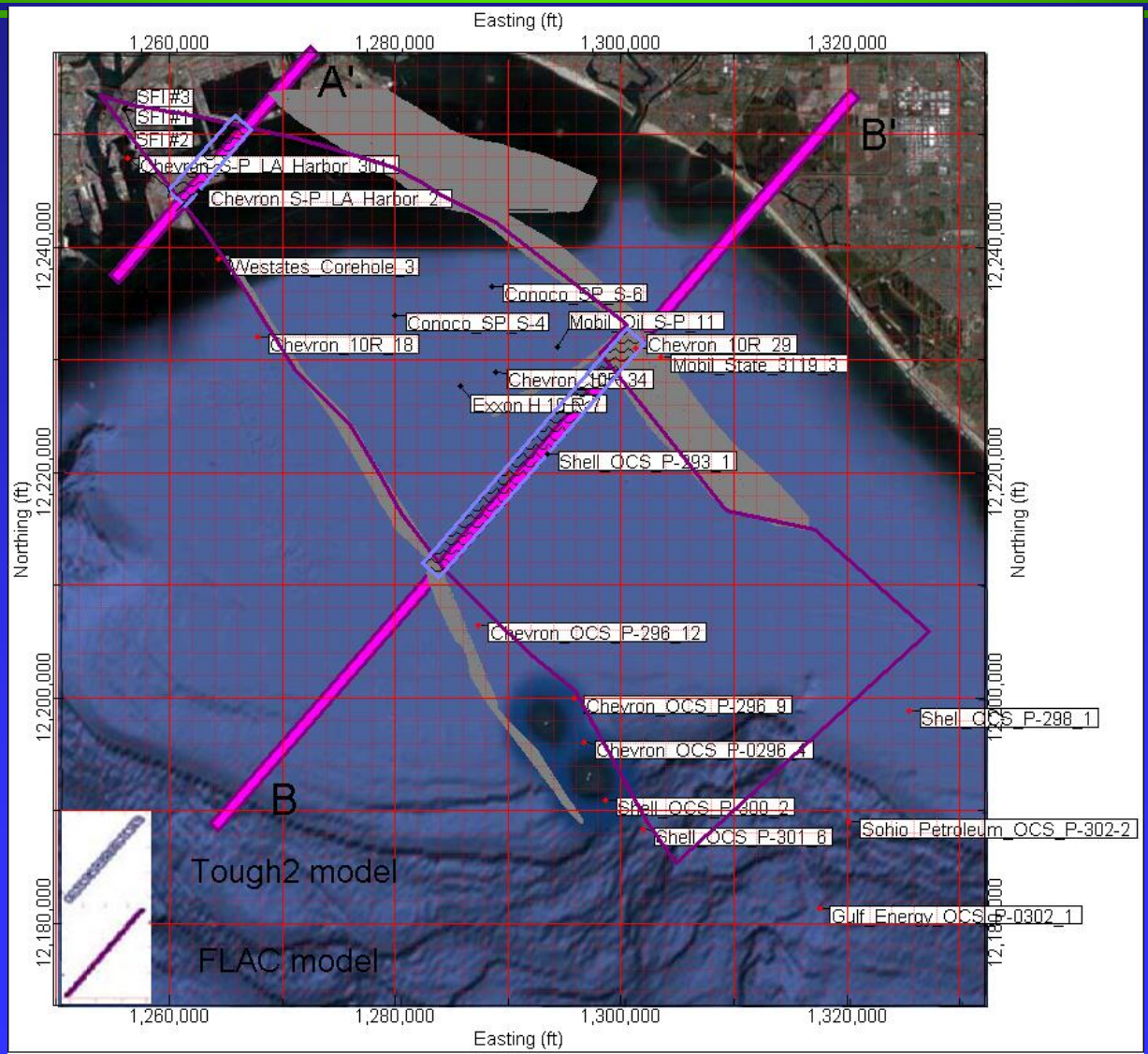
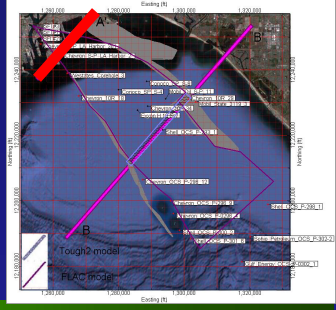
3D Stratigraphic Overview

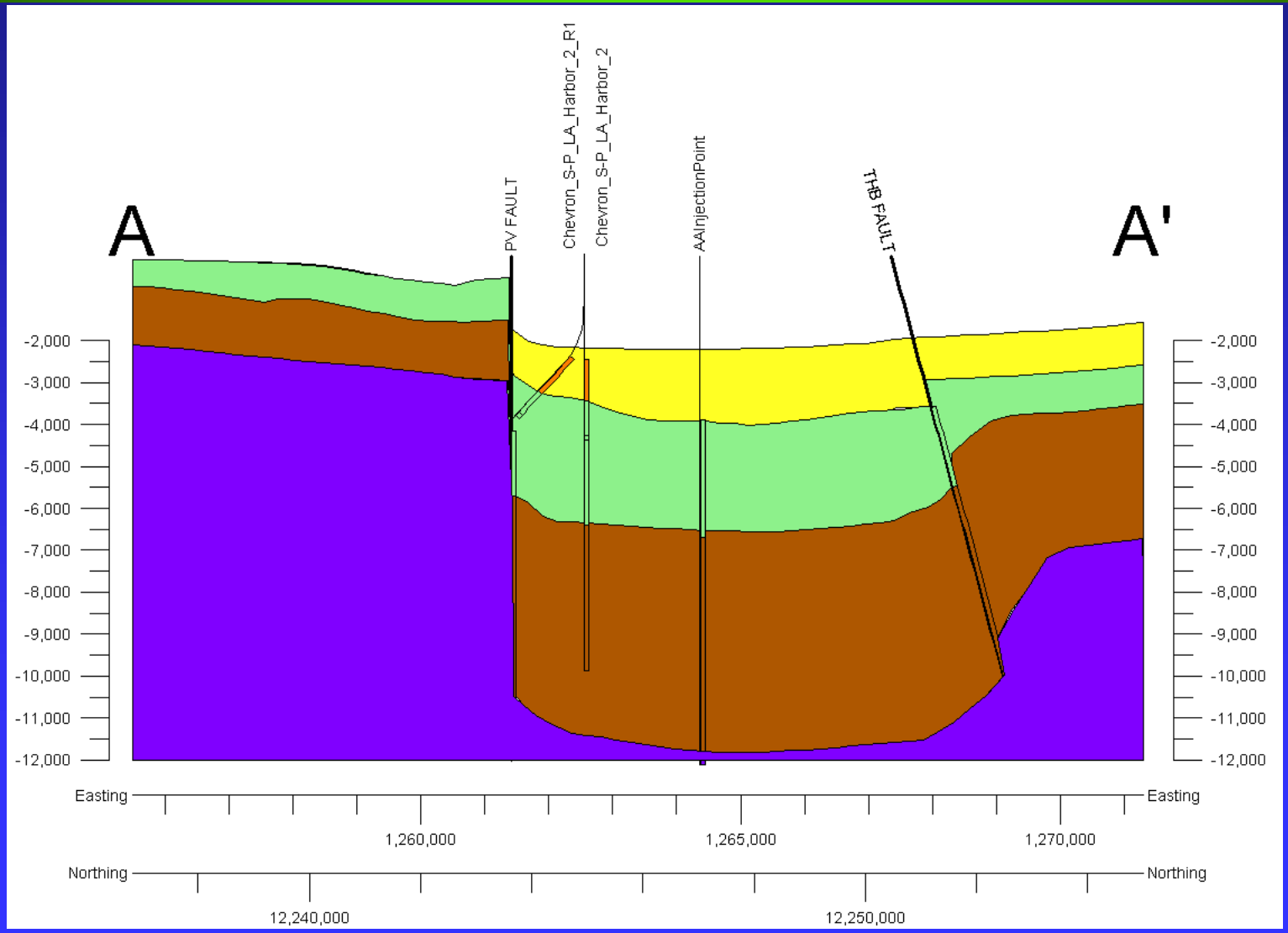


Project Area – Cross Sections for Geomechanical & Gas Migration Models

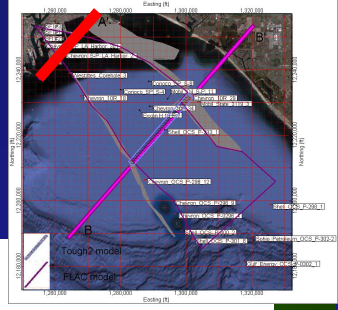


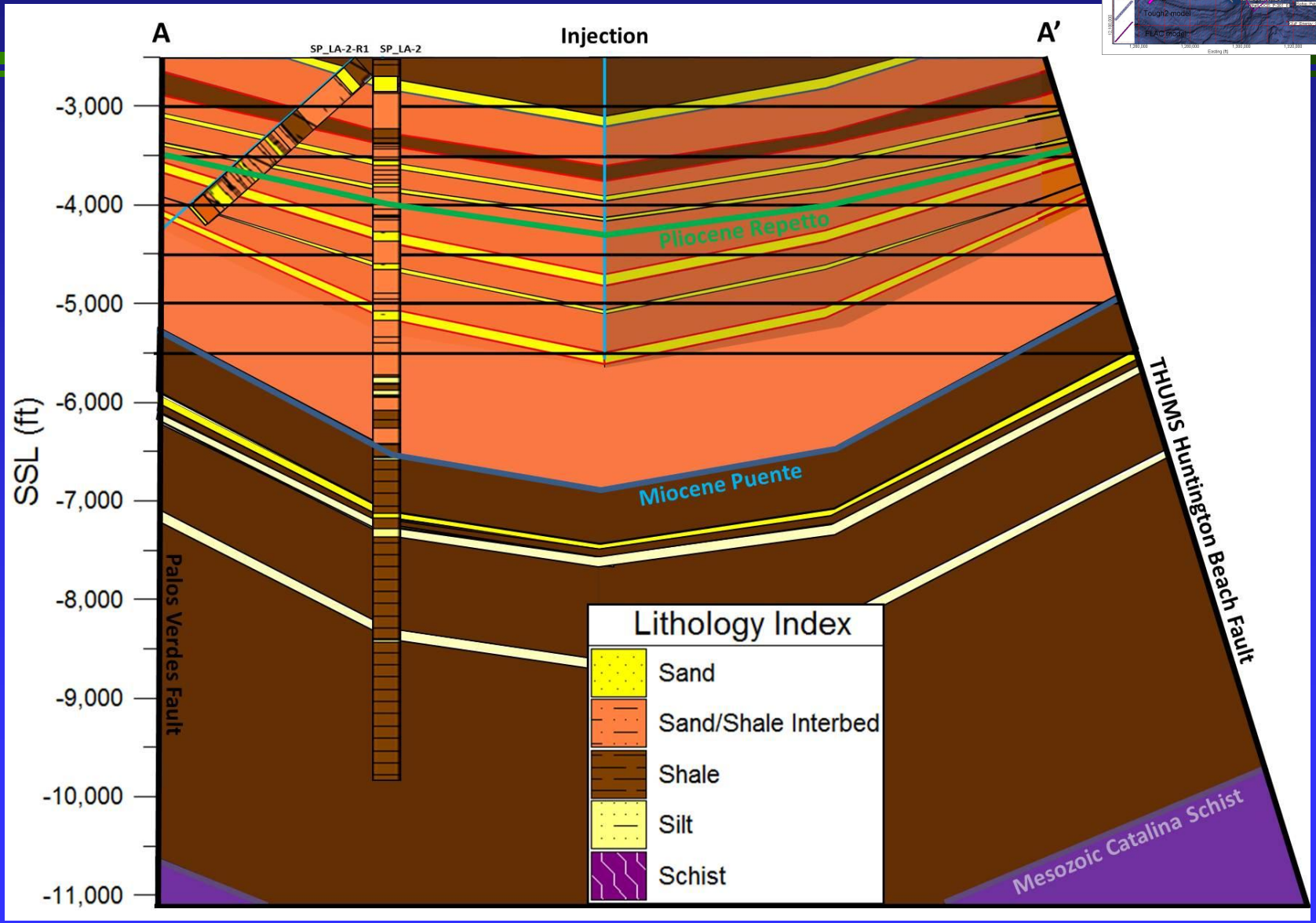
Cross Section AA' – Stratigraphy





Cross Section AA' – Lithology





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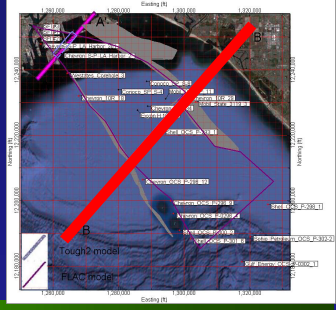
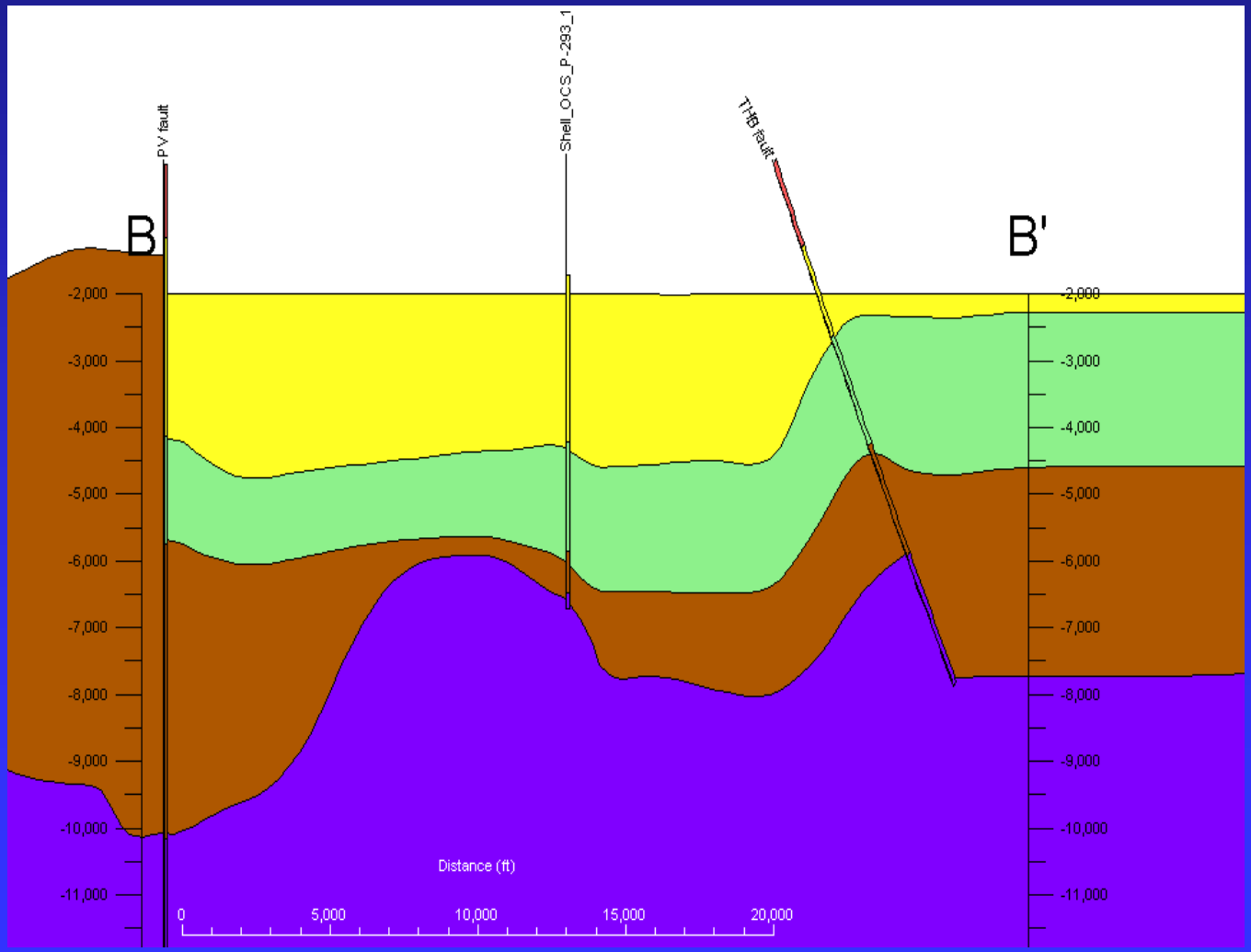
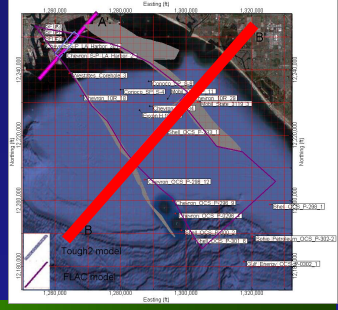
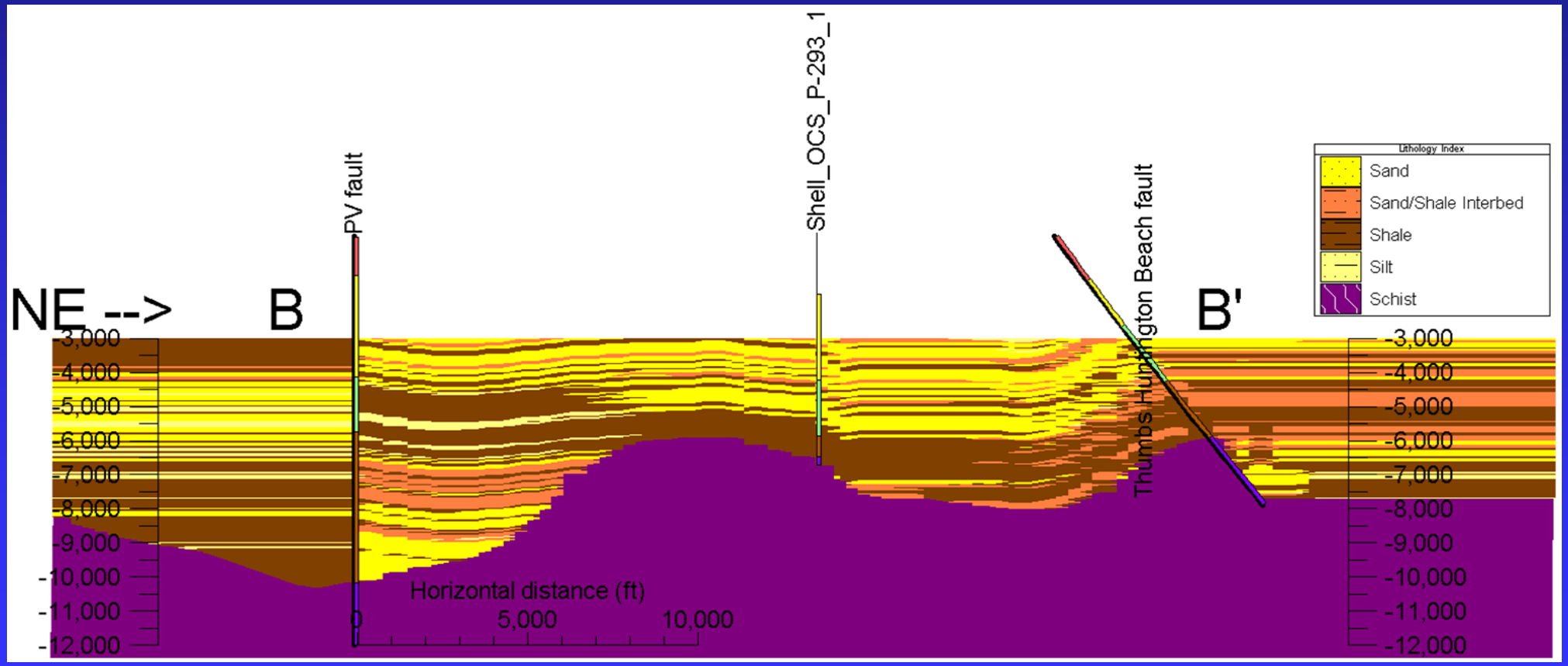
Cross Section BB' – Stratigraphy (2XVE)



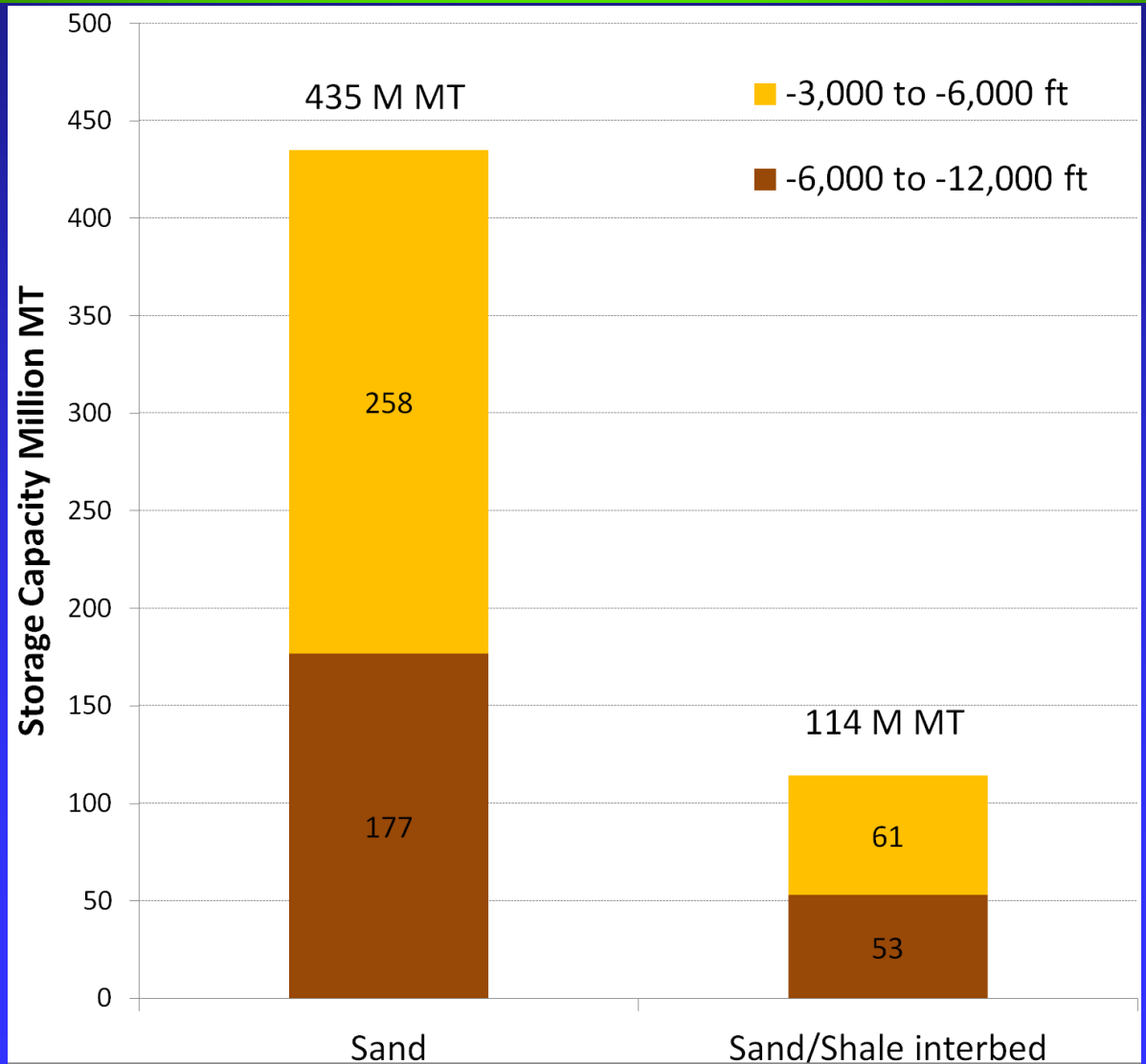


Cross Section BB' – Lithology

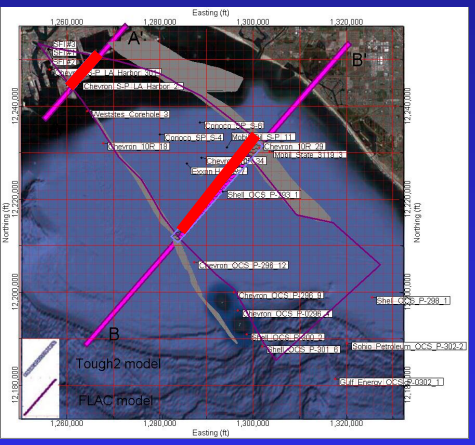


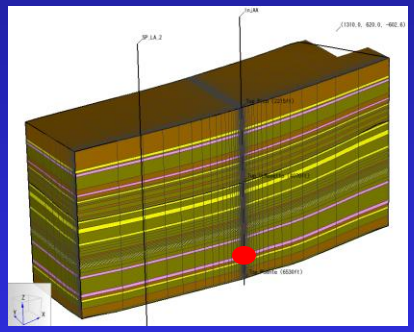


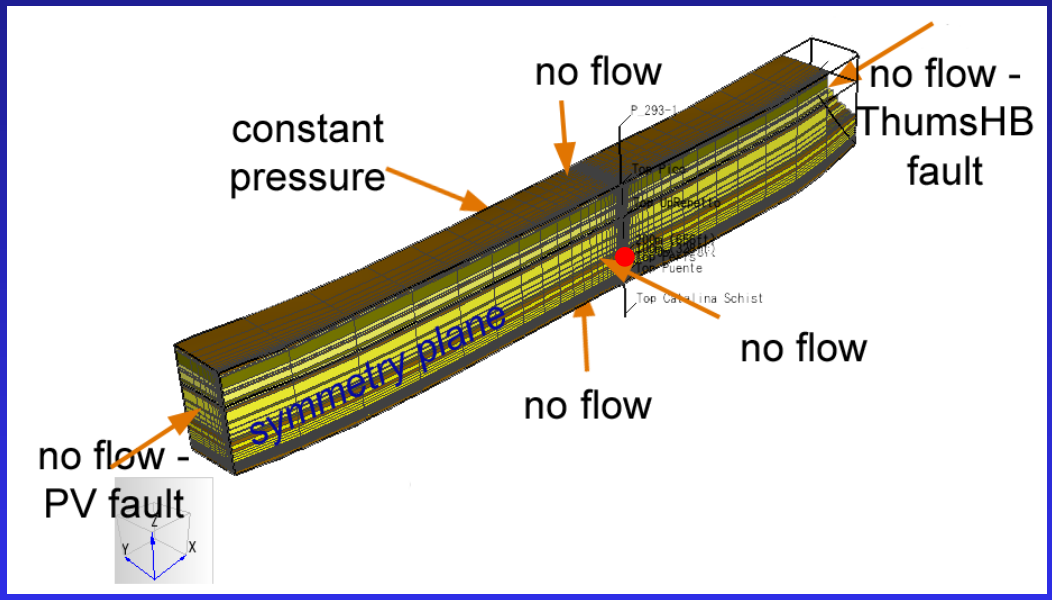
Estimated Storage Capacity



Gas Migration Models – Concept (not to scale)



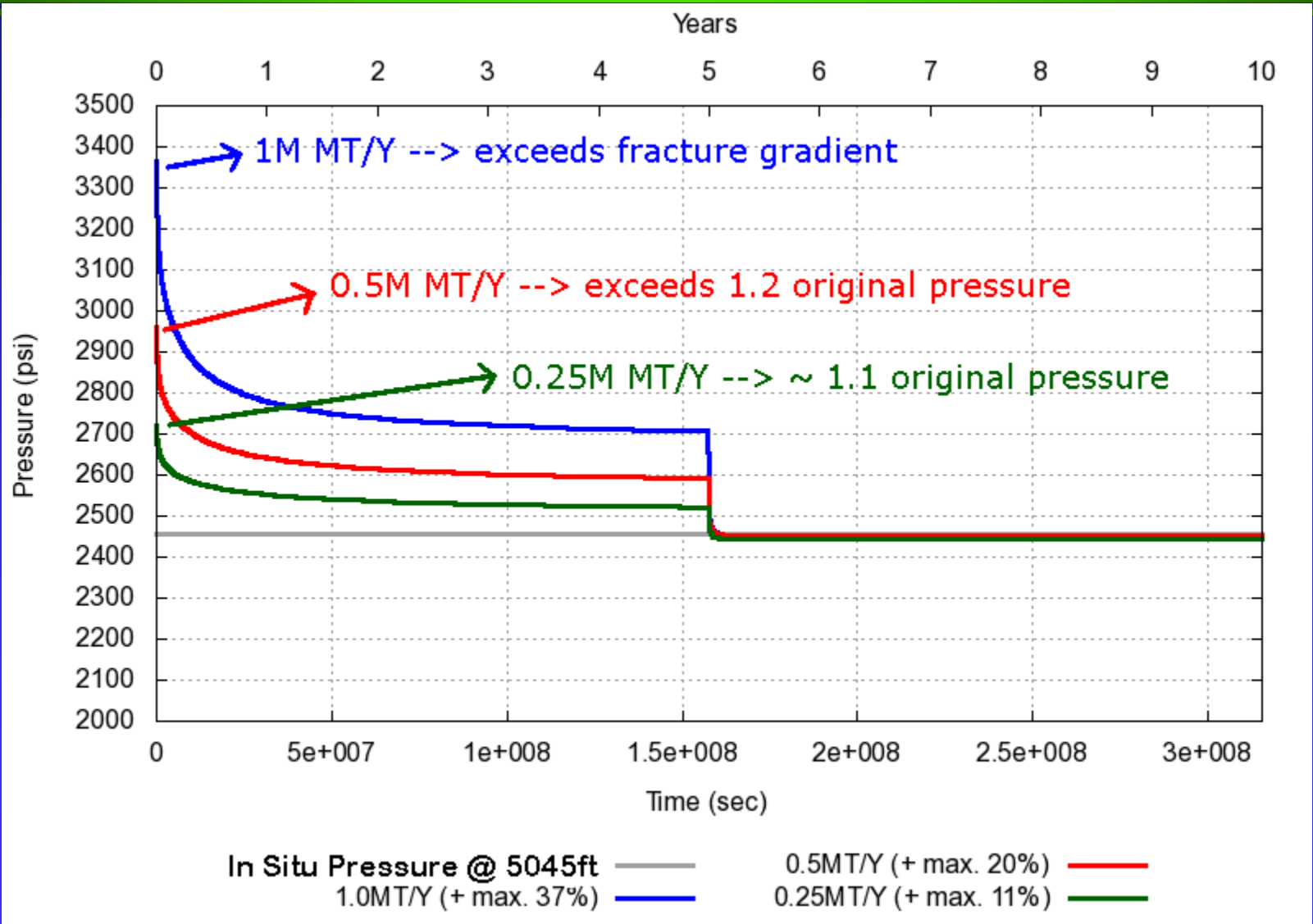




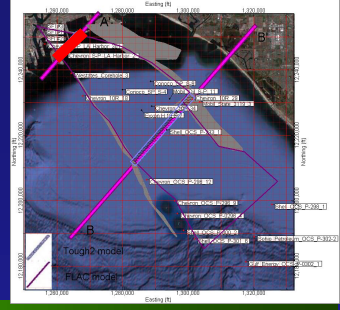
AA **BB**

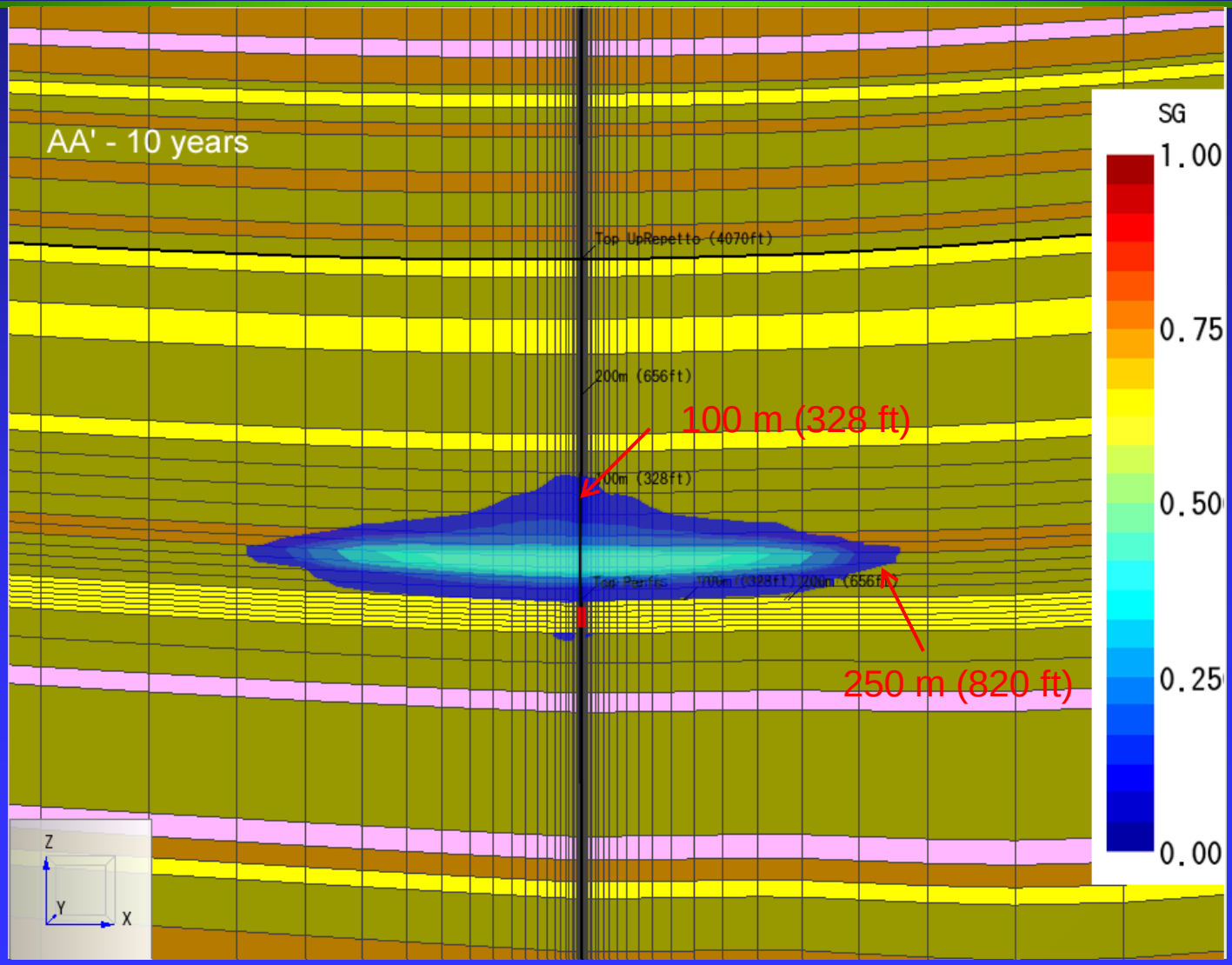
# of cells	60,000	68,000
SW-NE x SE-NW	2,600 x 620 m (8,500 x 2,000 ft)	7,830 x 620 m (26,000 x 2,000 ft)
Model interval	-600 to -2,000 m (-1970 to -6560 ft)	-465 to -1720 m (-1525 to -5643 ft)
Injection interval	-1570 to -1600 m (-5150 to 5250 ft)	-1535 to -1555 m (-5036 to -5100 ft)

Pressure at Injection Cell for 1M MT/Yr, 0.5M MT/Yr & 0.25M MT/Yr - Injection for 5 years at BB'

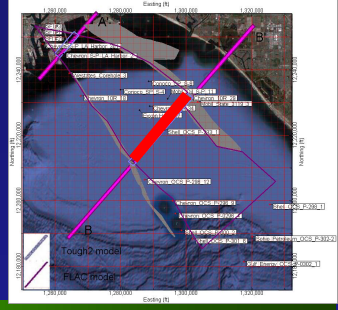


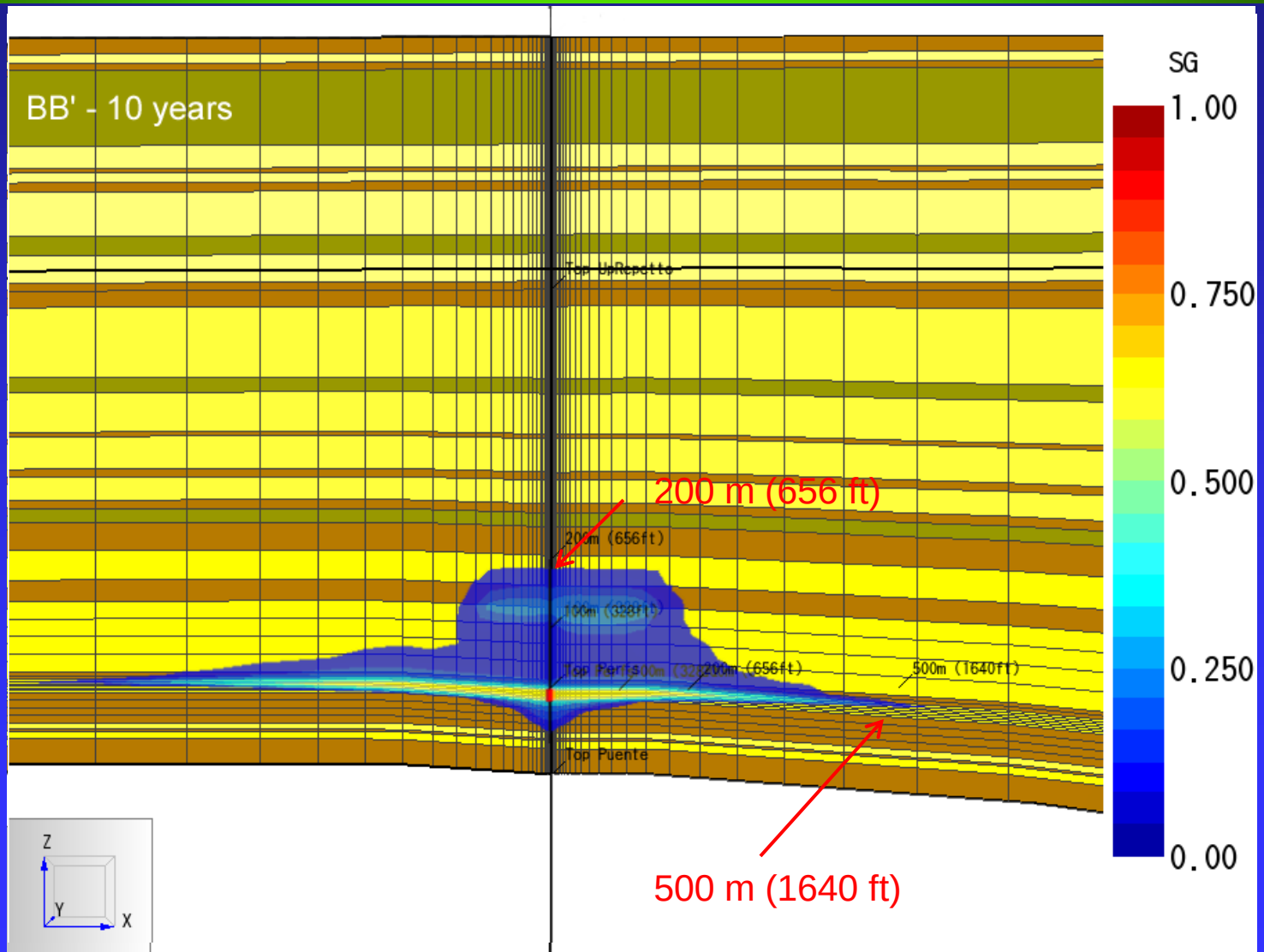
Tough2 Models – AA’ Gas Plume





Tough2 Models – BB' Gas Plume

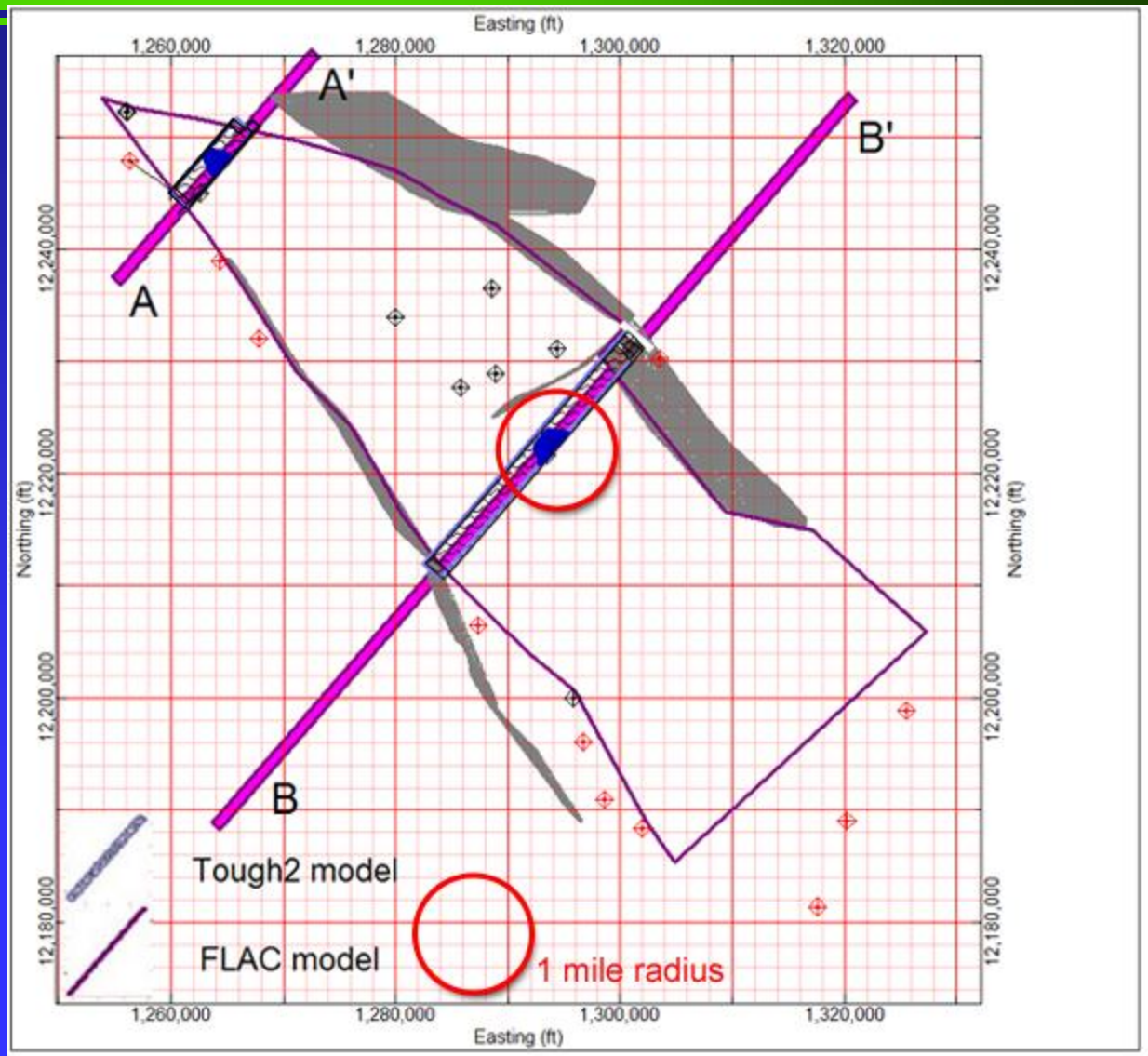




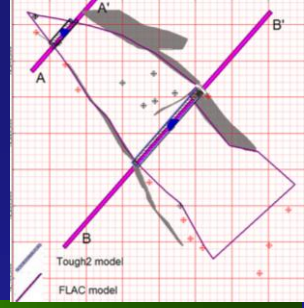
Gas migration modeling

Conclusions so far:

- max. 250,000 MT/Y per well
- min. distance between wells: 1 mile



Geomechanics Update



FLAC3D models have been developed along the two cross sections, A-A' and B-B'

- **Physical and thermal properties have been determined, and applied, from log data and core measurements from well DOE1 for A-A' and log data from Shell OCS P-293_1 for B-B';**

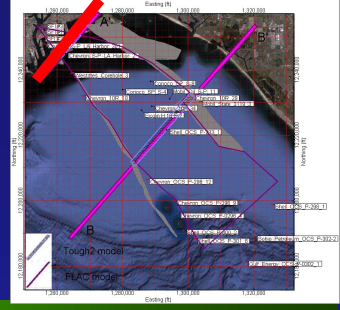
- **Pressure changes resulting from CO_2 injection, as determined by the migration models, have been input into models;**

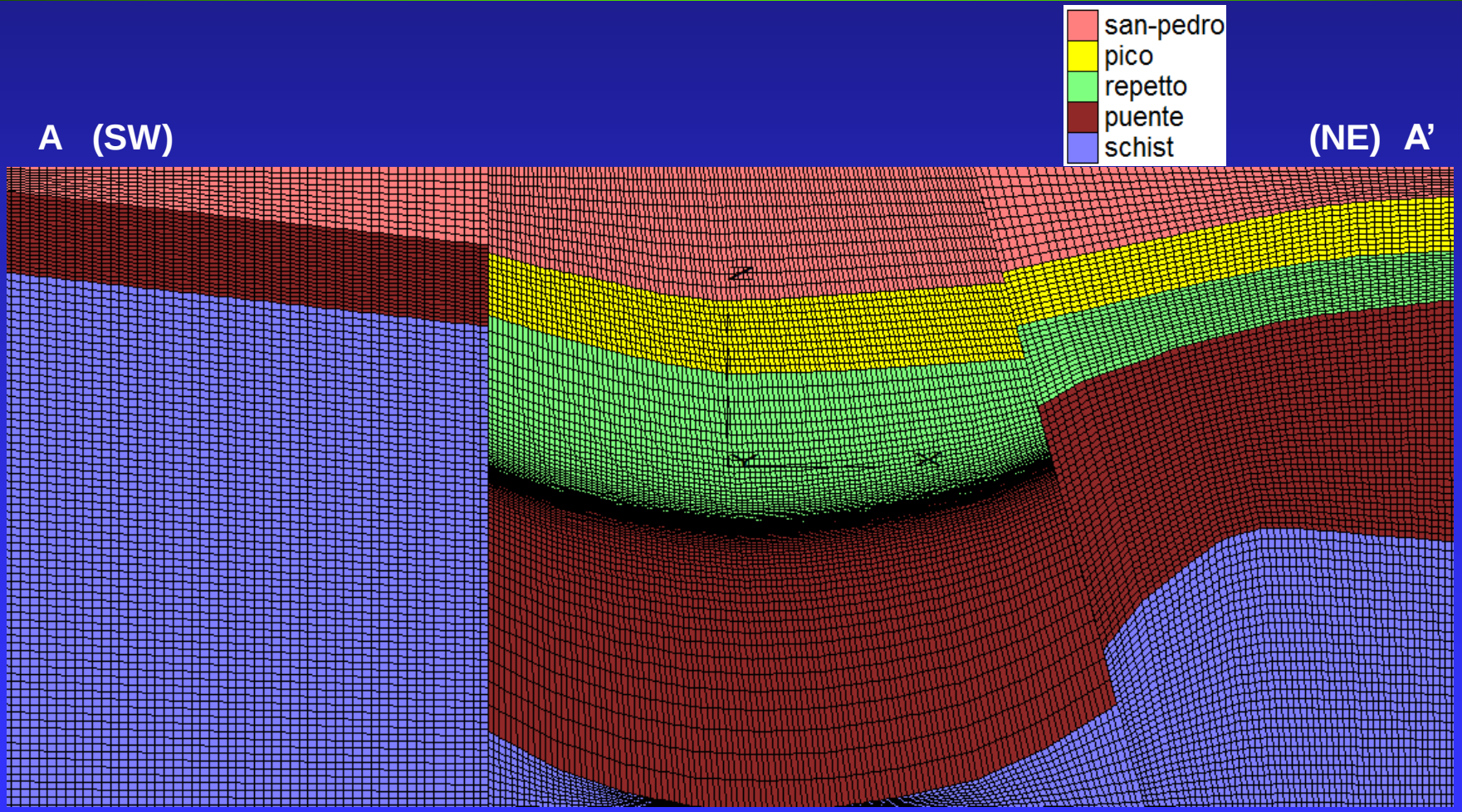
- **Initial and boundary conditions have been set;**

- **The geomechanical model for the B-B' cross section has been run for the first year of injection;**

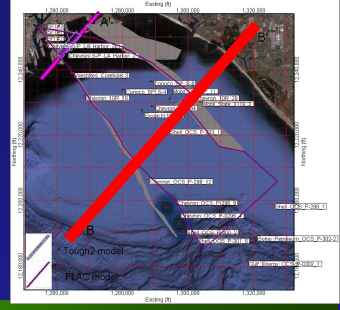
- **The geomechanical model for the A-A' cross section will be run next.**

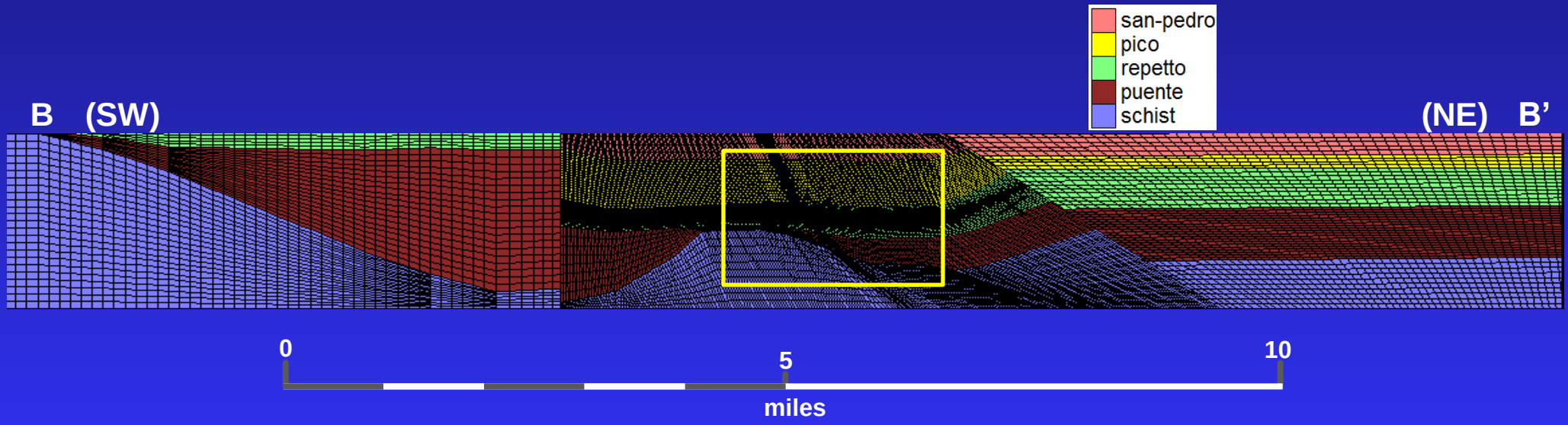
Cross Section AA’ – FLAC3D Model





Cross Section BB’ – FLAC3D Model

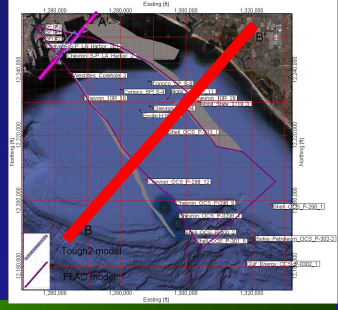


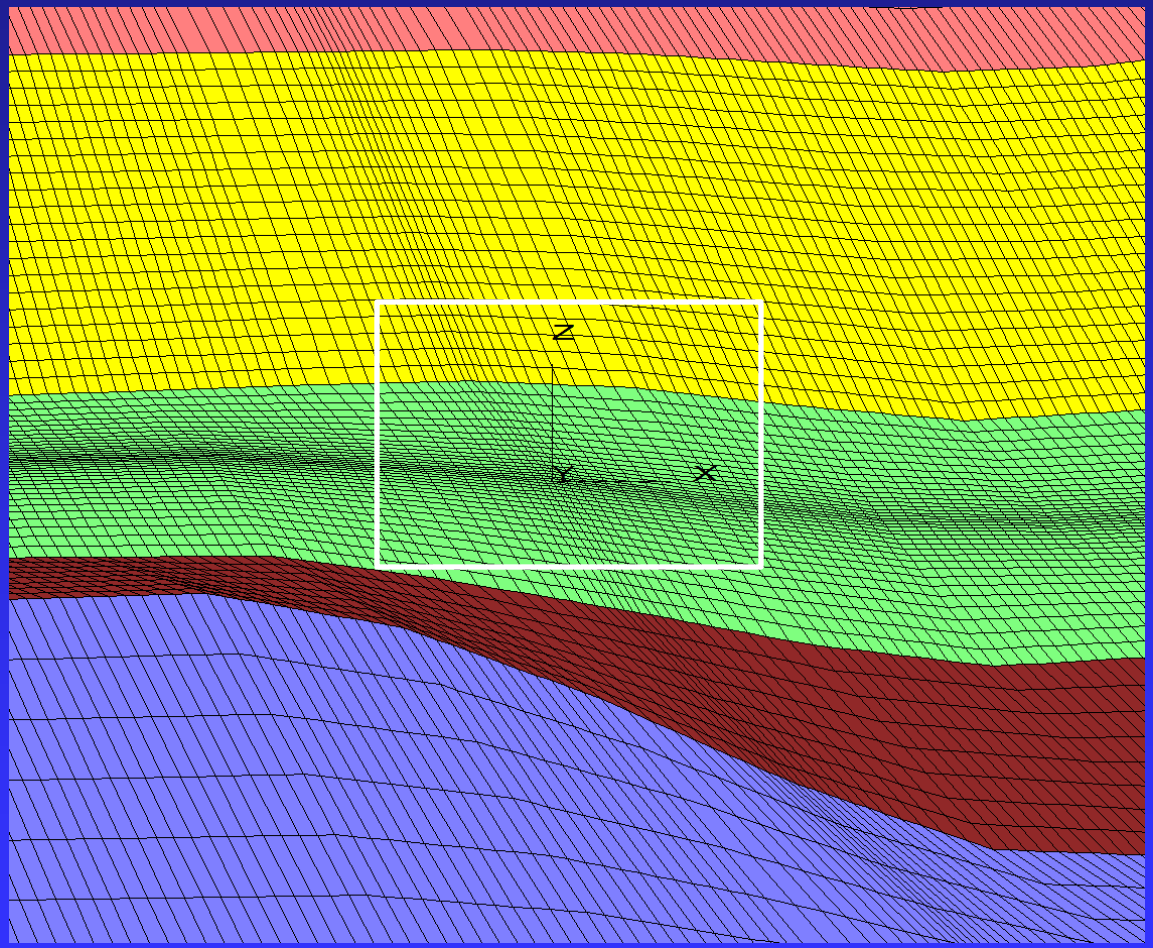


# of cells	30,000
SW-NE x SE-NW	86,000 x 100 ft
Model interval	-75 to -10,500 ft
Injection interval	-5036 to -5100 ft
Max Cell Size	600 ft X 400 ft

TTI

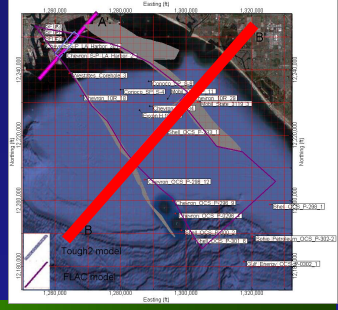
Cross Section BB' – FLAC3D Model

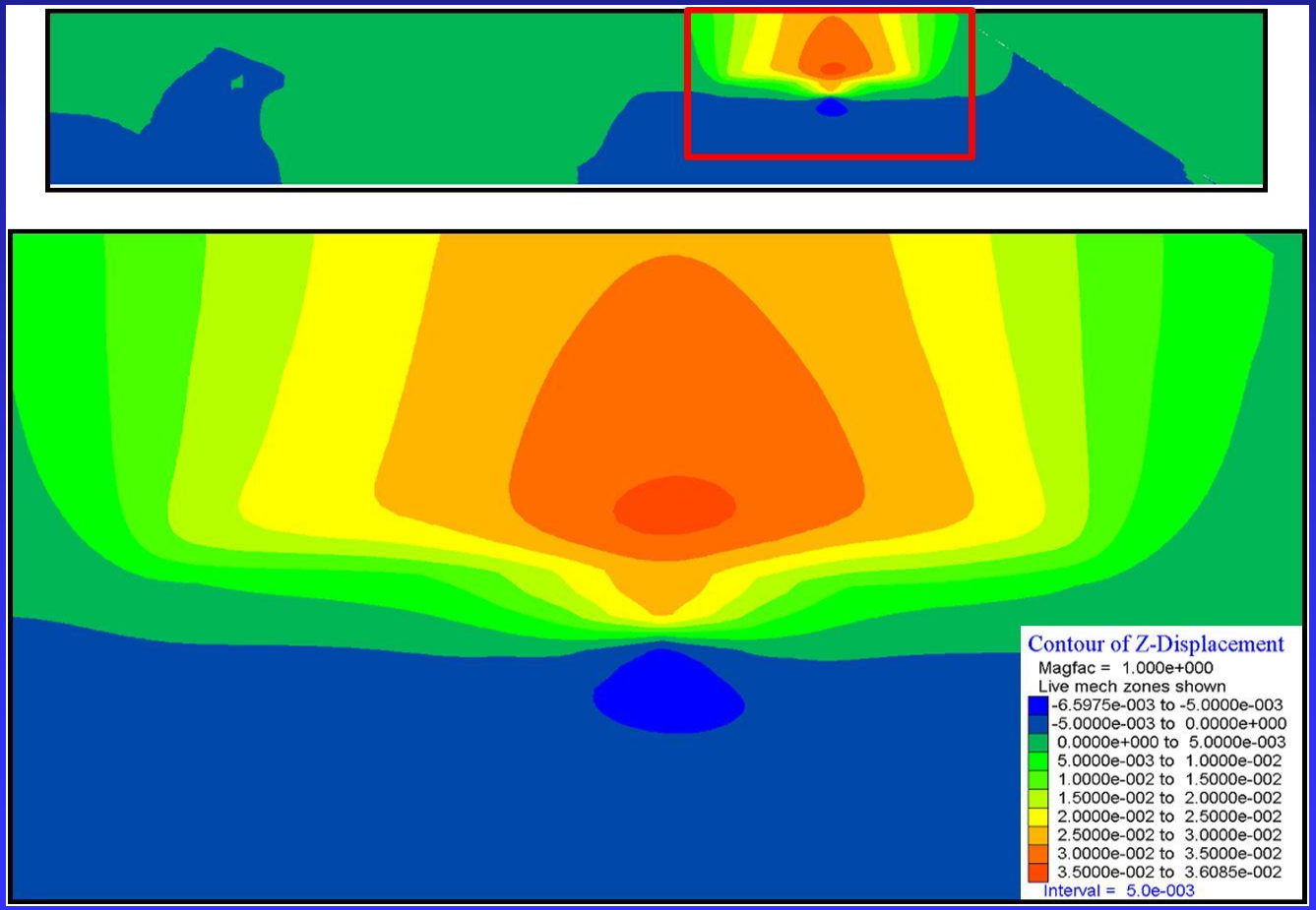




Min Cell Size	50 ft X 16 ft

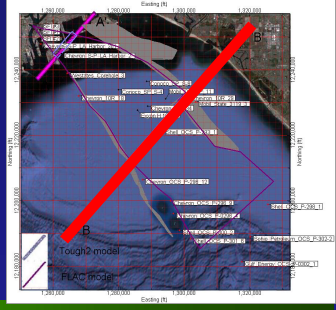
Cross Section BB' – Induced Vertical Displacement

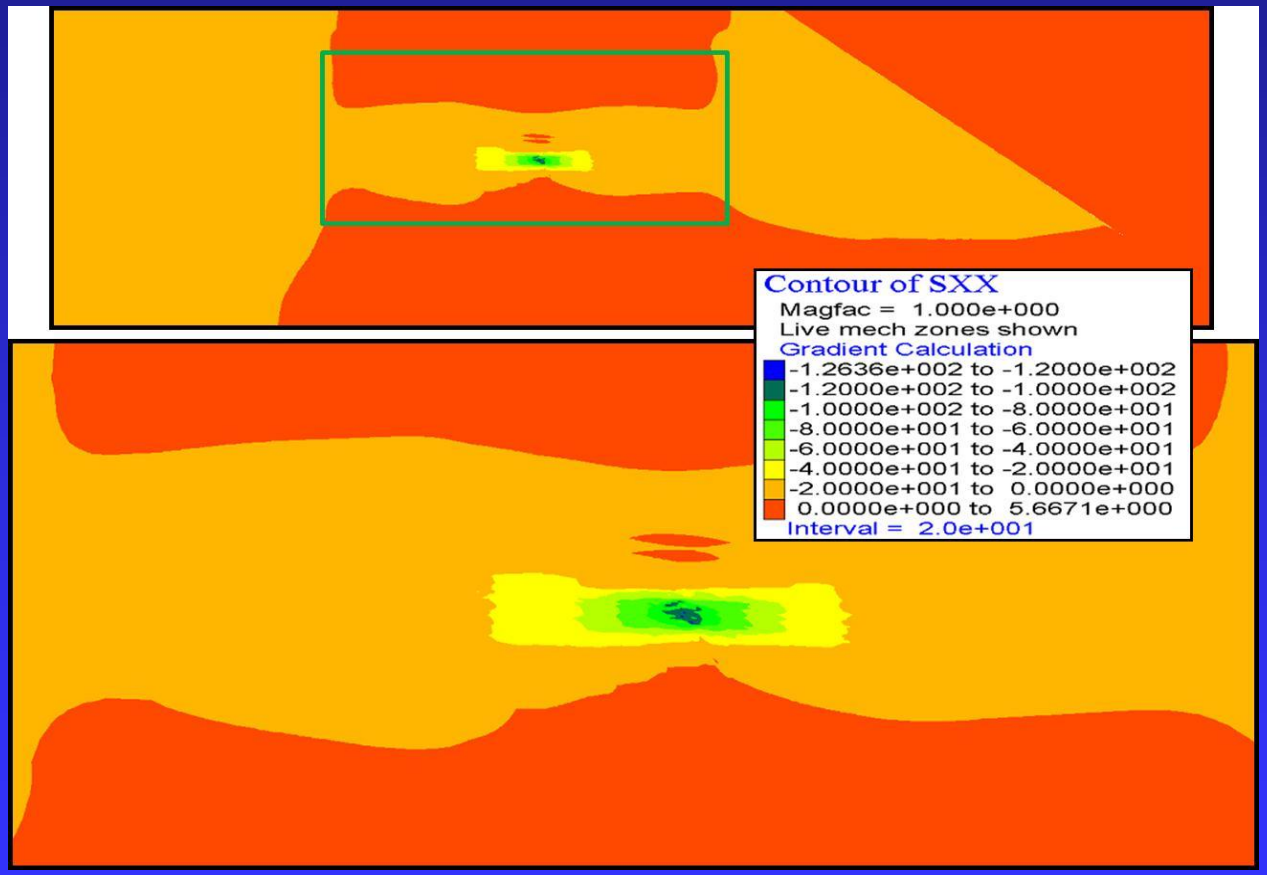




- Virtually 0 Throughout Graben
- 0.07" Below Injection
- Greatest About 0.44" 1000' Above Injection
- Could Be As Much As 0.33" Near Seafloor

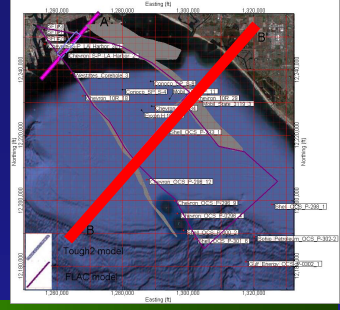
Cross Section BB' – Induced Horizontal Stress

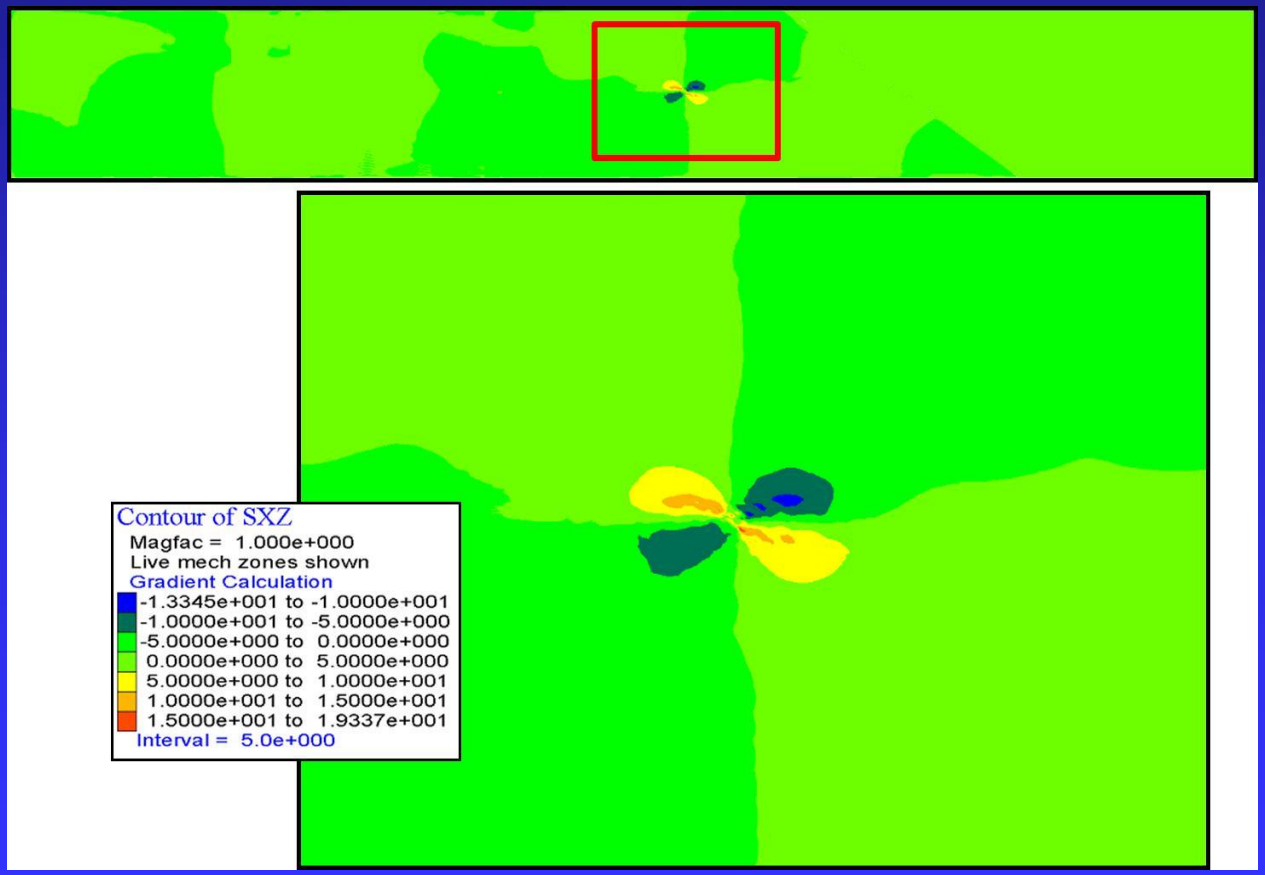




- Virtually 0 Throughout Graben
- Except In Few Thousand Feet Around Injection
- Greatest About 126 psi Of Compression At Injection
- Less Than 100 psi a Few Hundred Feet From Injection

Cross Section BB' – Induced Shear Stress





- Virtually 0 Throughout Graben
- Except In Few Thousand Feet Around Injection
- Greatest Is Under 20 psi Near Injection
- Less Than 10 psi a Few Hundred Feet From Injection

Efforts to Better Characterize Pliocene & Miocene for high-volume CO_2 Storage include

TTI

1) Improved evaluation and interpretation of existing 2D and 3D seismic data;

2) Acquisition and interpretation of additional 2D seismic lines;

3) Detailed log evaluation of existing exploration wells in the area;

4) Drilling and coring three new evaluation wells into the Graben (Pliocene and Miocene) and/or on the landward side of the THUMS-HB fault

5) Development of 3D geologic models, geomechanical models, and CO_2 injection and migration models for the region.

6) Analysis of industrial sources (top 20 in the LA Basin)

7) Engineering study of existing and new pipeline systems to transport CO_2 from significant local sources to sequestration sites (transport infrastructure study)

8) Risk analysis (include well integrity, induced and natural seismicity)

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SoCalCarb

Southern California Carbon Sequestration Research Consortium

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Sponsors & Participants

NETL | U.S. Department of Energy | Southern California Gas Company | City of Los Angeles | GeoEnvironment Technologies | TTI | USGS | University of California

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Home

Southern California Map (NASA JPL Shuttle Radar Topography Mission (SRTM))

The Southern California Carbon Sequestration Research Consortium (SoCalCarb) is a collaborative research group bringing together scientists and engineers from more than 10 public agencies, private companies, and universities to identify and validate the best regional opportunities for keeping CO_2 out of the atmosphere, thereby reducing our anthropogenic impact on the climate.

Led by Terralog Technologies USA, with funding support by the US Department of Energy and the California Energy Commission, SoCalCarb is pursuing characterization studies for large scale CO_2

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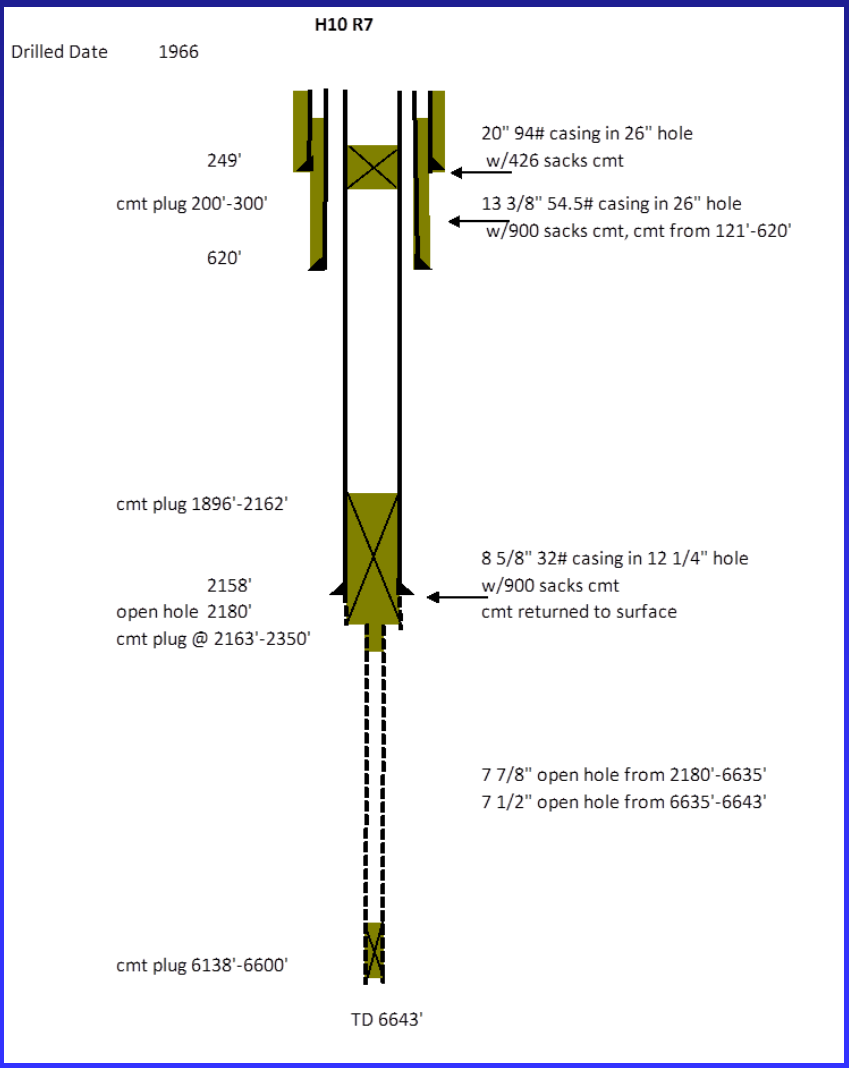
Well Leakage Risks



All 9 DOGGR 1960's wells open hole below surface casing.

All 6 Federal 1970's offshore wells no well history data

3 New wells drilled in 2007 and 2010 all cased and cemented. No well leakage risk.

Problem wells will either need to be sealed or (preferably) those areas must be avoided completely.

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Project Status Summary

- Acquired 175km of new seismic lines
- Drilled 1st characterization well into Pliocene
- Structure maps constructed for 4 horizons
- Geologic model near completion
- Initiated CO_2 migration modeling (TOUGH2): injecting 1 MT/yr results in pressure exceeding fracture gradient; 0.5 and 0.25 MMT/yr maintains pressure below fracture gradient
- Initiated geomechanical modeling (FLAC3D)
- Preliminary storage estimates >500 MMT
- Old well path may need to be sealed or avoided for large-scale CO_2 storage
- Source, sinks and pipeline interactive maps available online

Characterization of Pliocene and Miocene Formations in the Wilmington Graben, Offshore Los Angeles, for Large-Scale Geologic Storage of CO_2

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Bill Childers
Terralog Technologies USA, Inc

1. Project Background and Motivation
2. Project Plan, Status and Accomplishments
3. Next Steps

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Next Project Steps

- Obtain drilling permits for a characterization well into Miocene formations;
- Continue applying geomechanical models to estimate stresses and fault activation risks due to large-scale CO_2 injection;
- Extend gas migration modeling out to 50 years;
- Complete engineering studies of LA Basin sources and transportation systems;
- Risk characterization and documentation;
- Present updated results in Pittsburgh (Aug, 2012) .

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Project Sponsors and Participants:

DOE NETL

California Energy Commission

City of Los Angeles, Department of Public Works

Southern California Gas Company (transport infrastructure)

Cal State Long Beach, Dr. Dan Francis (seismic acquisition)

Legg Geophysics (seismic interpretation)

USGS, Dr. Dan Ponti (cores and samples repository)

Terralog Technologies USA (geology, geomechanics, reservoir eng and drilling contract management)