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

Project Number (FE0001922)

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GeoMechanics Technologies

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

August 20-22, 2013

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Background and Motivation

- The Los Angeles Basin provides a unique combination of significant need and significant opportunity for large scale CO2 sequestration
- Has numerous large power plants & oil refineries which produce more than 5 million MT of fossil fuel related CO2 emissions each year
- Prolific oil & gas producing basin with thick sediments (several billion barrel fields)

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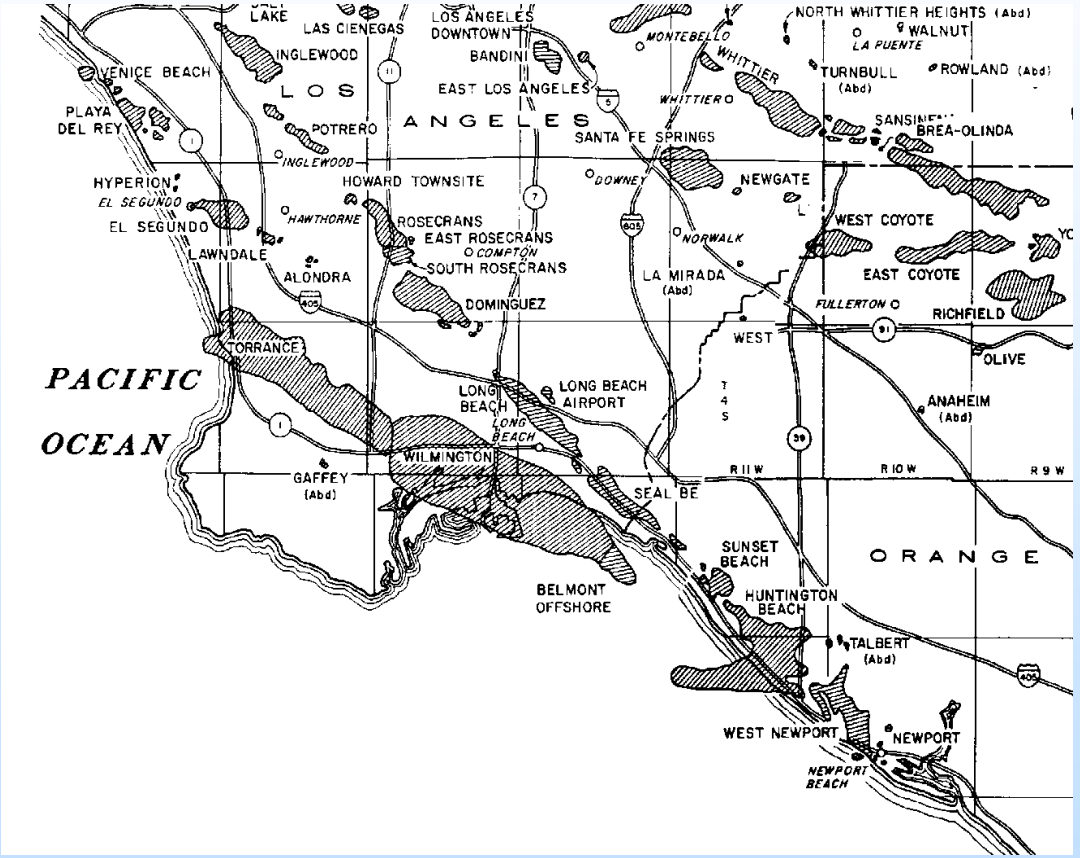
Background and Motivation

- Precedent and history for large scale injection (>3000 injection wells)
- Precedent and history for large scale gas storage (5 fields)
- But, siting large scale CO2 storage beneath a highly populated area is technically and politically impractical



Oil Fields in LA Basin

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Background and Motivation

The offshore Wilmington Graben presents significant advantages, including:

- Geologically isolated, yet accessible from onshore with existing oil and gas infrastructure;
- Very thick sediments nearly identical to those located onshore;
- Fewer existing wells to reduce leakage risk (11 wells).

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Goal and Objective

- The objective of this research project is to fully characterize Pliocene and Miocene sediments in the Wilmington Graben, offshore Los Angeles, for high volume CO2 storage, to evaluate risks, and to evaluate logistics for transport from local sources
  - The effort contributes to the Carbon Storage Program's goal to develop technologies to predict CO2 storage capacity in geologic formations to within 30%.
  - The effort also contributes to the Program's goal to develop technologies to demonstrate 99% of injected CO2 remains within the injection zones.
- One key goal is to confirm CO2 storage capacity in the Wilmington Graben exceeds 100 million metric tons.
  - Contributes to the understanding of injectivity, containment mechanisms, and storage capacity of the Wilmington Graben for large scale CO2 sequestration.
  - One of only two projects focused on offshore storage formations. Only project focused on turbidite geologic settings (common in Western US).

Benefits to the Program

- This project is contributing to the understanding of injectivity, containment mechanisms, and storage capacity of the Wilmington Graben basin.
- Broadens the experimental knowledge base of best practices for site characterization and approving storage site selection with the ultimate goal of developing practical guidelines for future commercially developed CO_2 storage sites.
- This effort contributes to the Carbon Storage Program's effort of conducting field tests to support the development of Best Practices for site selection, characterization, and operations.
- Unique evaluation of offshore storage in a turbidite geologic setting

Project Team 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)

Don Clarke (geologic evaluation and modeling)

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

GeoMechanics Technologies (geology, geomechanics, reservoir engineering and drilling contract management)

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Team Contributions

- Partnership with the City of LA (Renewable Energy Project) provided drilling site and existing EPA drilling permit in the North Wilmington Graben, expediting drilling DOE#1.
- Partnership with USGS provides a repository for all the cores and drill cutting samples
- Partnership with California State University, Long Beach provided seismic surveying capability and interest in better understanding the Palos Verdes Fault system
- Don Clarke and Mark Legg are the top geology and geophysics experts on Wilmington Area
- Beta Offshore operating and exploring on offshore edge of Graben, providing cost share for DOE#3
- GeoMechanics Technologies has successfully managed about 10 DOE projects over 15 years. We hold a drilling contractors license and are experienced and active in gas storage engineering and injection operations

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Work Plan:
Scope of Work

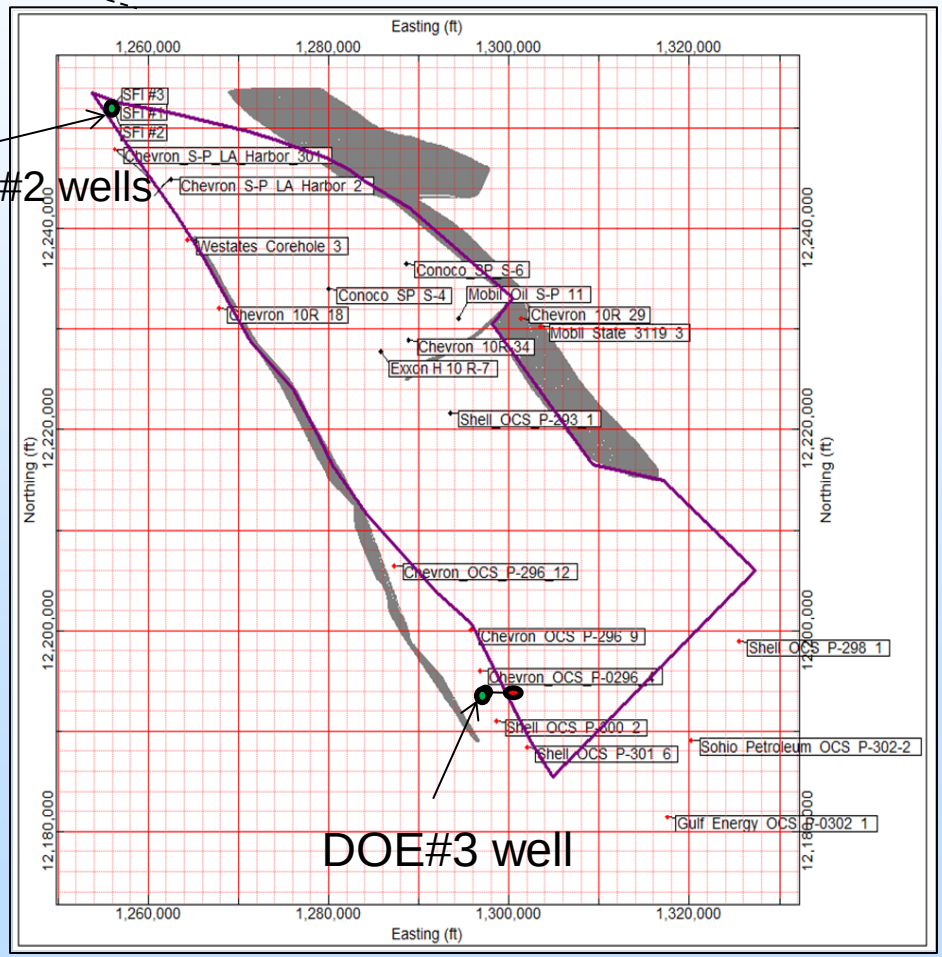
1) Detailed log evaluation of existing exploration wells in the area
2) Improved evaluation and interpretation of existing 2D and 3D seismic data plus new seismic data acquisition within a “data gap” area
3) Drilling and coring three new evaluation wells into the Graben (Pliocene and Miocene)
4) Development of 3D geologic models, geomechanical models, and CO_2 injection and migration models for the region – update with data from new DOE wells
5) Analysis of top 20 industrial sources in the LA Basin
6) Transport Infrastructure Study: engineering study of existing and new pipeline systems to transport CO_2 from significant local sources to sequestration sites
7) Risk analysis

Project Status
Accomplishments to date

- Detailed log evaluation of existing exploration wells in the area
- Improved evaluation and interpretation of existing 2D and 3D seismic data
- Acquisition and interpretation of additional 2D seismic lines
- DOE#1 (onshore Pliocene) well drilled and analyzed, DOE#2 (onshore Miocene) state permit approved July 31, 2013, w drilling planned for 4th qtr 2013, DOE#3 (offshore Miocene) BSEE permit submitted, with approval expected in September 2013, and drilling planned for 1st qtr, 2014.
- Complete initial development of 3D geologic models, geomechanical and CO_2 injection and migration models. Currently revising and improving based on Peer Review recommendations.
- Completed analysis of top 20 industrial sources in the LA Basin and transportation infrastructure. Developed interactive map/atlas (www.socalcarb.org)
- Risk analysis. 60% completed

Well Data Review and Formation Evaluation

DOE#1 and DOE#2 wells



DOE#3 well

Collect log data from about 12 exploration wells located in State and Federal waters

Evaluate sand, silty-sand, and shale sequences

Combine into common database

Supplement with 3 new wells

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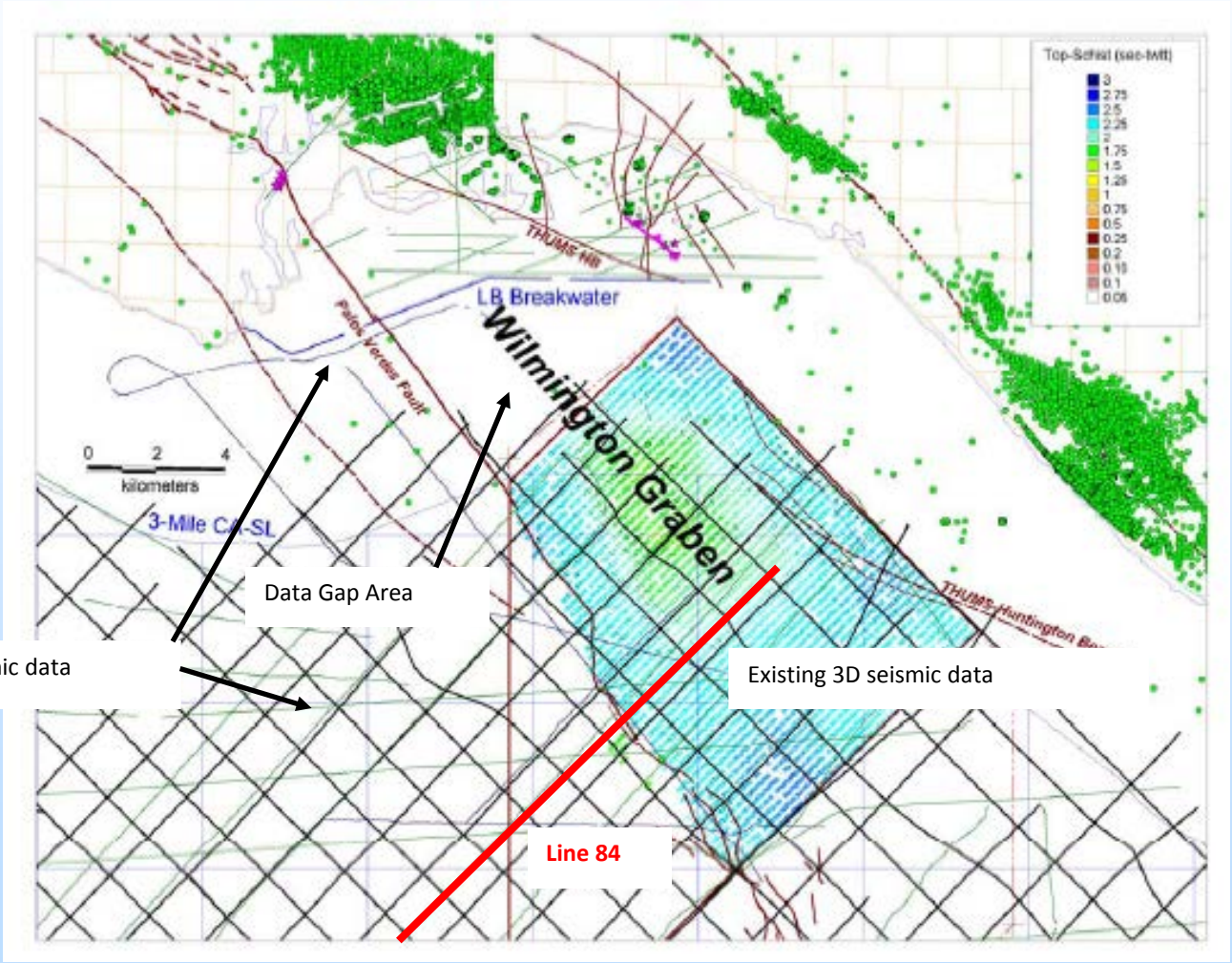
Seismic Data Analysis and Acquisition

Collect new seismic data in “gap area”

Combine and reinterpret existing data

Establish horizons for 3D geologic model



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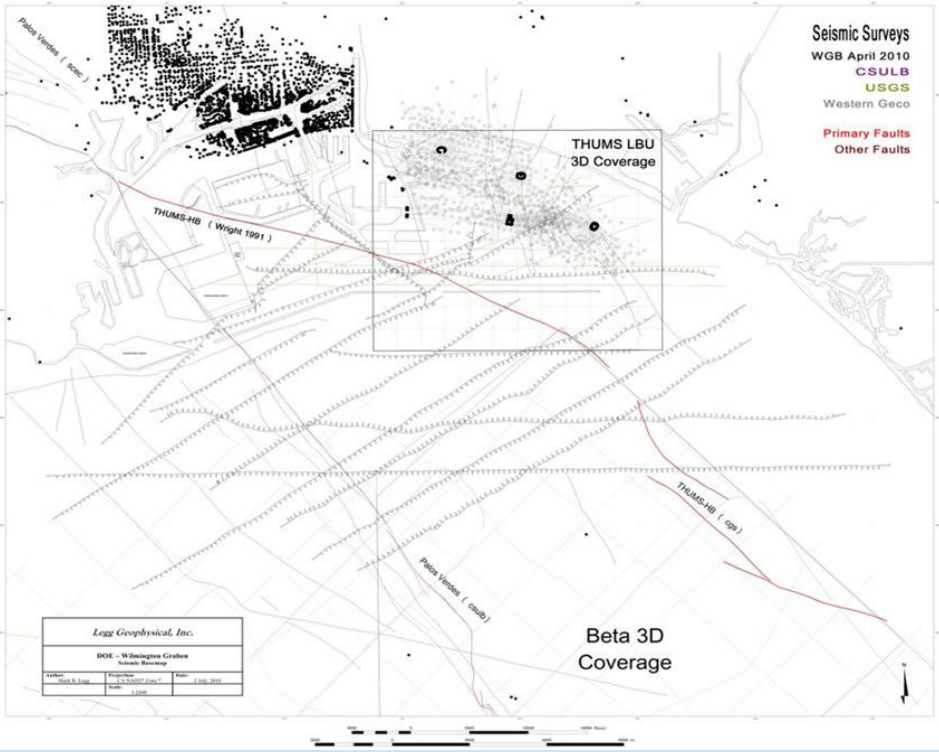
Seismic Data Analysis and Acquisition

New seismic data collected over 175km of lines inside and outside breakwater, with ties to previous data

CA State Long Beach Seismic Acquisition Boat



Shot Point Map for 175km of new seismic lines

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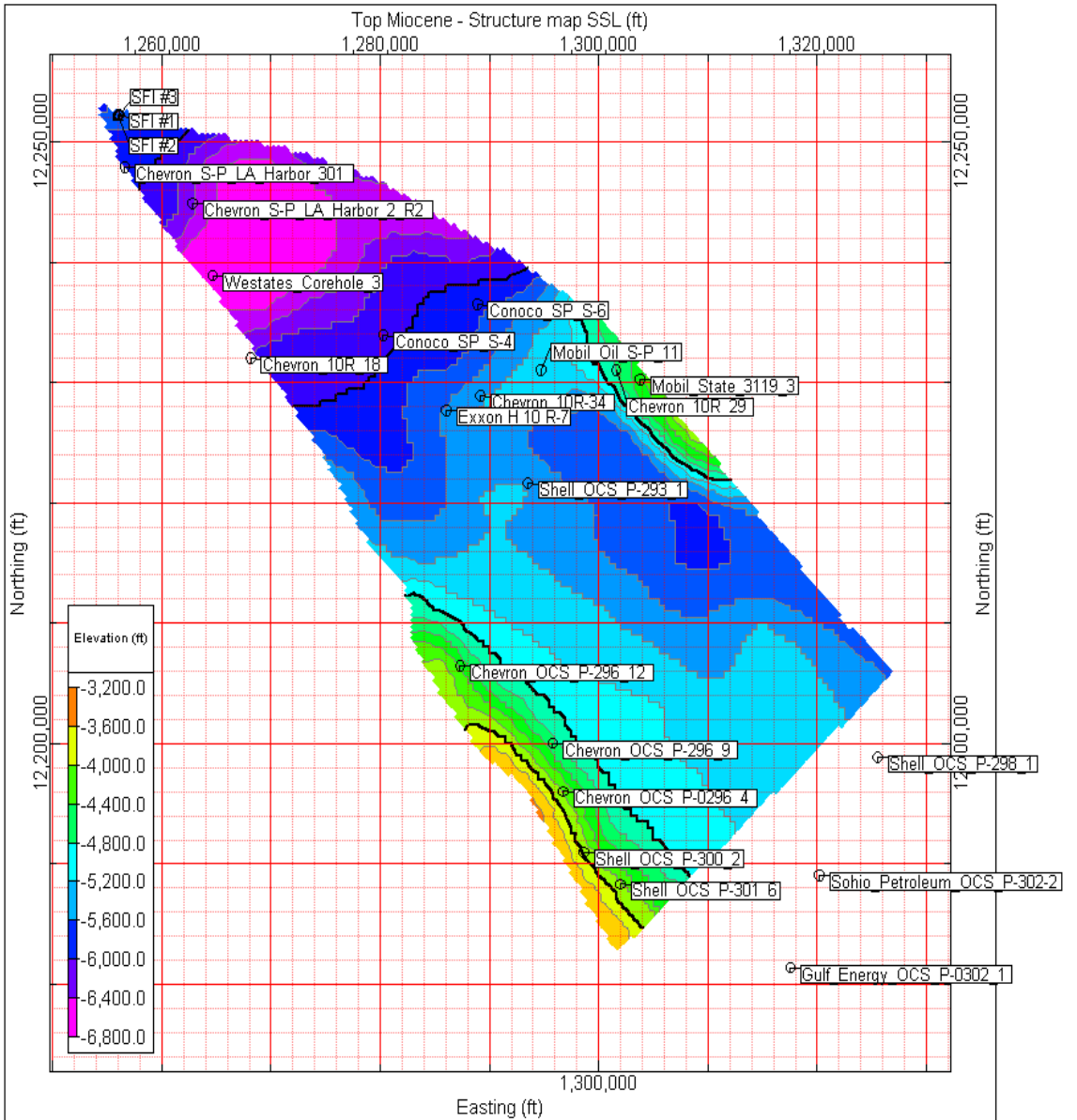
Seismic Data Analysis and Acquisition

Top Miocene structure map



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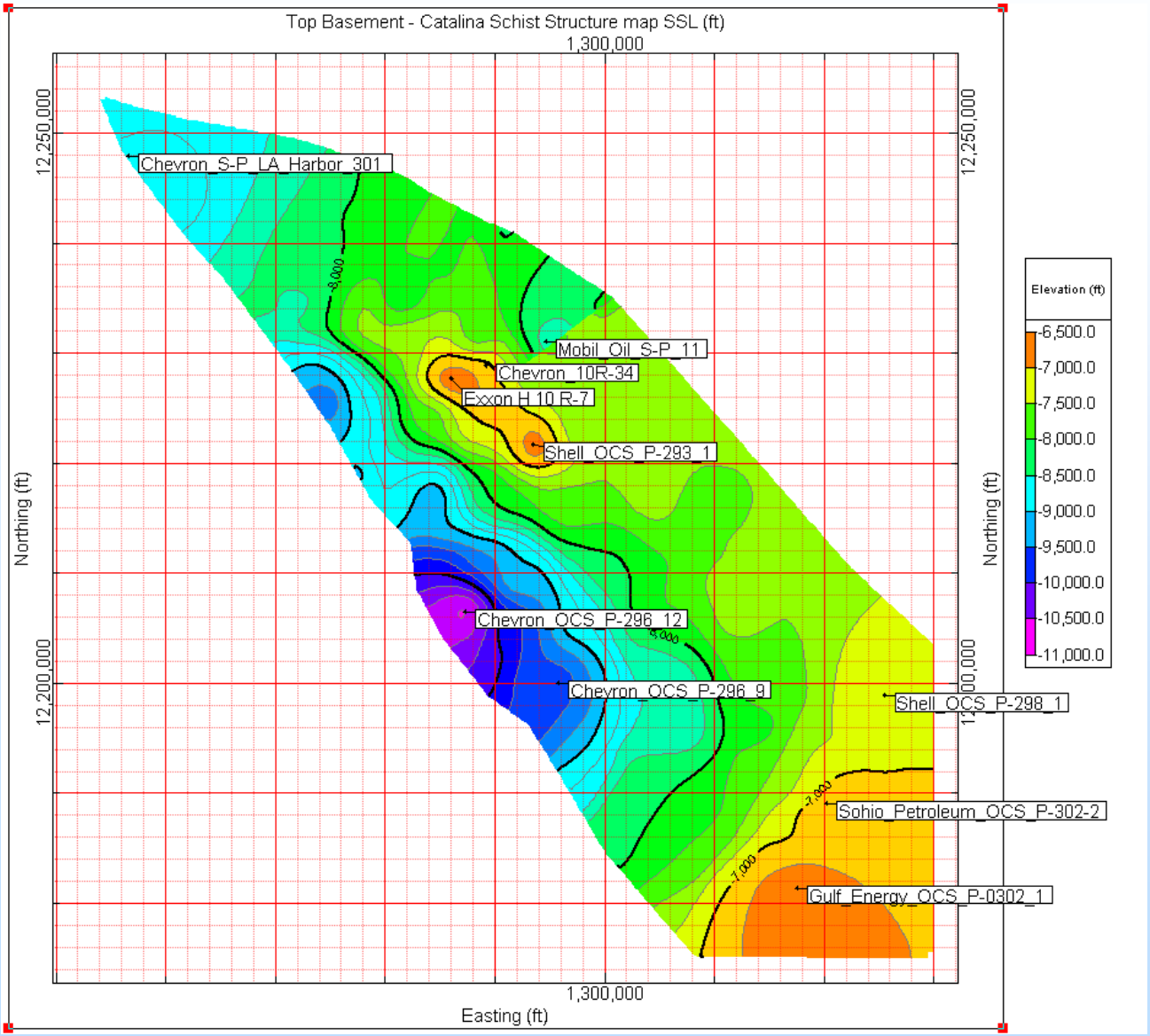
Top Basement structure map



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New well drilling, logging, core analysis

- DOE#1 well drilled to a depth of 5400ft, penetrating to near base of Pliocene
  - 200 ft of viable Pliocene age storage formation and 500 ft of caprock identified
  - Sand porosity 24-31%, permeability 50-353 md.
  - Shale porosity 23-29%, permeability <2 md
- DOE#2 well permit application approved 7/31/13
- DOE#3 permit application submitted to BSEE 6/21/13

DOE#1 well

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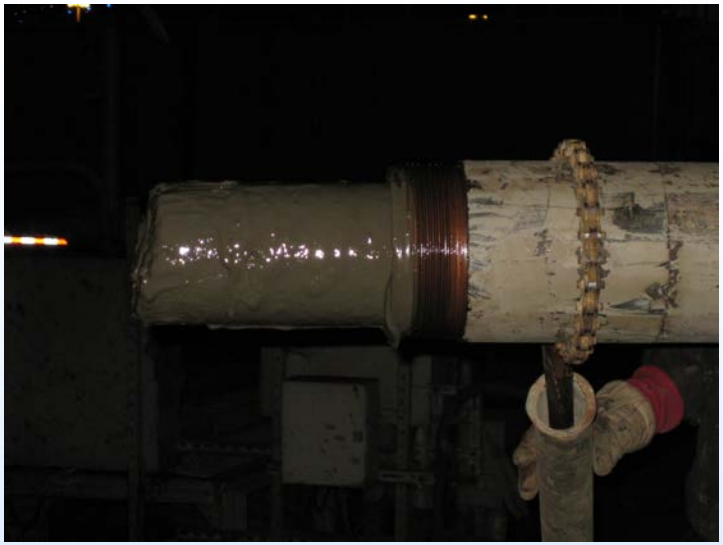
New well drilling, logging, core analysis

Formation evaluation data from new wells used to update geologic, geomechanical and gas migration models.

Results for well 1:

- **200 ft of viable Pliocene age storage formation and 500 ft of caprock identified**
- **Sand porosity 24-31%, permeability 50-353 md.**
- **Shale porosity 23-29%, permeability <2 md**



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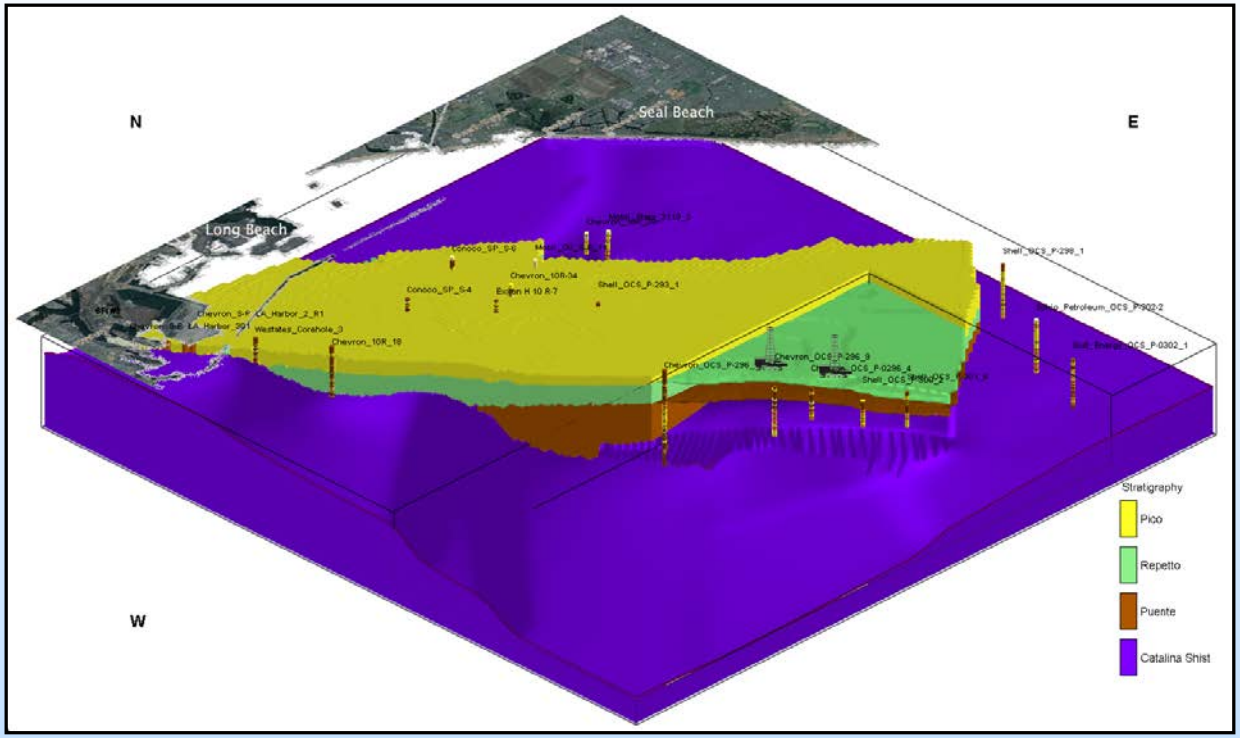
3D Geologic Model Development

Using acquired seismic data, well log data, assembled a 3D geologic earth model

Four lithology types: sand, sand-shale, silt, shale

Apply geologic model to:

1. **Estimate storage capacity**
2. **Develop geomechanical model and simulation**
3. **Develop CO2 injection and migration model and simulation**



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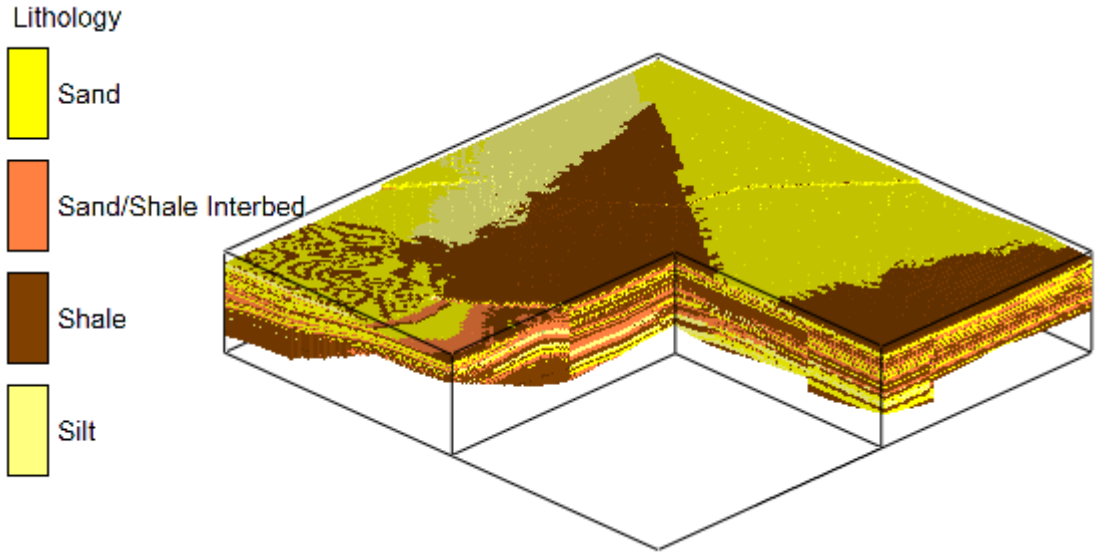
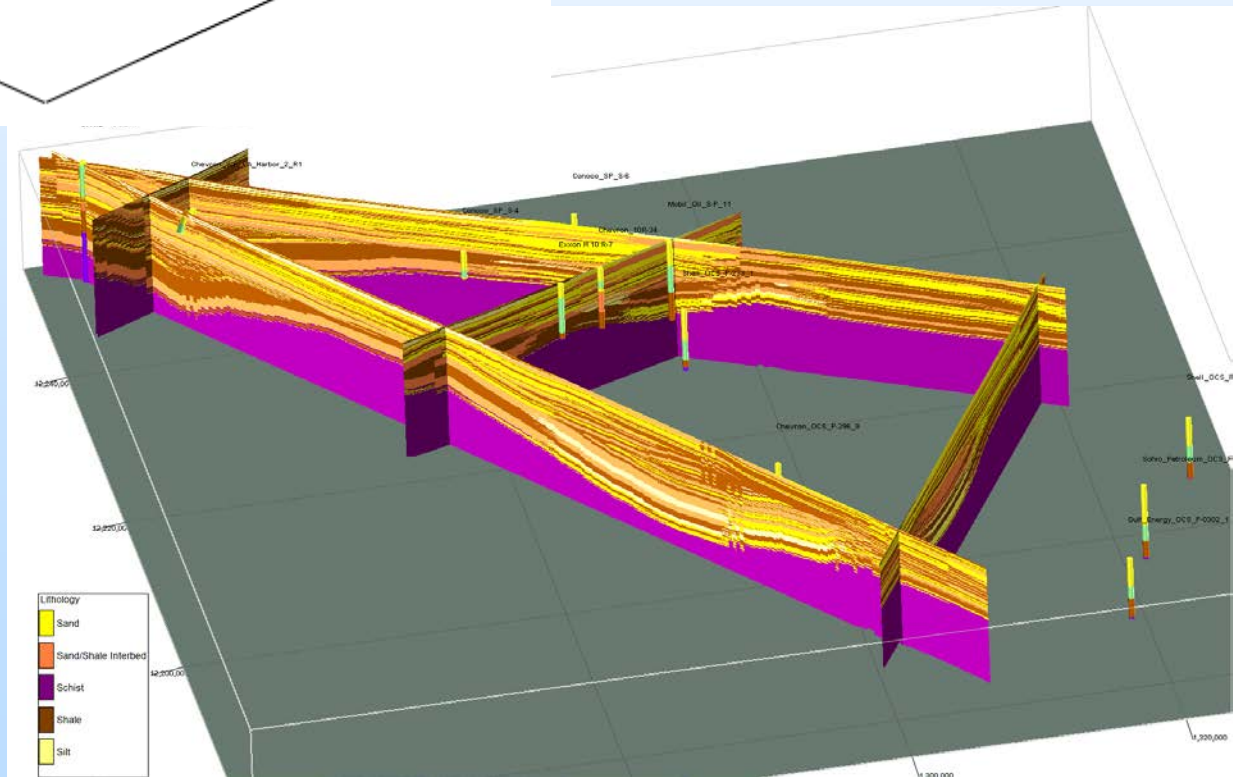
Geologic Model of Wilmington-Graben



(Top Left) Lithology Model with cut-away view . (Bottom Right) Fence-Diagram.



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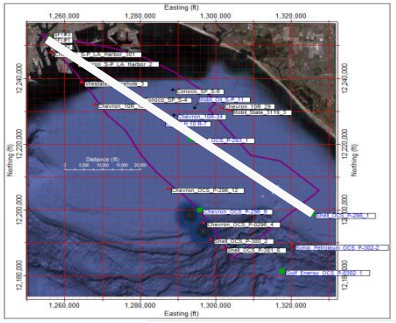
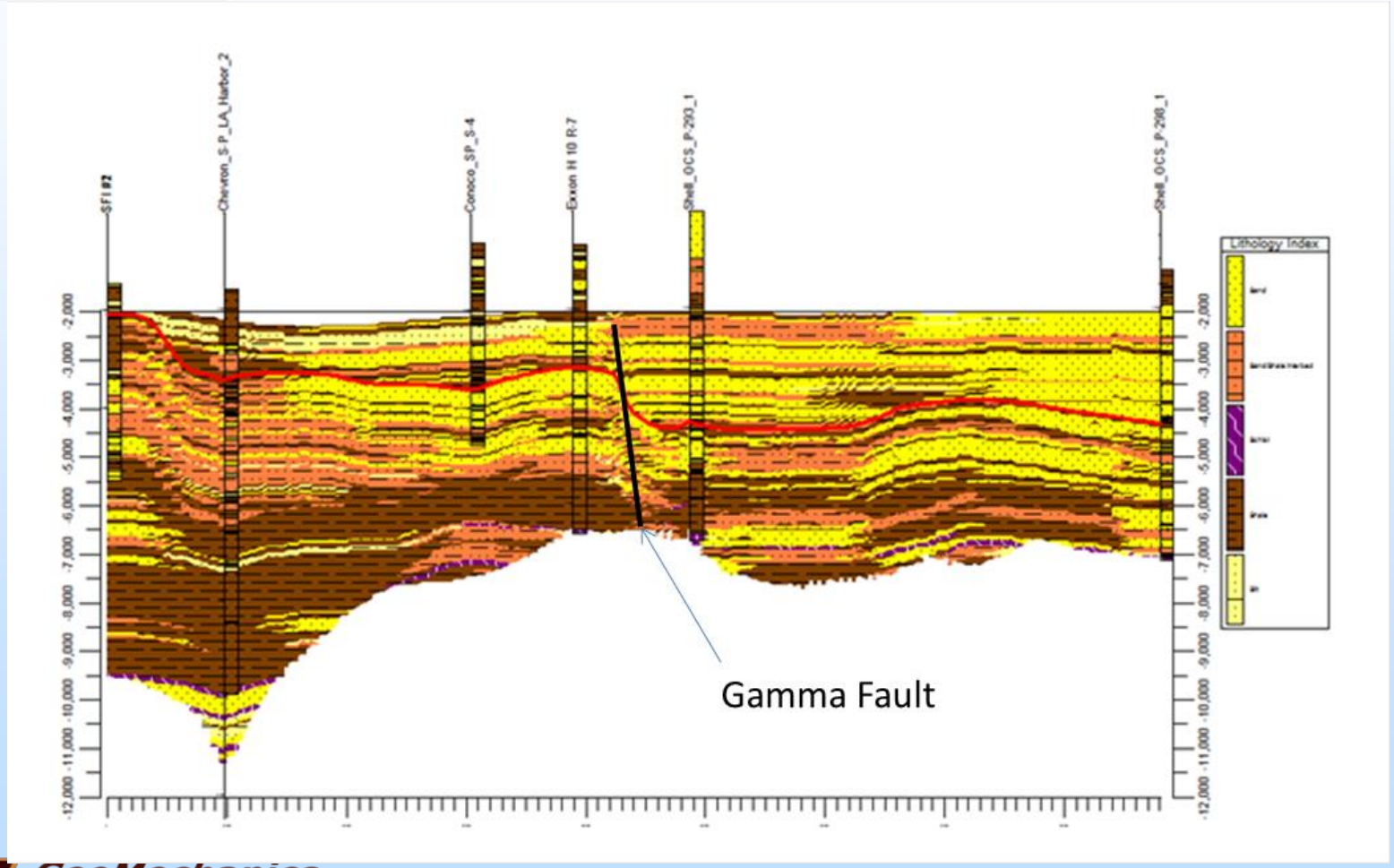


NW-SE Cross Section



Red line: Top Repetto Unconformity

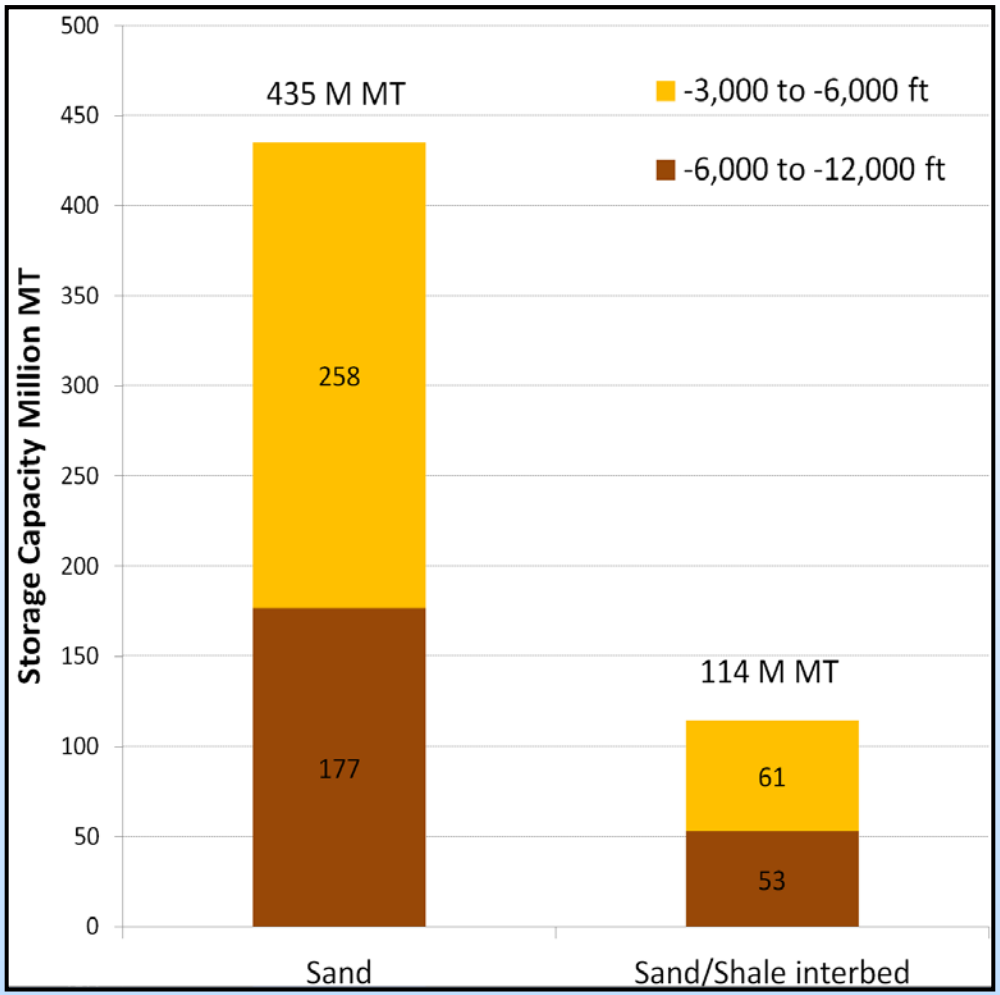
Preliminary Storage Capacity

Apply geologic model to:

1. **Estimate storage capacity**
2. **Develop geomechanical model and simulation**
3. **Develop CO2 injection and migration model and simulation**

Preliminary minimum storage capacity estimate is 258 million MT for the Pliocene and 177 million MT for the Miocene

Miocene estimates to be improved with new well data



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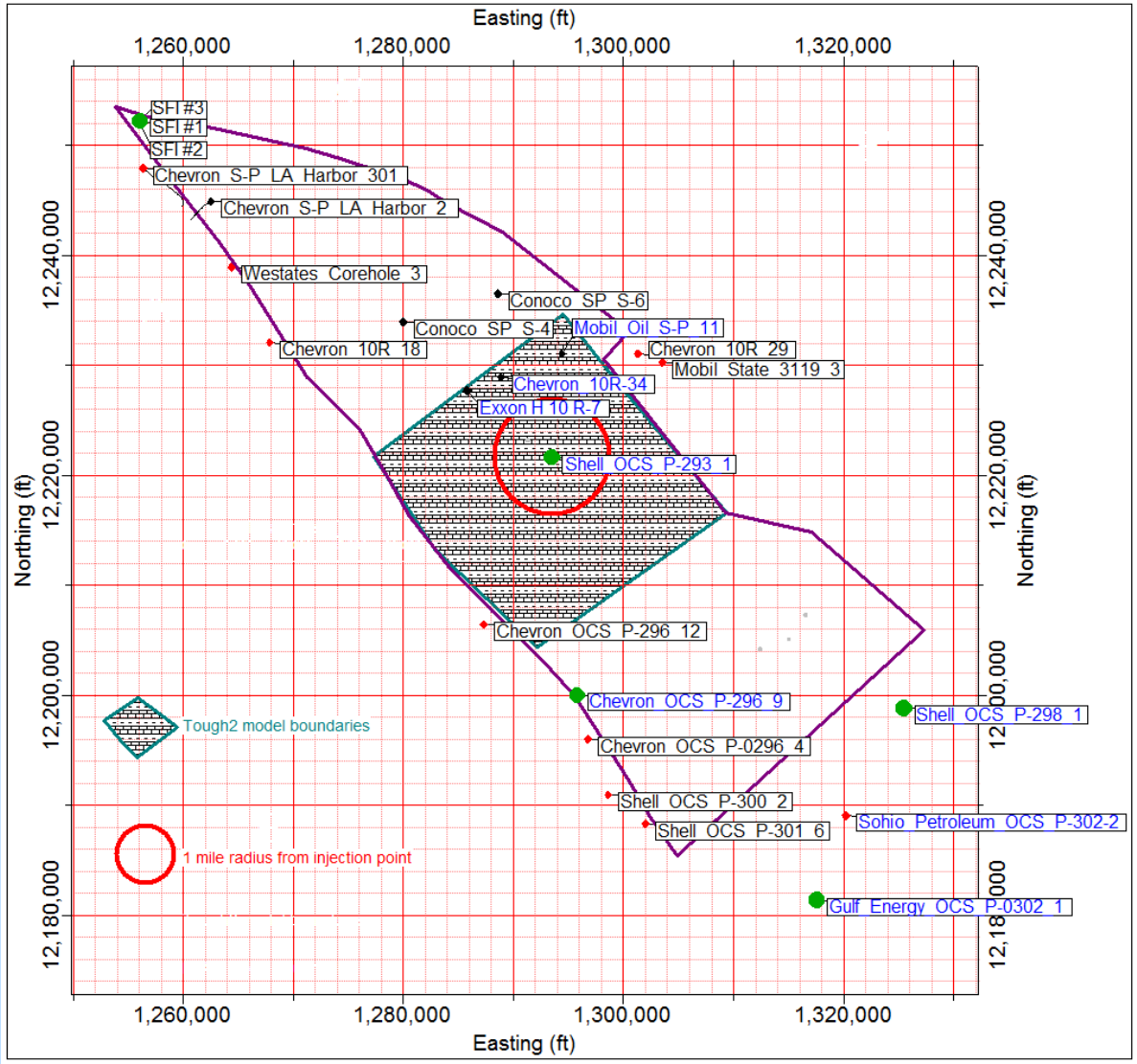
New Extends of Tough2 Model Area

Focus on center of Graben

3D model 20,000 x 20,000ft

Apply TOUGH2/ECO2N, use Shell_OCS_P293-1 as injection well over an interval of 150m



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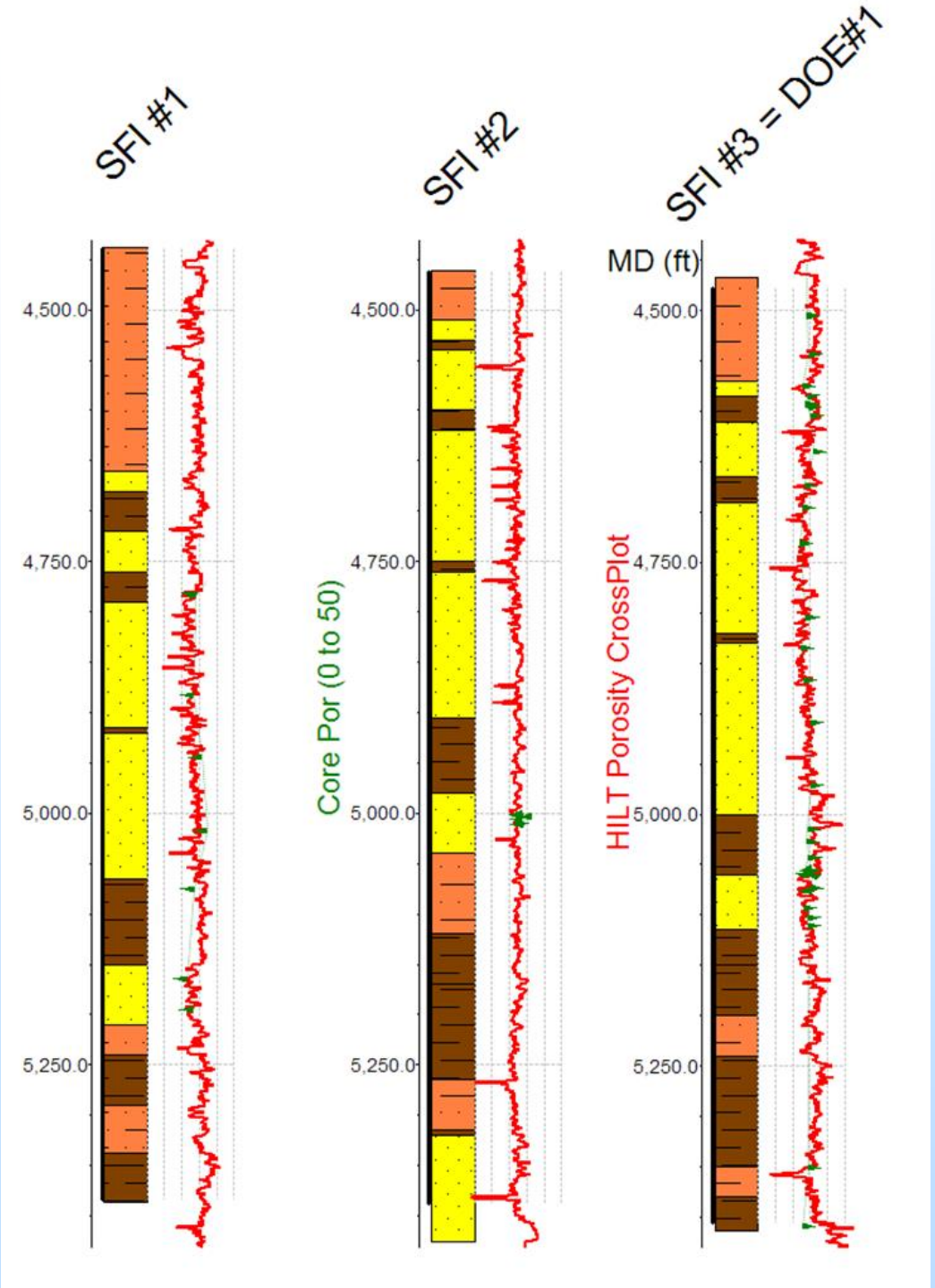
Comparison between Porosity Log & Core Porosity

- Core porosity



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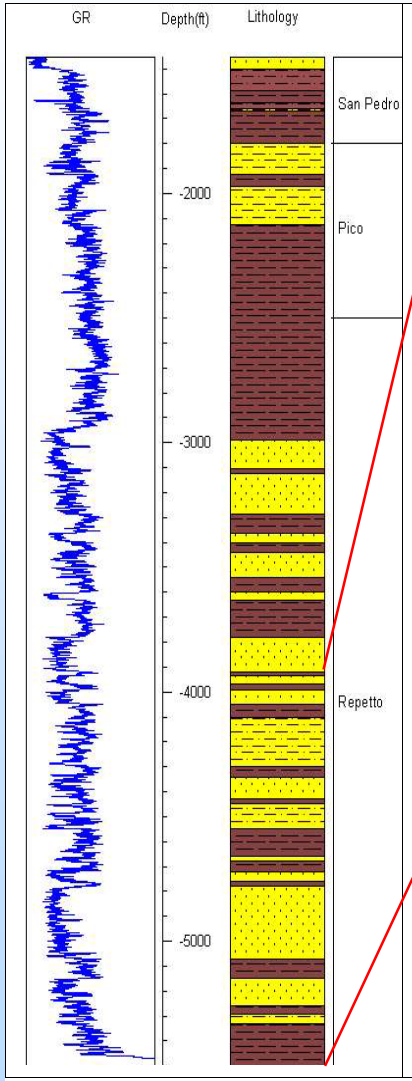
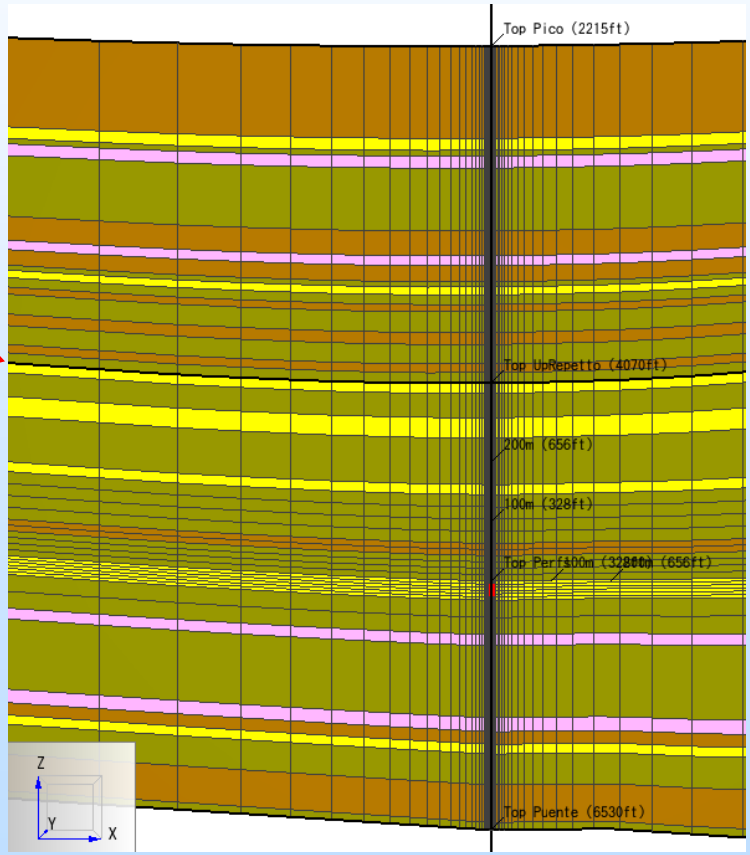
Reservoir Layering for Simulation Model



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



Porosity and Permeability Correlation

Porosity – permeability correlation

Core samples available (NOTE small # of samples for entire Graben available!)

Available data at well:	Confining pressure (PSI)	# of sand	# of shale	# of silt	# of sand/shale
SFI01	300	5	1	0	0
SFI02	400	6	0	0	0
SFI02	1500	6	0	0	0
SFI03	250	14	6	0	5
others	n/a	Not used	Not used	Not used	23

Kozeny-Carman equations established using best fit between $perm_{meas}$ and $porosity_{meas}$ term:

Sand: $Perm_{sand}(mD) = 9408 * n^3$

Shale: $Perm_{shale}\ (mD) = 71.044 * n^2/(1-n)^2$

Sand/Shale interbed: $Perm_{sa/sh}\ (mD) = 367 * n^2/(1-n)^2$

Silt: $Perm_{silt}(mD) = 9408 * n^3$

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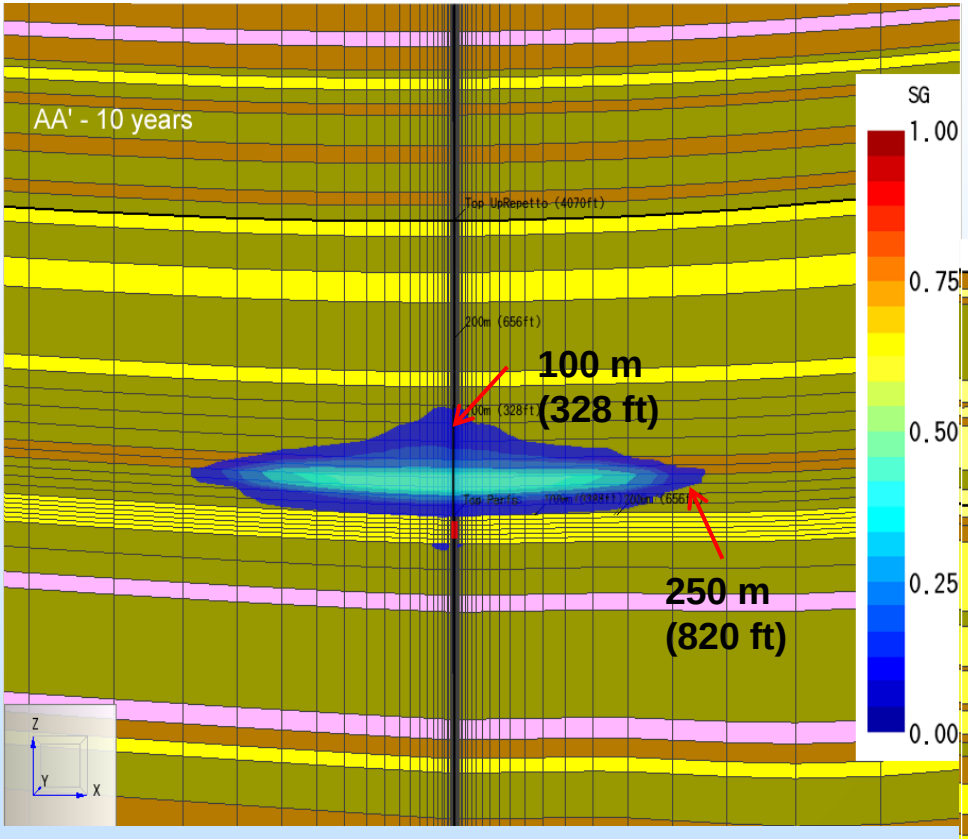
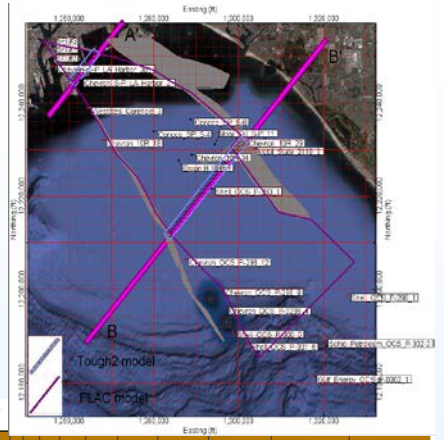
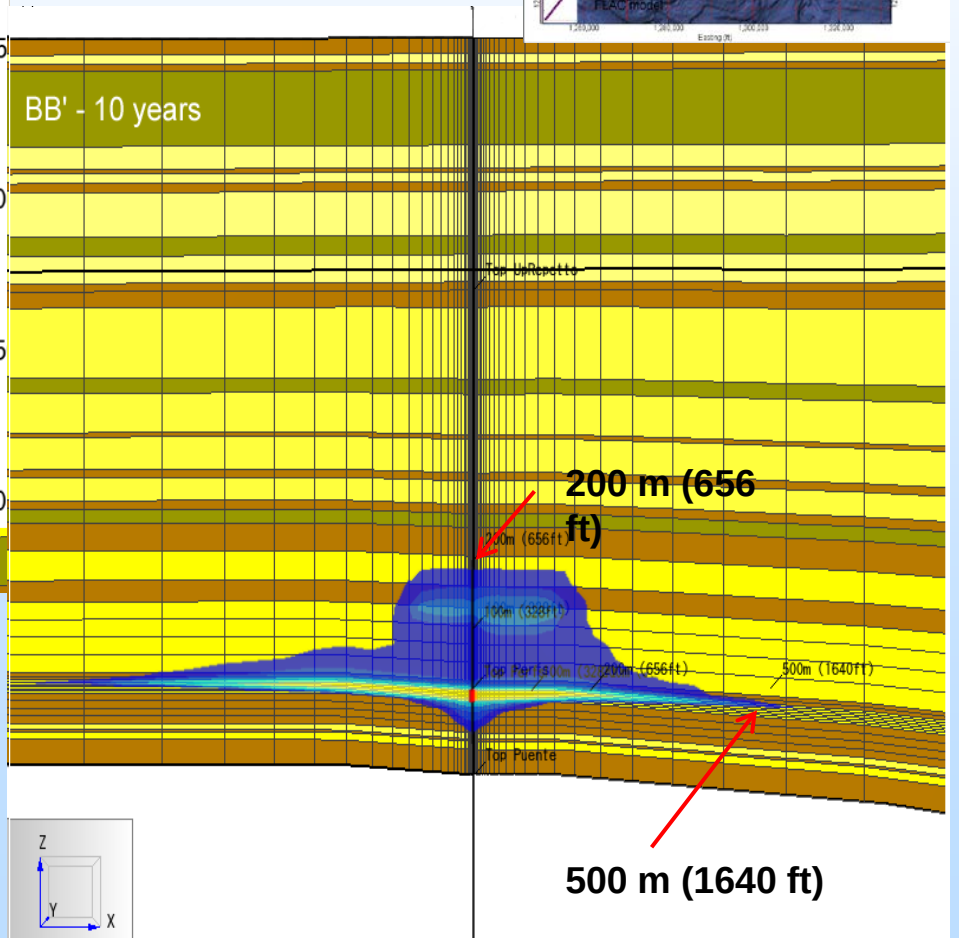
Gas Saturation Contours after 10 Years (preliminary model results)







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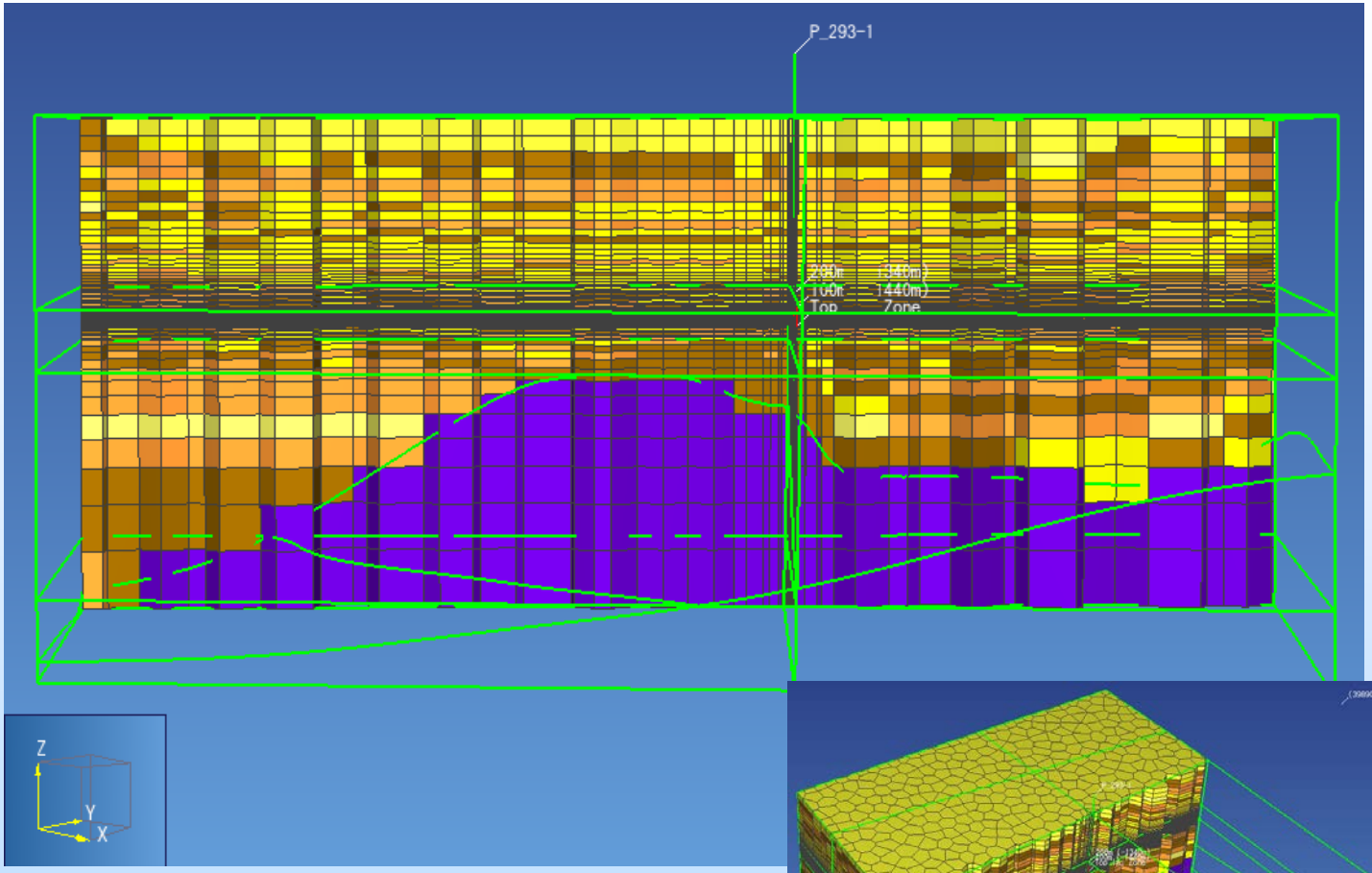
Revised Lithology with Heterogeneity Modeled

Heterogeneity modeled in RW, mapped to Tough2 model

Injection cell size: 6m3

Multiple characterizations for alternative risk scenarios



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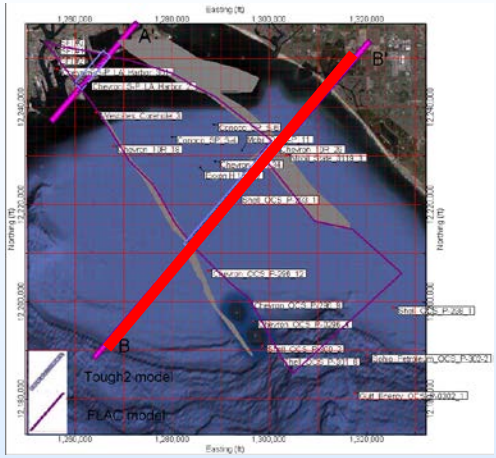
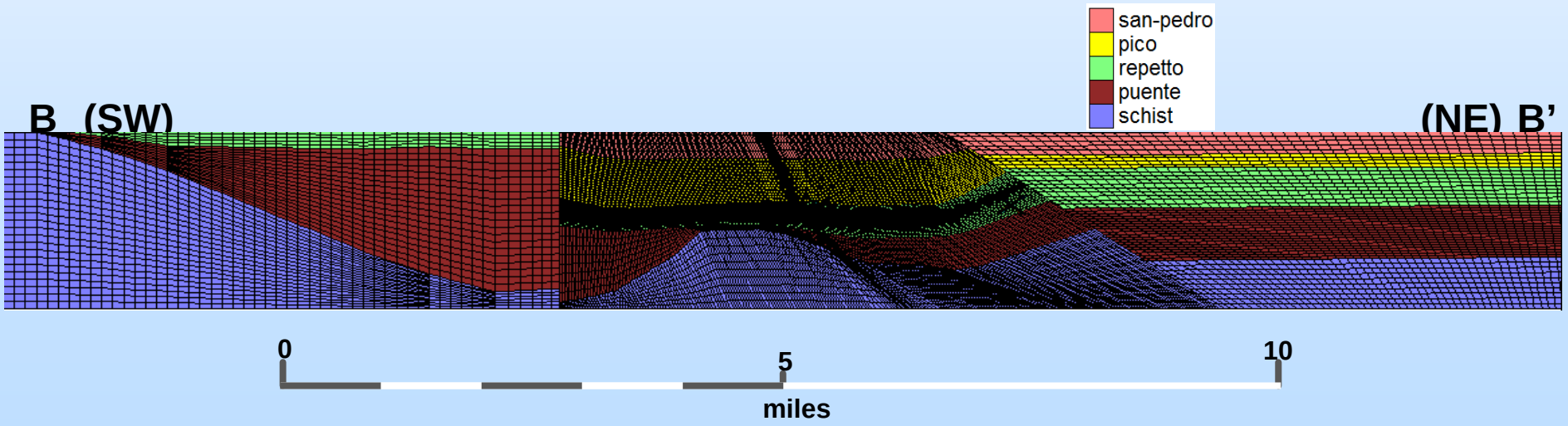
3D Geomechanical Model Development

Develop Geomechanical Model to assess:

1. **Induced seafloor deformations**
2. **Induced stresses**
3. **Fault activation risks**

Apply FLAC3D code for two areas in the Graben (north and central)





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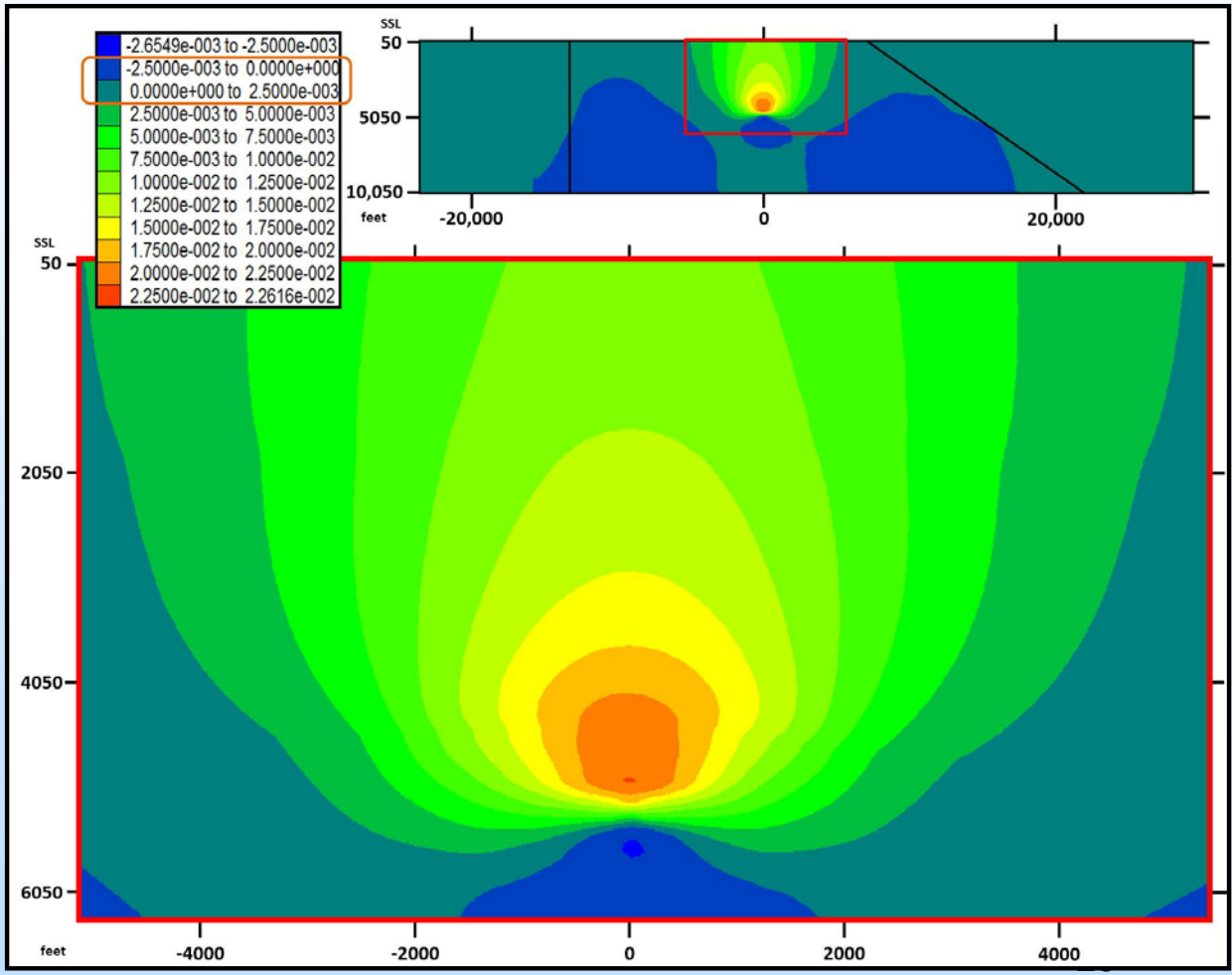
Vertical displacement at seafloor

Develop Geomechanical Model to assess:

1. **Induced seafloor deformations**
2. **Induced stresses**
3. **Fault activation risks**

Apply FLAC3D code for two areas in the Graben (north and central)



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Risk Analysis and Practical Logistics

Risk Assessment Includes:

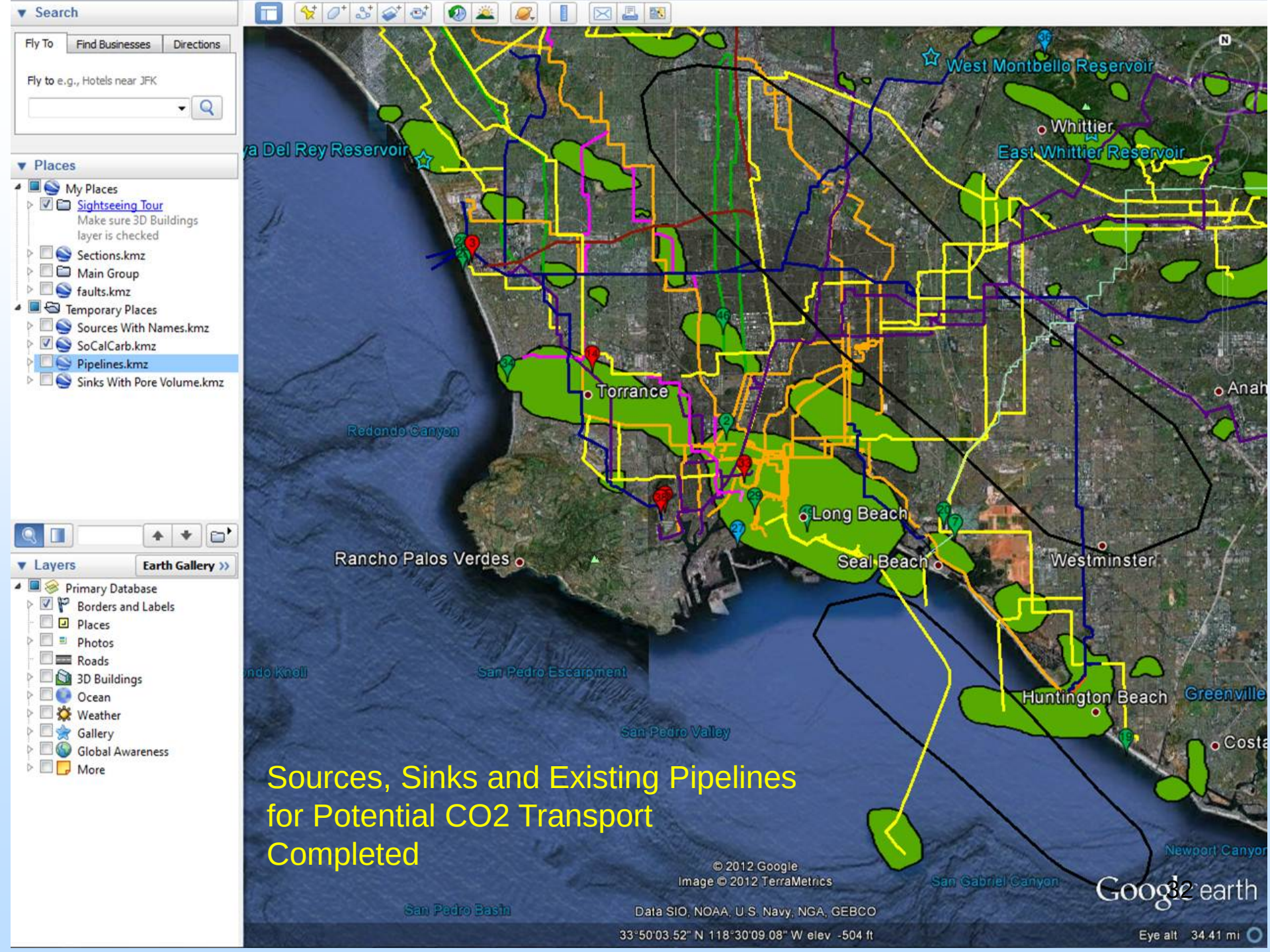
- Lateral Migration to Poorly Cemented Offset Wells
  - Detailed well record review
  - Reservoir scale fluid and migration modeling
- Injection Well Failure and Transmission
  - Stress analysis, near-well migration modeling
- Caprock Integrity Study
  - Geomechanical analysis of fracture and fault activation risk
- Natural Seismicity Risks
  - Historical review of impacts on O&G and Gas Storage operations
- Induced Seismicity Risks
  - Analog review, geomechanical analysis, microseismic monitoring
- CO2 Migration to Sea Floor
  - Analog review, rate assessment, and biologic impact estimate

Risk Analysis and Practical Logistics

Logistics Evaluation Includes:

1. Identify and characterize top 20 sources in LA Basin
   - Include on Interactive Google Earth Map
   - Contribute to NATCARB Atlas and Database

2. Evaluate pipeline and storage field infrastructure in LA Basin
   - Location and design of existing oil and gas lines
   - Location of existing storage fields
   - Requirements for transport from major sources to Graben area
   - Typical design and cost for CO2 transmission lines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Fly To
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Places
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Sightseeing Tour
Make sure 3D Buildings layer is checked
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Main Group
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SoCalCarb.kmz
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Layers
Earth Gallery
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3D Buildings
Ocean
Weather
Gallery
Global Awareness
More
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Whittier
East Whittier Reservoir
Del Rey Reservoir
Torrance
Redondo Canyon
Long Beach
Rancho Palos Verdes
Seal Beach
Westminster
San Pedro Escarpment
Huntington Beach
Greenville
San Pedro Valley
Newport Canyon
San Gabriel Canyon
San Pedro Basin
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
33°50'03.52" N 118°30'09.08" W elev -504 ft
Eye alt 34.41 mi
Google earth
Sources, Sinks and Existing Pipelines for Potential CO2 Transport Completed

Next Step

- Drill and complete DOE#2 and DOE#3 wells
- Establish revised material properties for the different lithologies, based on revised porosity data and permeability estimation and rerun gas migration modeling
- Rerun geomechanical modeling using revised material properties
- Complete risk assessment and documentation

Challenges Permitting 3 wells for Wilmington Graben

Dealing with multiple locations (city, state lands, and federal waters) diverse organizations, and regulations:

- City of Los Angeles
- US EPA
- State Division of Oil and Gas and Geothermal Resources
- BSEE
- CEQA compliance (state implementation of NEPA)

DOE#1 : Onshore well, CLA partner, permitted by EPA
DOE# 2 : Onshore well, CLA partner, permitted by DOGGR and EPA
DOE#3 : Offshore well, BOC partner, permitted by BSEE

Summary

- Significant Accomplishments
  - DOE#1 well drilled and completed
  - 175km of new seismic acquired, analyzed, and interpreted
  - 3D Geologic Model developed for entire graben
  - Interactive map of sources, sinks, pipeline completed
- Key Findings
  - About 500 million metric tons storage capacity available (at ~ 3% saturation); Not all accessible due to offset wells, Additional deep capacity likely
  - Injection pressures remain less than 1.1 x initial reservoir pressure if injection limited to 250,000 MT/Y per well
  - CO2 gas plume migrates 1000m horizontally and 350m vertically after 5 years of injection and 50 years of observation if injection limited to 150m interval.

Appendix

– These slides will not be discussed during the presentation, but are mandatory

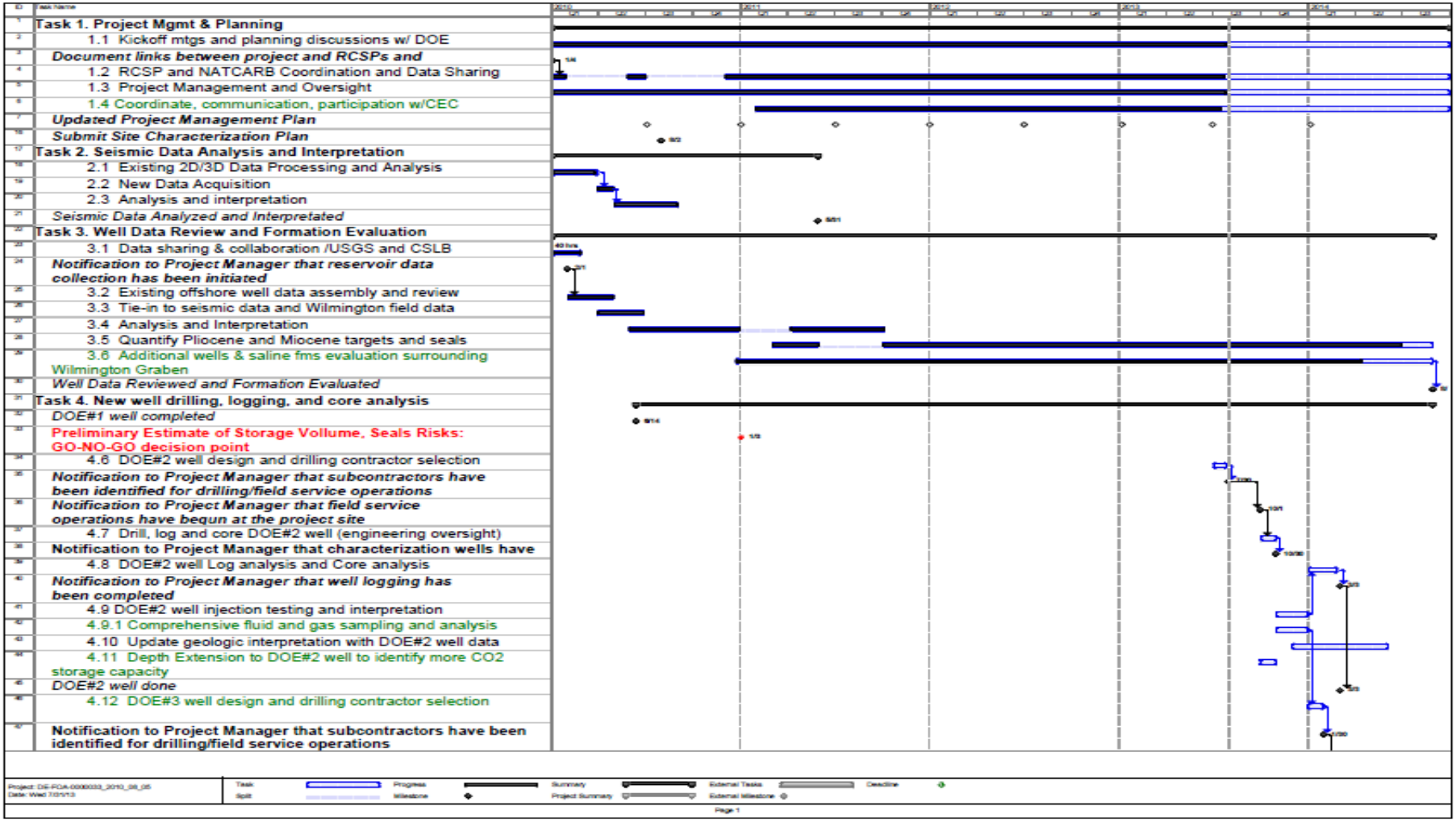
Organization Chart

- Principal Investigator
  - Dr. Mike Bruno
- Project Manager & Sr Geologist
  - Jean Young
- Sr Research Engineer
  - Julia Diessl
  - Kang Lao
  - Claudia Gruber
- Research Engineer
  - Jing Xiang
- Research Geologist
  - Nicky White
  - Bill Childers
- Contractors
  - Dr. Mark Legg
  - Dr. Dan Francis
  - Don Clarke
  - Drilling crew
  - Logging crew
- Partners
  - City of Los Angeles
  - California Energy Commission
  - CA State University, Long Beach
  - USGS

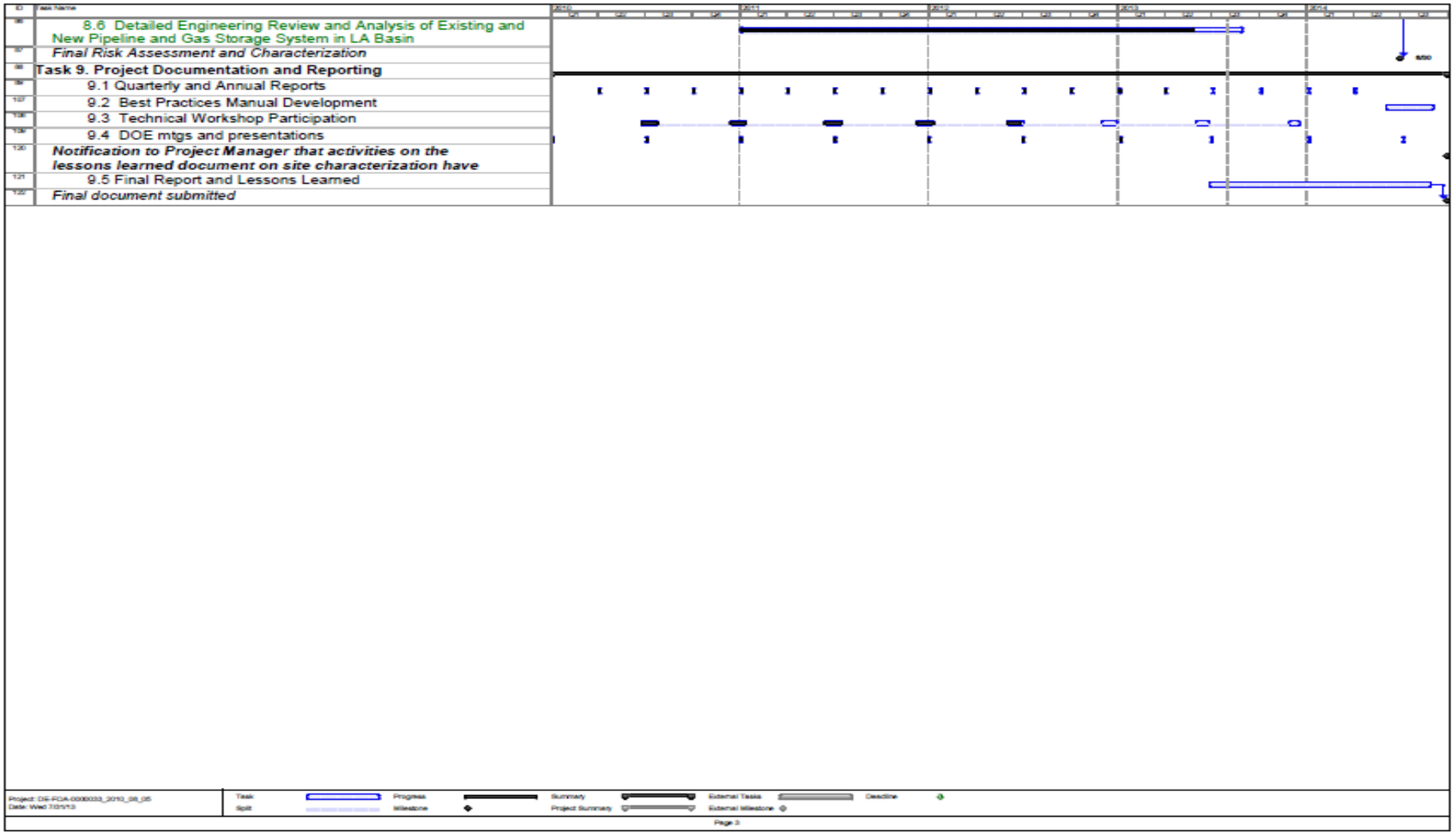
Gantt Chart


Task 1. Project Mgmt & Planning
1.1 Kickoff mtgs and planning discussions w/ DOE
Document links between project and RCSPs and
1.2 RCSP and NATCARB Coordination and Data Sharing
1.3 Project Management and Oversight
1.4 Coordinate, communication, participation w/CEC
Updated Project Management Plan
Submit Site Characterization Plan
Task 2. Seismic Data Analysis and Interpretation
2.1 Existing 2D/3D Data Processing and Analysis
2.2 New Data Acquisition
2.3 Analysis and interpretation
Seismic Data Analyzed and Interpretated
Task 3. Well Data Review and Formation Evaluation
3.1 Data sharing & collaboration /USGS and CSLB
Notification to Project Manager that reservoir data collection has been initiated
3.2 Existing offshore well data assembly and review
3.3 Tie-in to seismic data and Wilmington field data
3.4 Analysis and Interpretation
3.5 Quantify Pliocene and Miocene targets and seals
3.6 Additional wells & saline fms evaluation surrounding Wilmington Graben
Well Data Reviewed and Formation Evaluated
Task 4. New well drilling, logging, and core analysis
DOE#1 well completed
Preliminary Estimate of Storage Vollume, Seals Risks: GO-NO-GO decision point
4.6 DOE#2 well design and drilling contractor selection
Notification to Project Manager that subcontractors have been identified for drilling/field service operations
Notification to Project Manager that field service operations have begun at the project site
4.7 Drill, log and core DOE#2 well (engineering oversight)
Notification to Project Manager that characterization wells have
4.8 DOE#2 well Log analysis and Core analysis
Notification to Project Manager that well logging has been completed
4.9 DOE#2 well injection testing and interpretation
4.9.1 Comprehensive fluid and gas sampling and analysis
4.10 Update geologic interpretation with DOE#2 well data
4.11 Depth Extension to DOE#2 well to identify more CO2 storage capacity
DOE#2 well done
4.12 DOE#3 well design and drilling contractor selection
Notification to Project Manager that subcontractors have been identified for drilling/field service operations
Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline

Gantt Chart


Task 1. Project Mgmt & Planning
1.1 Kickoff mtgs and planning discussions w/ DOE
Document links between project and RCSPs and
1.2 RCSP and NATCARB Coordination and Data Sharing
1.3 Project Management and Oversight
1.4 Coordinate, communication, participation w/CEC
Updated Project Management Plan
Submit Site Characterization Plan
Task 2. Seismic Data Analysis and Interpretation
2.1 Existing 2D/3D Data Processing and Analysis
2.2 New Data Acquisition
2.3 Analysis and interpretation
Seismic Data Analyzed and Interpretated
Task 3. Well Data Review and Formation Evaluation
3.1 Data sharing & collaboration /USGS and CSLB
Notification to Project Manager that reservoir data collection has been initiated
3.2 Existing offshore well data assembly and review
3.3 Tie-in to seismic data and Wilmington field data
3.4 Analysis and Interpretation
3.5 Quantify Pliocene and Miocene targets and seals
3.6 Additional wells & saline fms evaluation surrounding Wilmington Graben
Well Data Reviewed and Formation Evaluated
Task 4. New well drilling, logging, and core analysis
DOE#1 well completed
Preliminary Estimate of Storage Vollume, Seals Risks: GO-NO-GO decision point
4.6 DOE#2 well design and drilling contractor selection
Notification to Project Manager that subcontractors have been identified for drilling/field service operations
Notification to Project Manager that field service operations have begun at the project site
4.7 Drill, log and core DOE#2 well (engineering oversight)
Notification to Project Manager that characterization wells have
4.8 DOE#2 well Log analysis and Core analysis
Notification to Project Manager that well logging has been completed
4.9 DOE#2 well injection testing and interpretation
4.9.1 Comprehensive fluid and gas sampling and analysis
4.10 Update geologic interpretation with DOE#2 well data
4.11 Depth Extension to DOE#2 well to identify more CO2 storage capacity
DOE#2 well done
4.12 DOE#3 well design and drilling contractor selection
Notification to Project Manager that subcontractors have been identified for drilling/field service operations
Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline

Gantt Chart


8.6 Detailed Engineering Review and Analysis of Existing and New Pipeline and Gas Storage System in LA Basin
Final Risk Assessment and Characterization
Task 9. Project Documentation and Reporting
9.1 Quarterly and Annual Reports
9.2 Best Practices Manual Development
9.3 Technical Workshop Participation
9.4 DOE mtgs and presentations
Notification to Project Manager that activities on the lessons learned document on site characterization have
9.5 Final Report and Lessons Learned
Final document submitted