Assessment of CO2 Storage Resources in Depleted Oil and Gas Fields in the Ship Shoal Area, Gulf of Mexico

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GeoMechanics Technologies

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 1-3, 2017

Presentation Outline

- Introduction
- Technical Status
- Accomplishments To Date
- Lessons Learned
- Synergy Opportunities
- Project Summary
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  - Organization Chart
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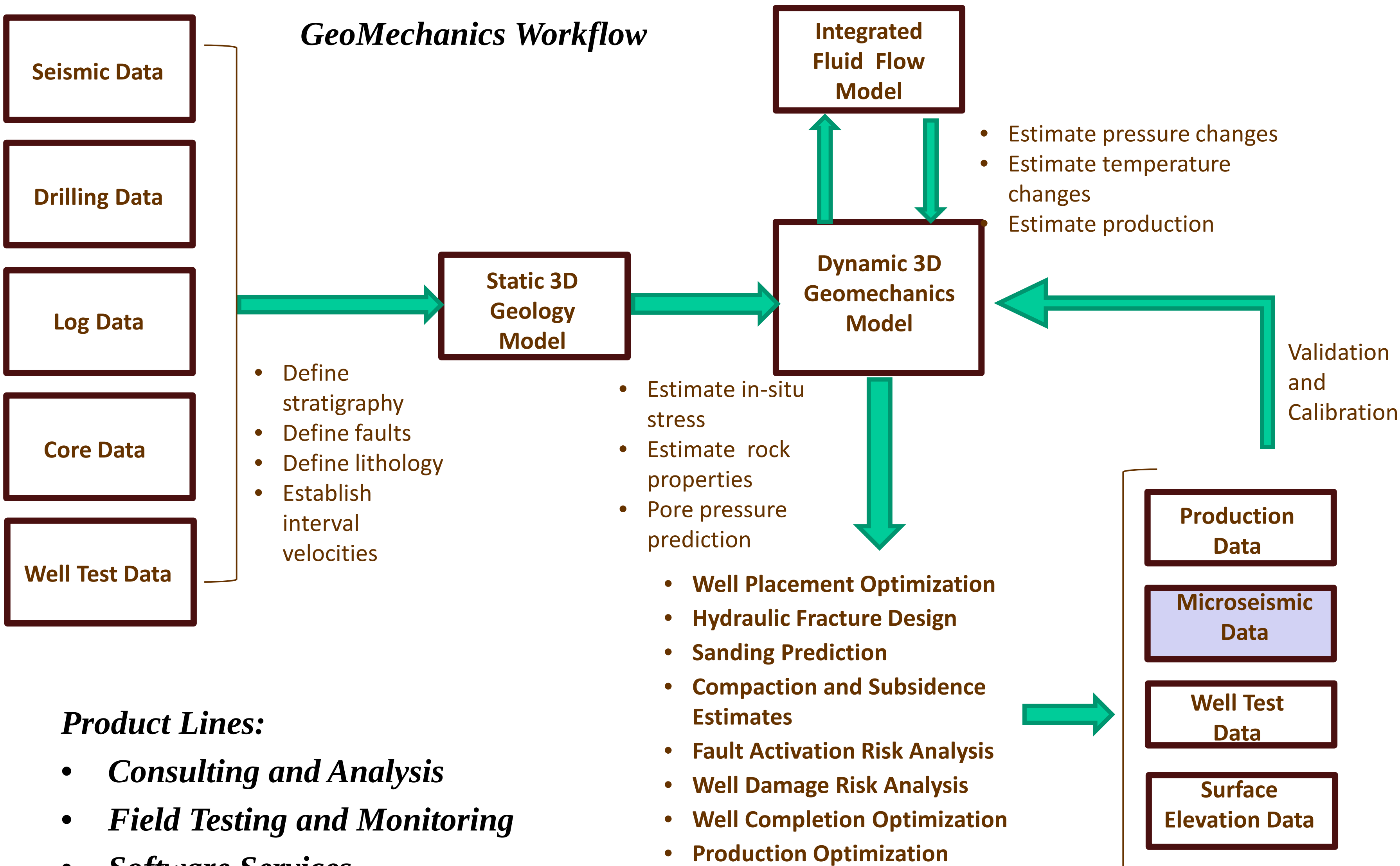
GeoMechanics Technologies

Advanced Geomechanics from the Wellbore to Reservoir scale

- ***3D Geomechanical Earth Models***
- ***Compaction and Subsidence Analysis***
- ***Well Damage Analysis and Design***
- ***Fracture Stimulation Design***
- ***Induced Faulting and Seismicity Analysis***
- ***Thermal and Geothermal Simulation***
- ***Salt Drilling and Salt Cavern Mechanics***
- ***Wellbore Stability and Solids Production***

Services provided to more than 50 clients for projects in more than 20 countries

GeoMechanics Workflow



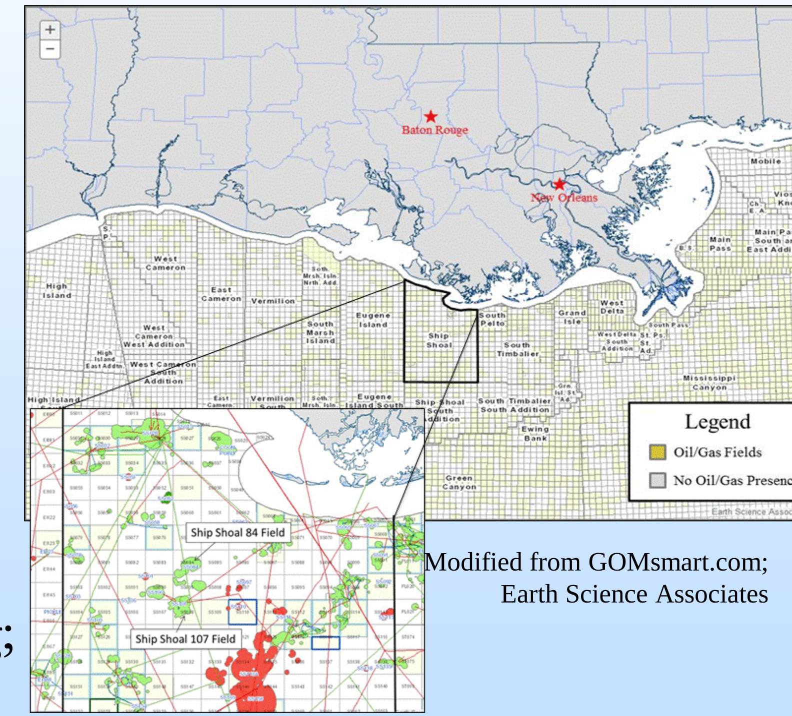
Product Lines:

- ***Consulting and Analysis***
- ***Field Testing and Monitoring***
- ***Software Services***

Project Overview

Goals and Objectives

The primary goals are to identify storage capacity in Plio-Miocene structural traps throughout the Ship Shoal Area and to determine the risks associated with high volume CO_2 storage.



Modified from GOMsmart.com; Earth Science Associates

Phase I

- Geologic data review;
- Geologic modeling;
- Storage capacity estimation; and
- Preliminary risk assessment.

Phase II

- Fluid flow and geomechanical modeling;
- Risk assessment;
- CO_2 transportation; and
- Refined storage capacity estimation.

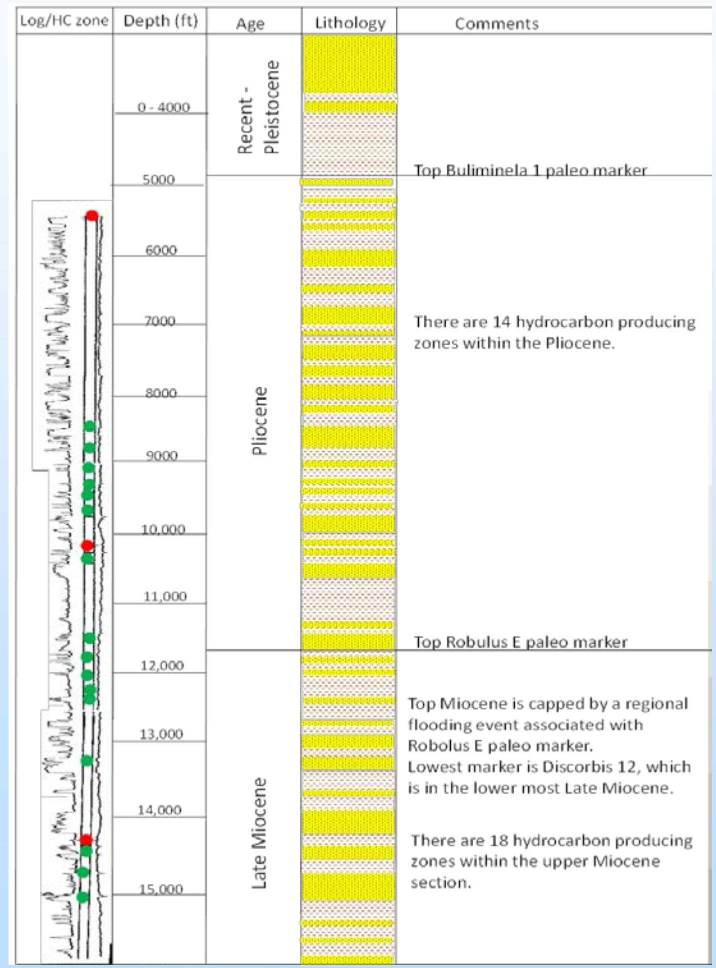
Technical Status

Geologic Data Review

- Completed and submitted a geologic data review and formation evaluation summarizing the depositional history of the Ship Shoal Area.

Geologic Time (M.Y.)	Province	System	Series	Storage Assessment Unit (SAU)	Biostratigraphic Zonation: Gulf of Mexico
~0.01	Cenozoic	Quaternary	Pleistocene	Undifferentiated	*Sangamon fauna* *Trimosina* "A" 1st *Trimosina* "A" 2 nd *Hyalinea* "B" / *Trimosina* "B" *Angulogerina* "B" 1 st *Angulogerina* "B" 2 nd *Lenticulina* 1 *Valvulineria* "H"
~2.8		Tertiary	Pliocene	Undifferentiated	*Buliminella* 1 *Textularia* "X"
~5.5			Miocene	Upper Miocene	*Robulus* "E" / *Bigenerina* "A" *Cristellaria* "K" *Discorbis* 12 *Bigenerina* 2 *Textularia* "W"
~10.5				Middle Miocene	*Bigenerina humblei* *Cristellaria* "I" *Cibicides opima*
				Lower Miocene II	*Amphistegina* "B" *Robulus* 43 *Cristellaria* 54 / *Eponides* 14 *Gyroidina* "K"
~18.5				Lower Miocene I	*Discorbis* "B" *Marginulina* "A" *Siphonina davisi* *Lenticulina hanseni*
~24.8			Oligocene		*Marginulina texana*
~38.0			Eocene		
~55.0			Paleocene		
~63.0					

Biostratigraphic zonation and associated storage assessment units



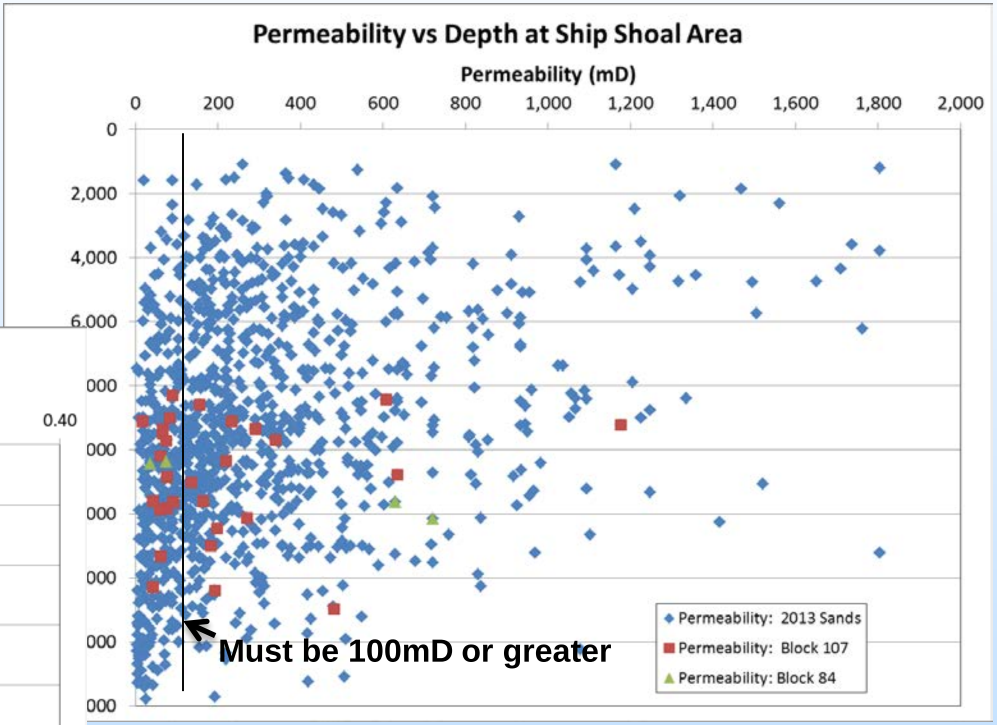
Generalized stratigraphic column for SS Block 107 field

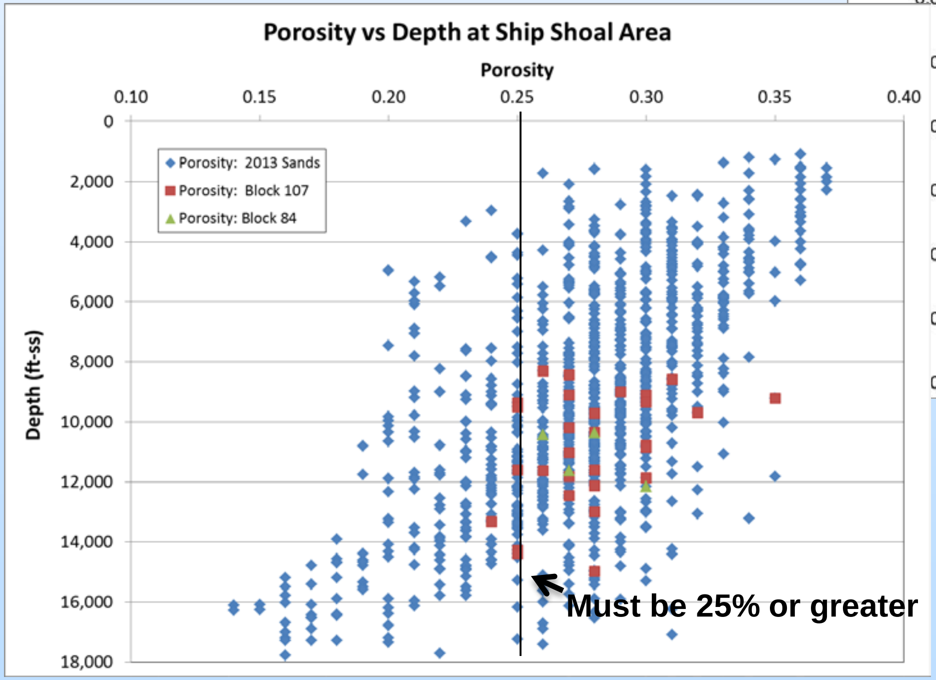
Technical Status

Geologic Data Review

Geologic Data Review

Porosity and permeability evaluation

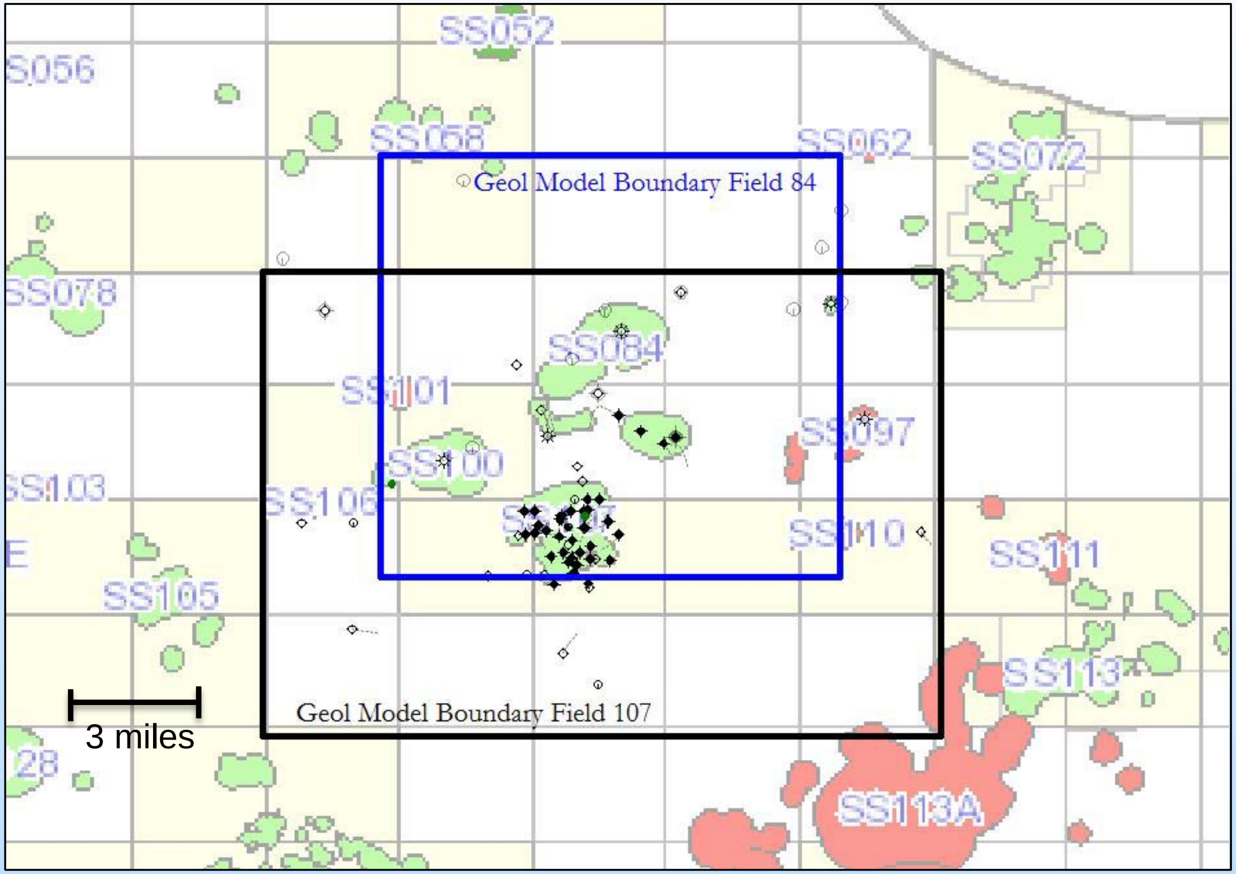




Technical Status

Geologic Model Development

- Developed detailed geologic models for Ship Shoal Fields 84 and 107.



Field 84

- 20 wells collected and used as input

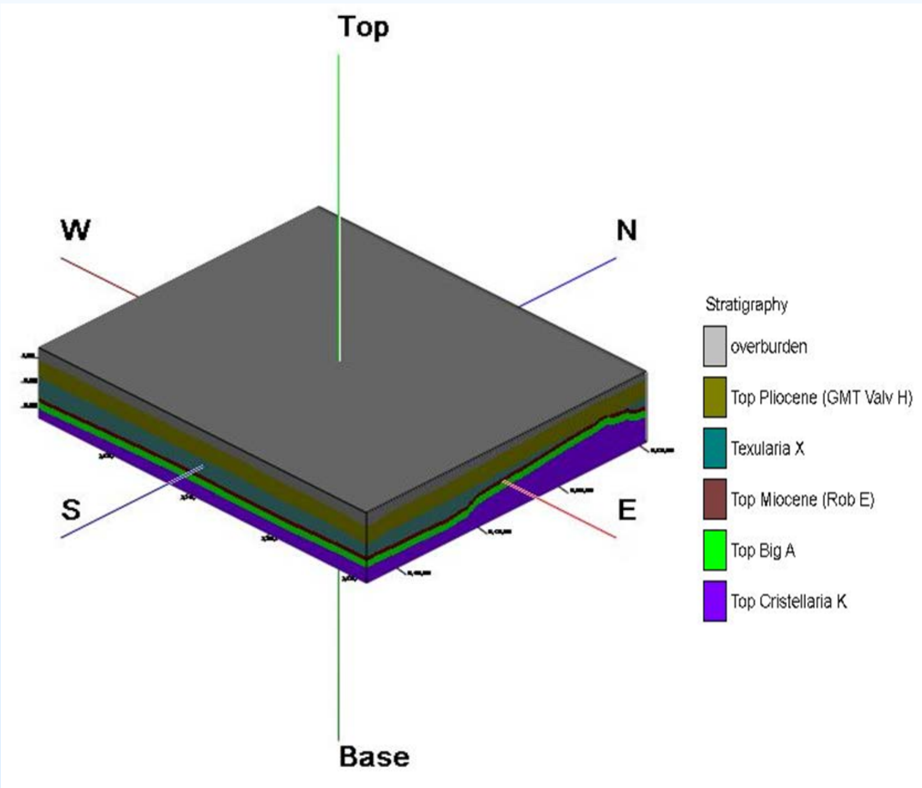
Field 107

- 77 wells collected and used as input

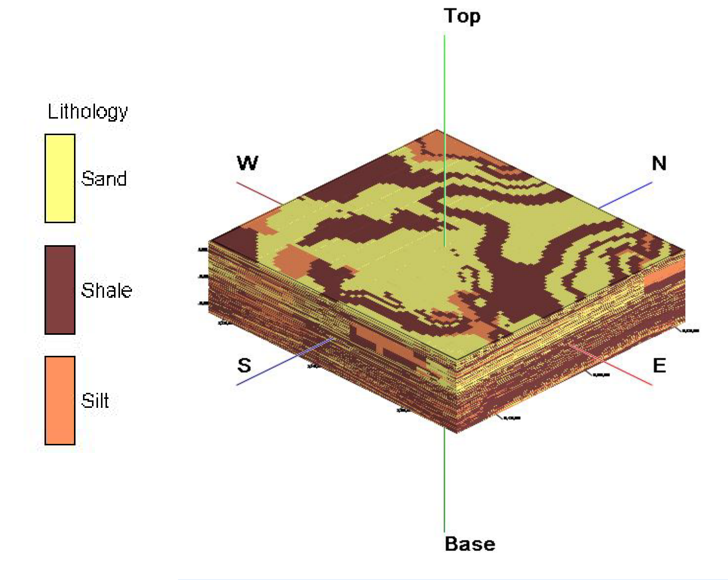
Technical Status

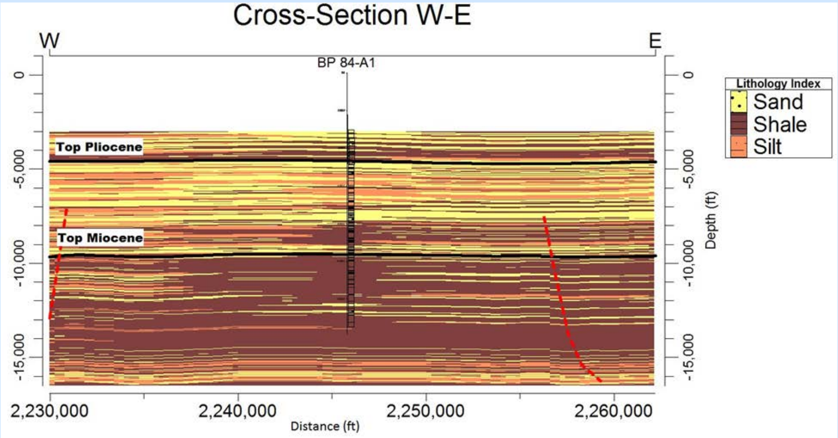
Field 84 Geologic Model Development

Field 84 Stratigraphy Model



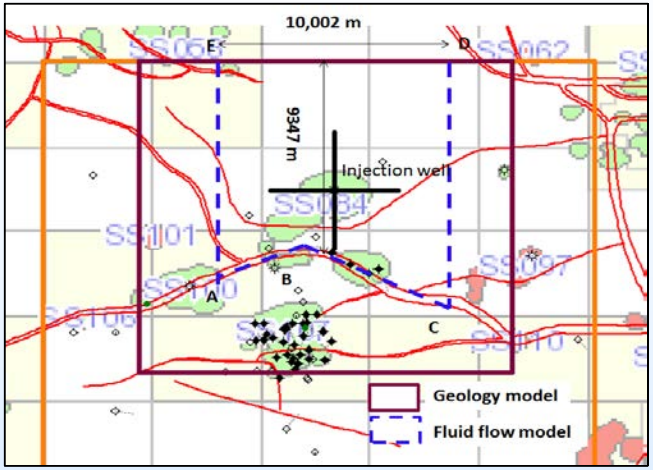
Field 84 Lithology Model

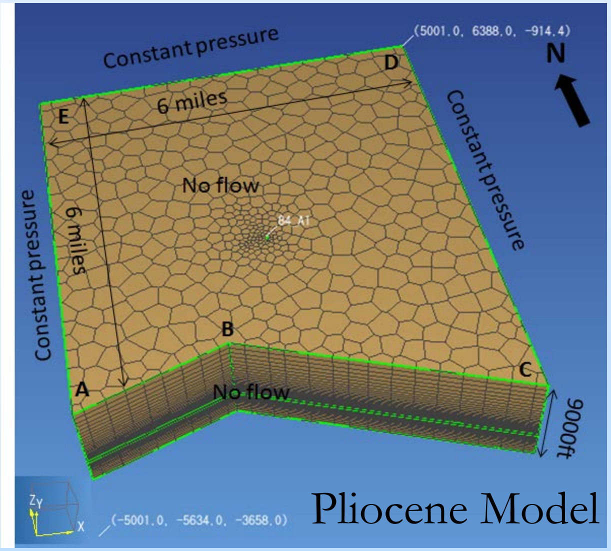




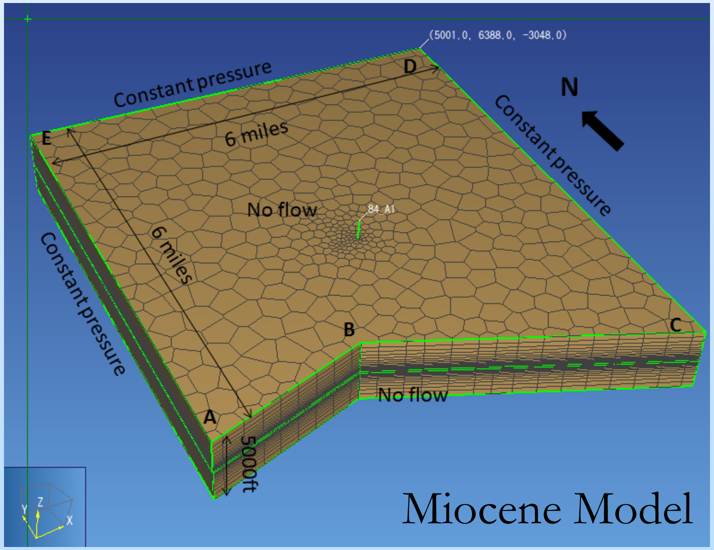
Technical Status

Field 84 Injection and Migration Modeling





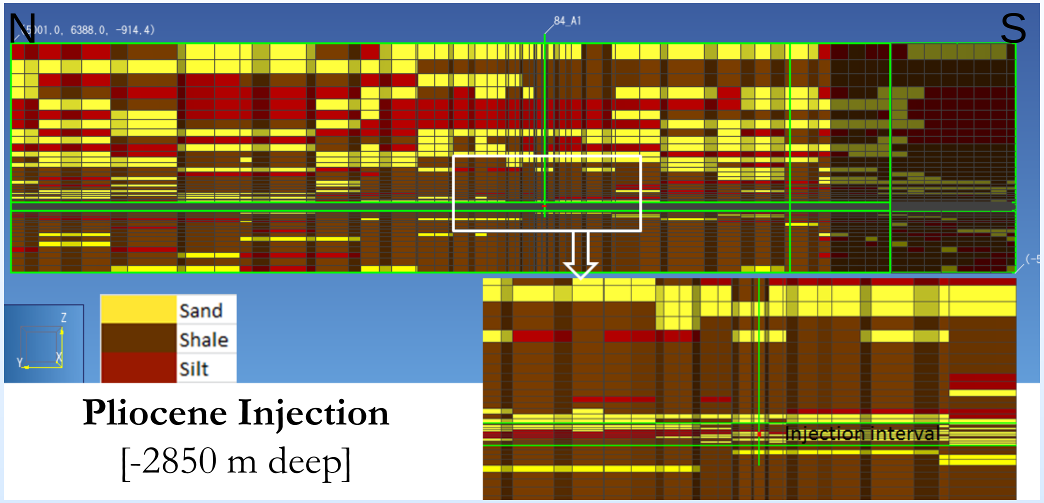
Model vertical span: -1500 to -4500 m SSL



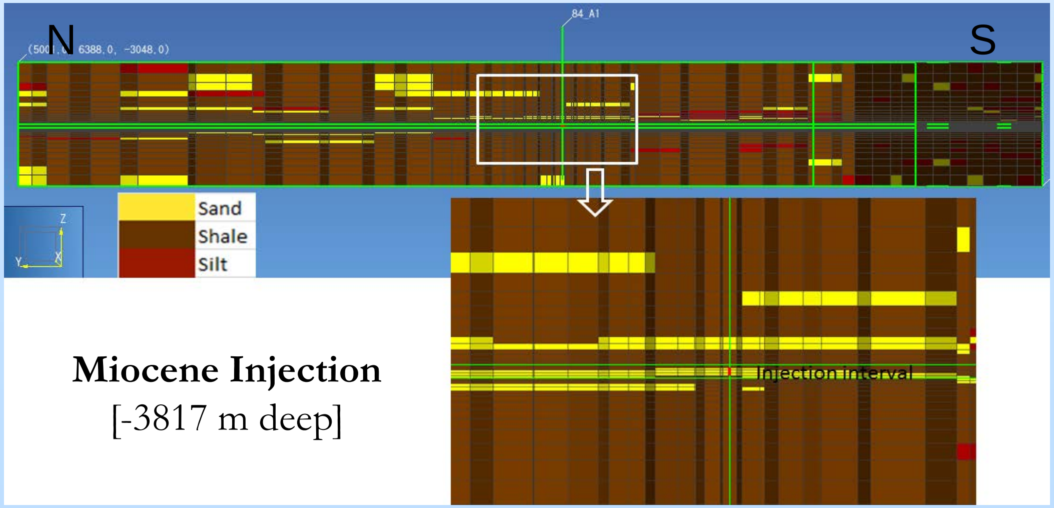
Model vertical span: -2200 to -4500 m SSL

Technical Status

Field 84 Injection and Migration Modeling



Pliocene Injection
[-2850 m deep]



Miocene Injection
[-3817 m deep]

Technical Status

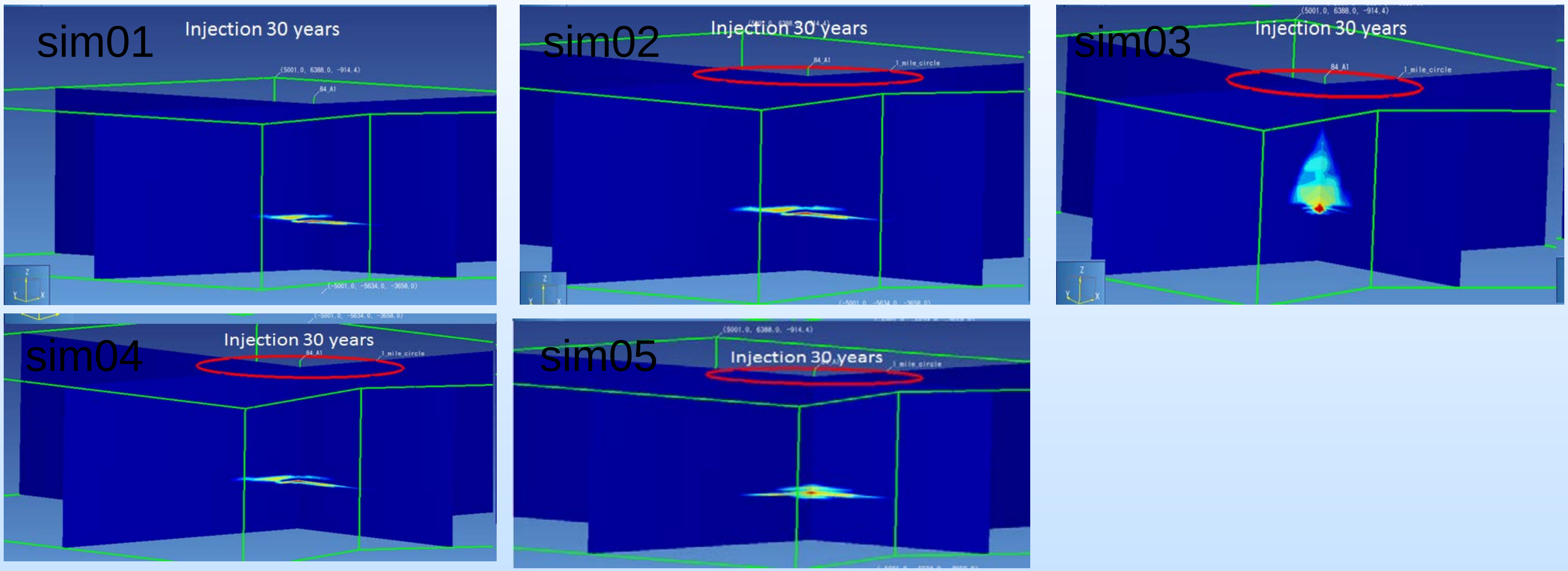
Field 84 Injection and Migration Modeling

field 84-scenarios		permeability & porosity	Z-perm/XY-perm	capillary pressure	30 years injection	30 years observation
sim01 (baseline)	Pliocene	baseline	½	baseline	Contained	Contained
	Miocene				Contained	Contained, crash at 2 year
sim02 (half porosity)	Pliocene	1/2 porosity in silt and shale compared to baseline	½	baseline	Contained	Contained
	Miocene		1/10 in shale	lower in shale	Contained	Contained
sim03 (no capillary)	Pliocene	same as sim02	½	no	Contained	Leakage
	Miocene				Leakage	
sim04 (sandy)	Pliocene	based on sim02, silt->sand	½	baseline	Contained	Contained
	Miocene		1/10 in shale	lower in shale	Contained	Contained
sim05 (shaly)	Pliocene	based on sim02, silt->shale	1/10 in shale	lower in shale	Contained	Contained, crash at 3.6 year
	Miocene		1/10 in shale	lower in shale	Contained	Contained

Technical Status

Field 84 Injection and Migration Modeling

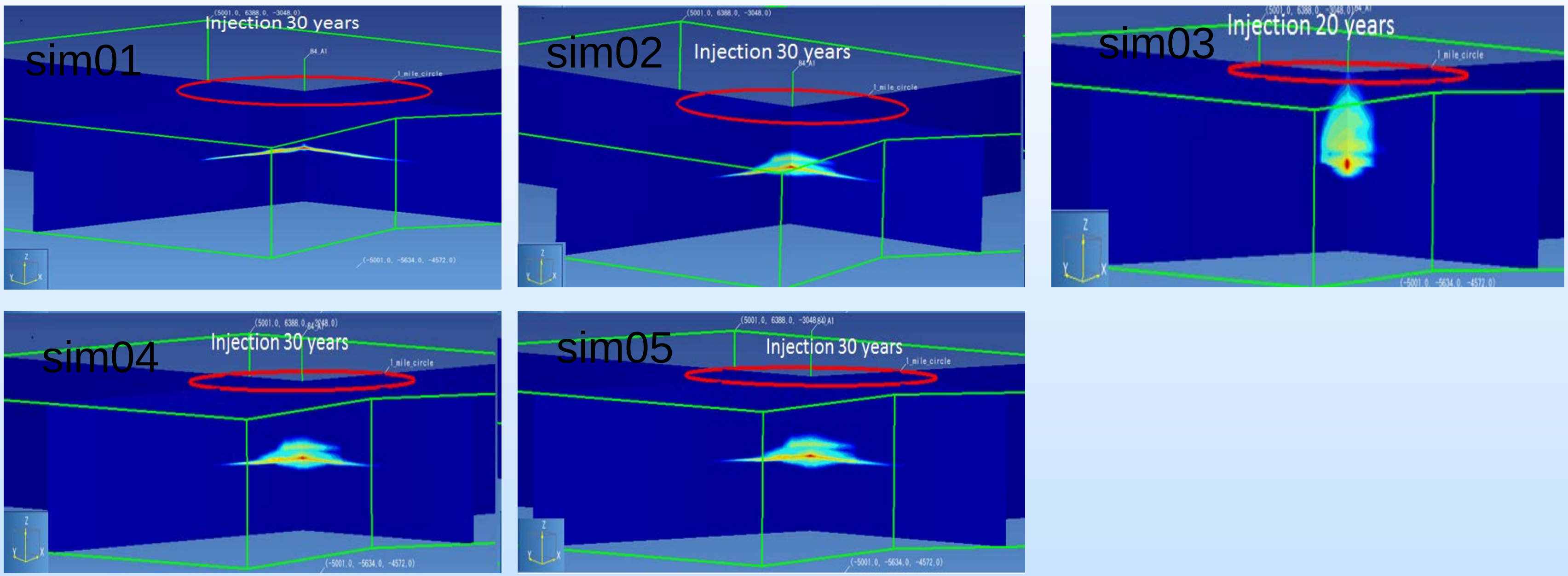
– Field 84 (Pliocene Injection)



Technical Status

Field 84 Injection and Migration Modeling

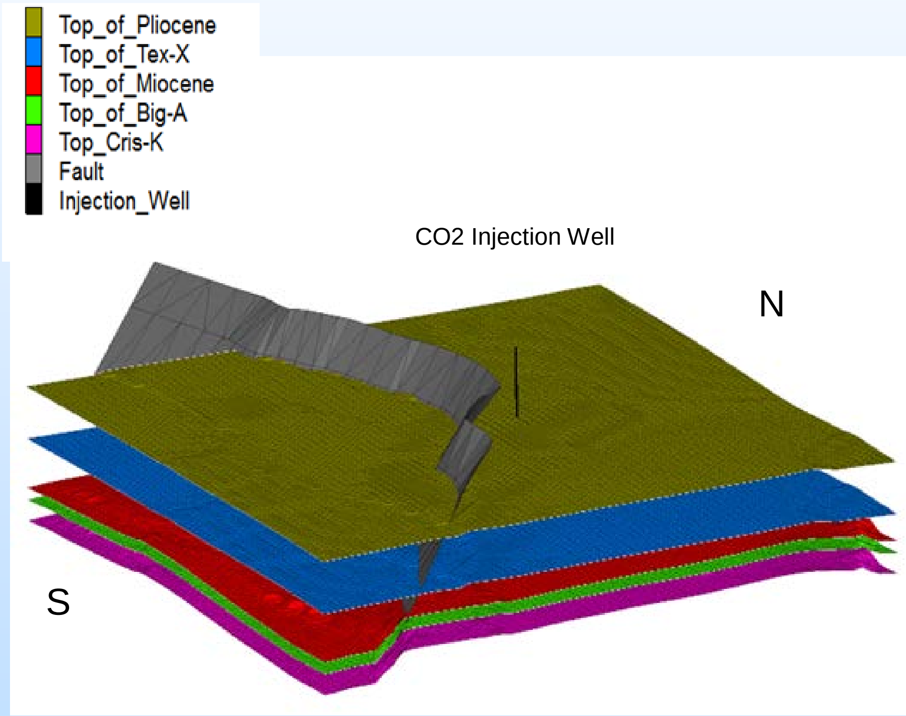
– Field 84 (Miocene Injection)

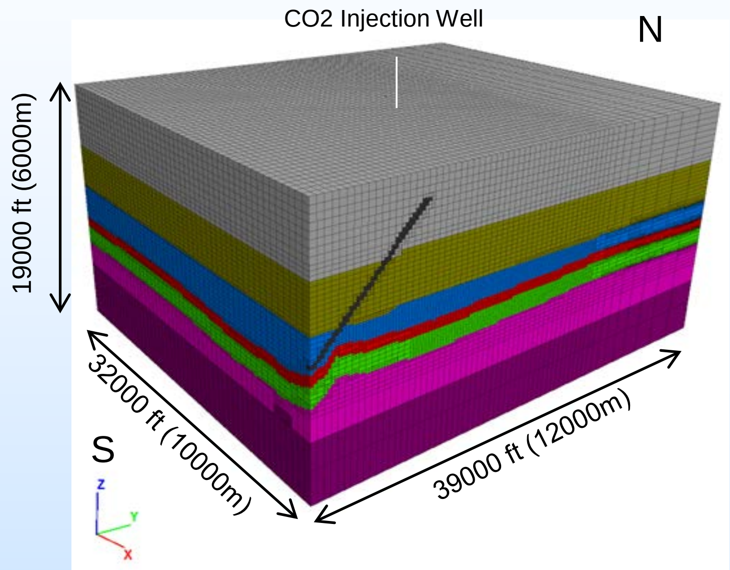


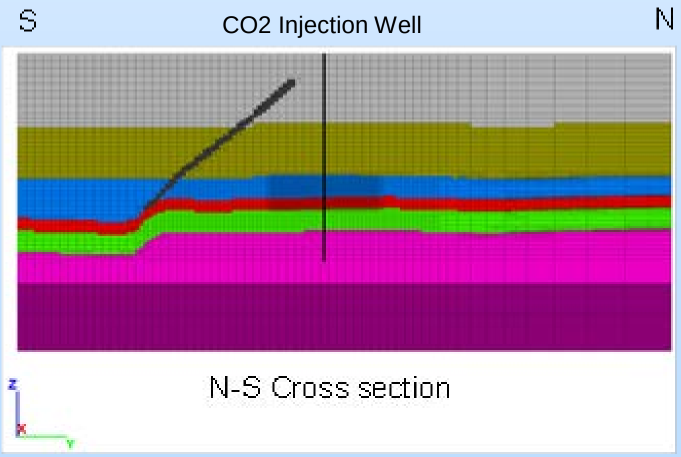
Technical Status

Field 84 Geomechanical Modeling

3D Geomechanical model assembled to evaluate potential fault activation and induced displacement & stresses



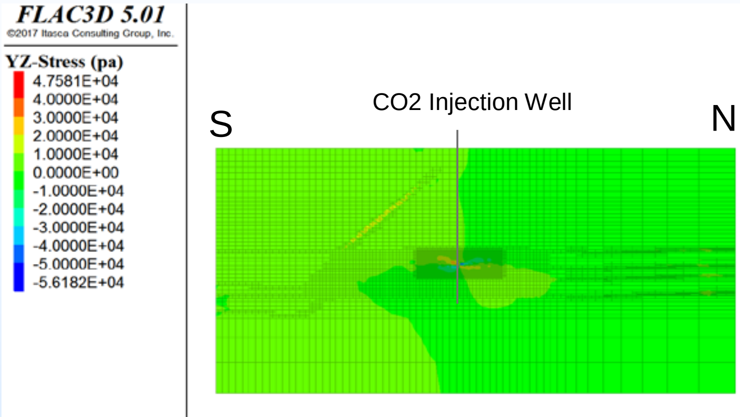




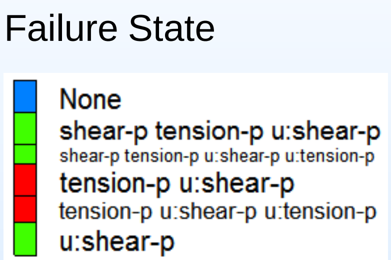
Technical Status

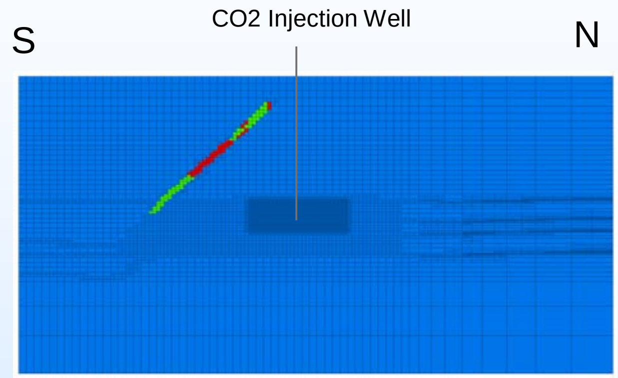
Field 84 Geomechanical Modeling

3D Geomechanical model - Potential fault activation analysis

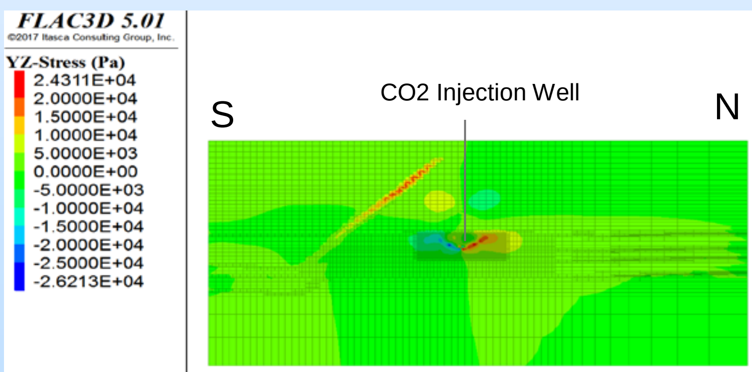


Sim01 – Base of Pliocene (Baseline)

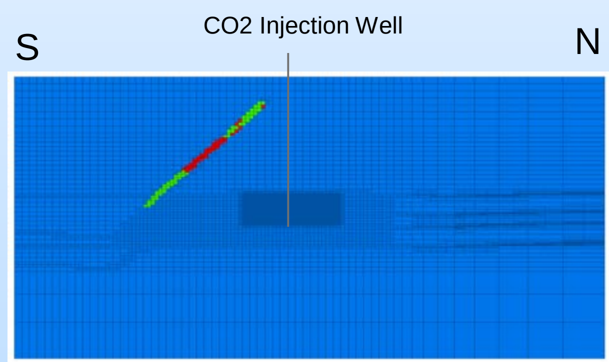




No shear and tension failure along the fault were induced at the present failure state



Sim03 – Base of Pliocene (No capillary pressure)



No shear and tension failure along the fault were induced at the present failure state

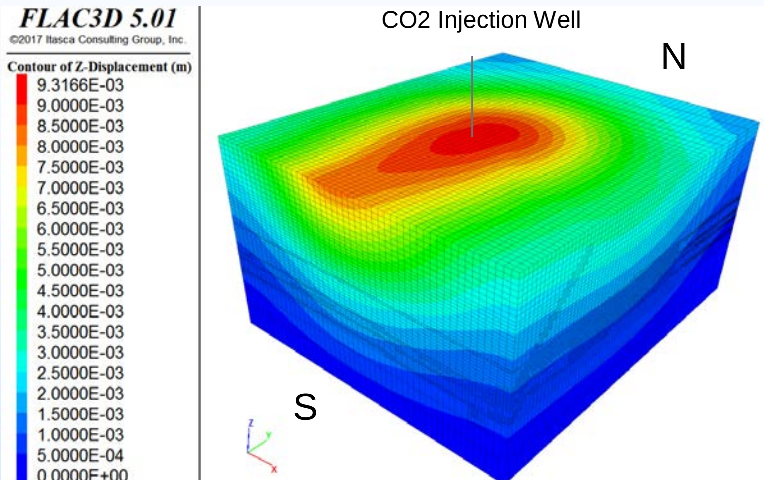
Low induced shear stress were obtained with less than 1E5Pa (14 psi) for various injection and input parameter scenarios evaluated at the base of Pliocene and Upper Miocene.

Low risk of fault activation was evidenced.

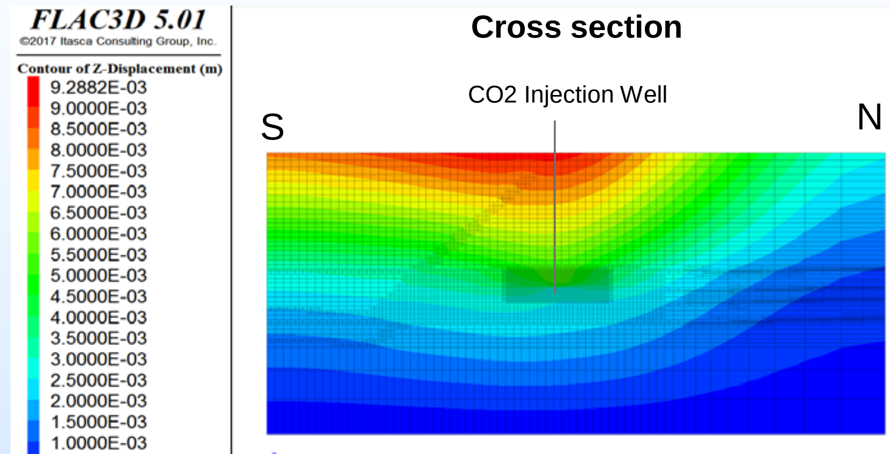
Technical Status

Field 84 Geomechanical Modeling

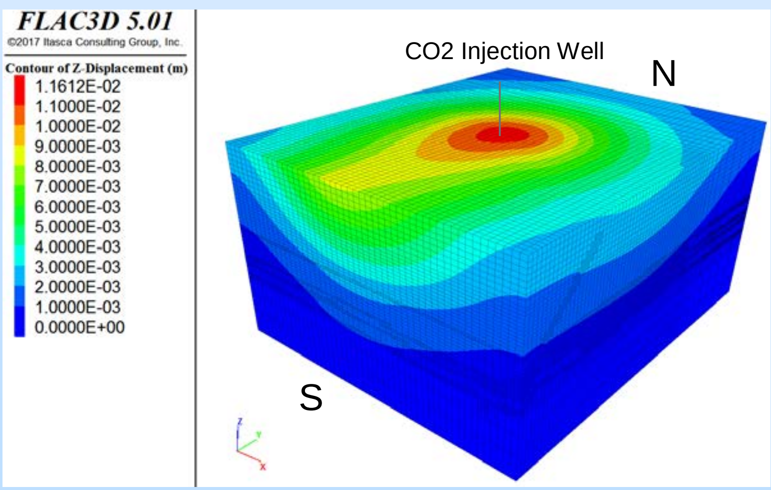
3D Geomechanical model – Induced uplift surface displacement – Base of Pliocene



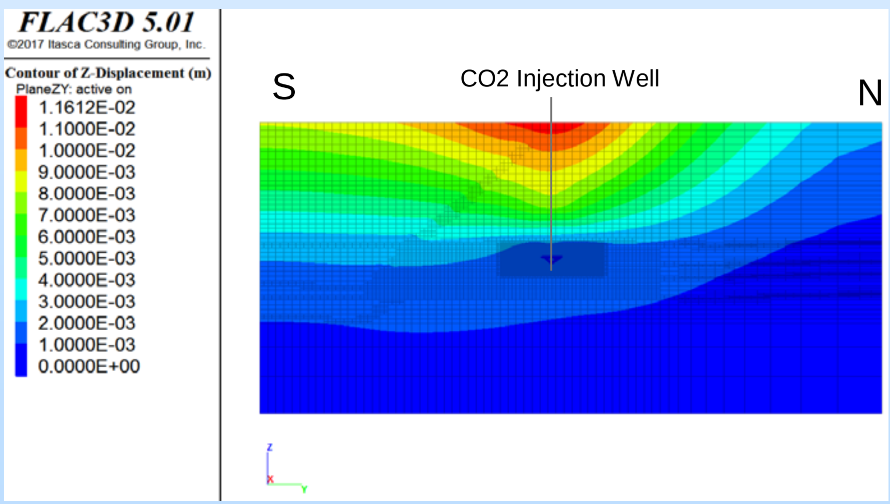
Sim01 – Base of Pliocene (Baseline)



Sim01 – Base of Pliocene (Baseline)



Sim03 – Base of Pliocene (No capillary pressure)

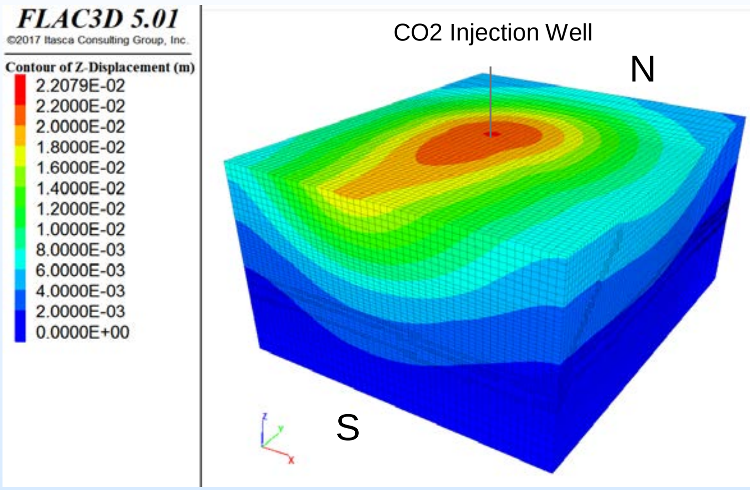


Sim03 – Base of Pliocene (No capillary pressure)

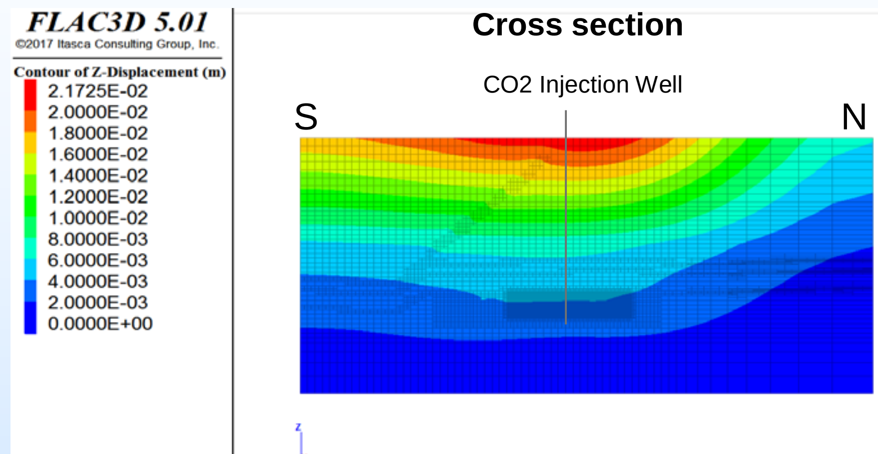
Technical Status

Field 84 Geomechanical Modeling

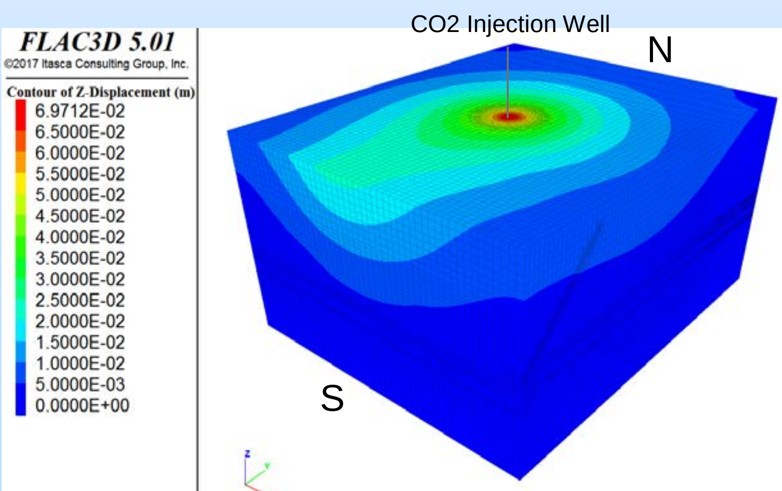
3D Geomechanical model – Induced uplift surface displacement – Upper Miocene



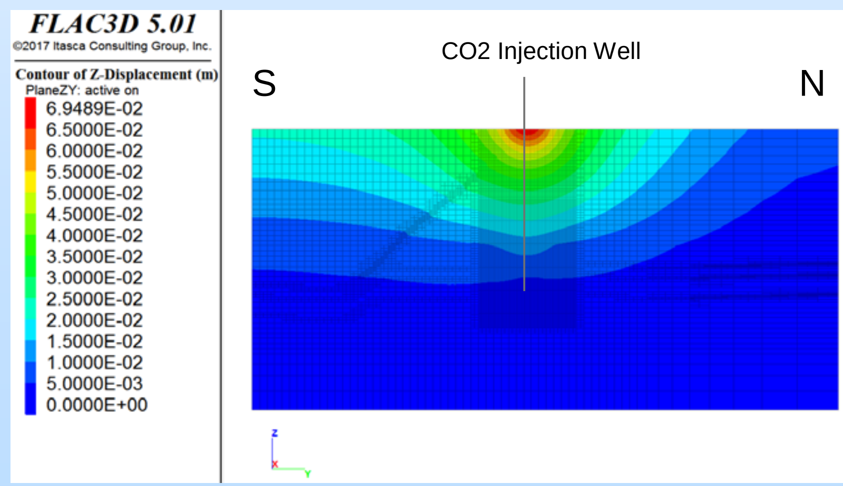
Sim01 – Upper of Miocene (Baseline)



Sim01 – Upper of Miocene (Baseline)



Sim03 – Upper of Miocene (No capillary pressure)

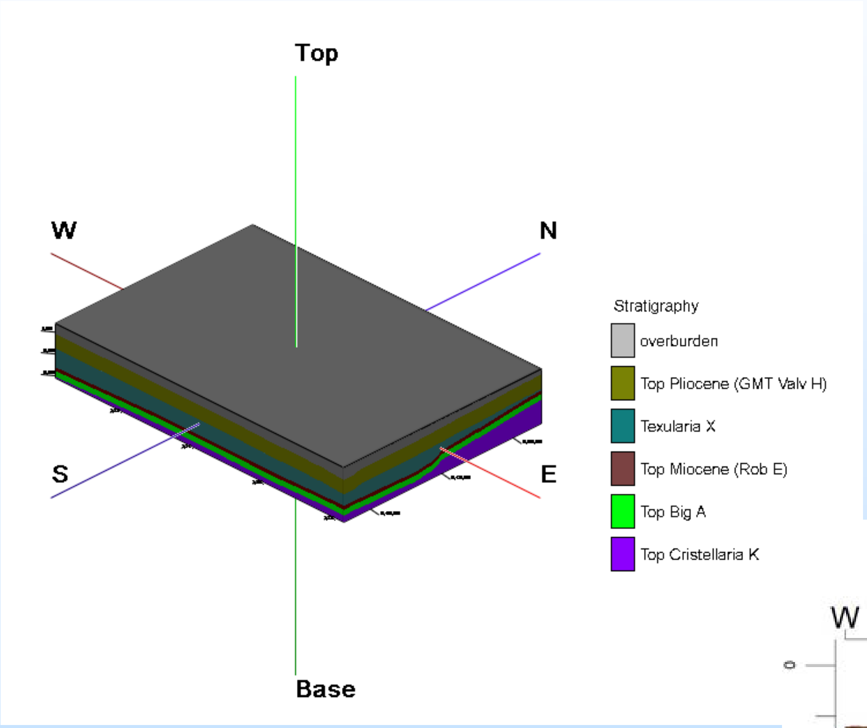


Sim03 – Upper of Miocene (No capillary pressure)

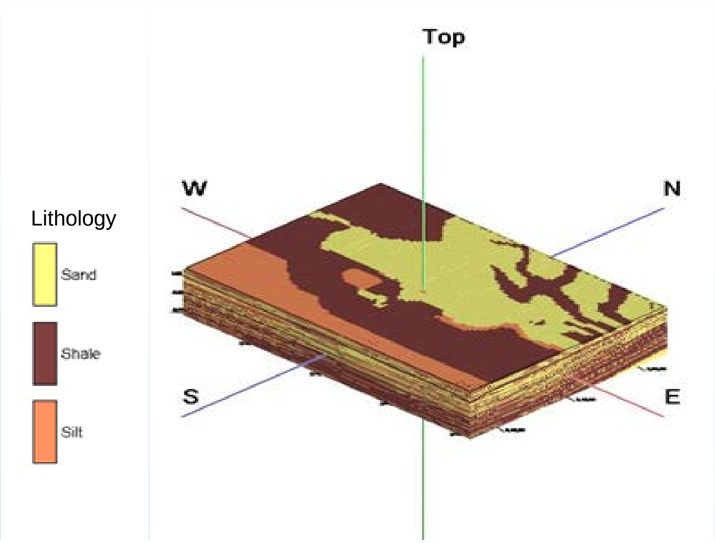
Technical Status

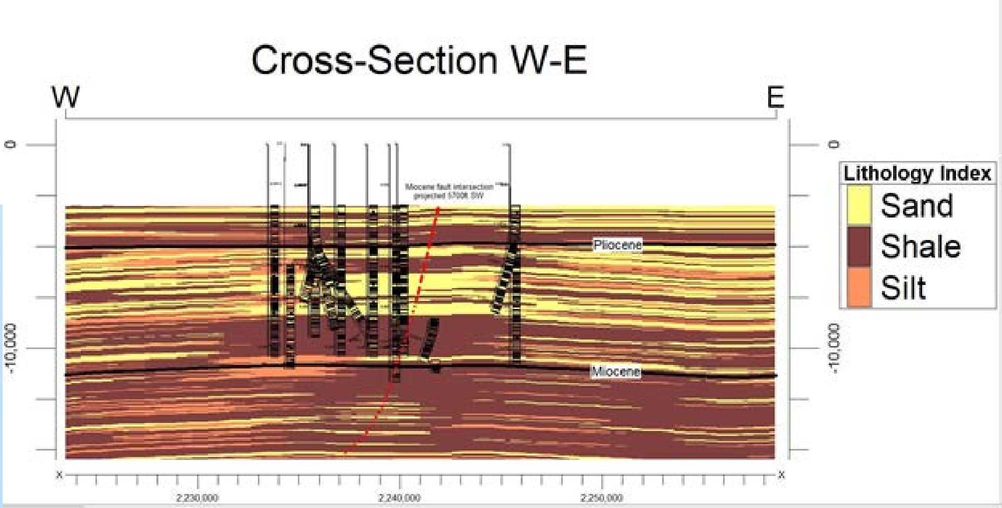
Field 107 Geologic Model Development

Field 107 Stratigraphy Model



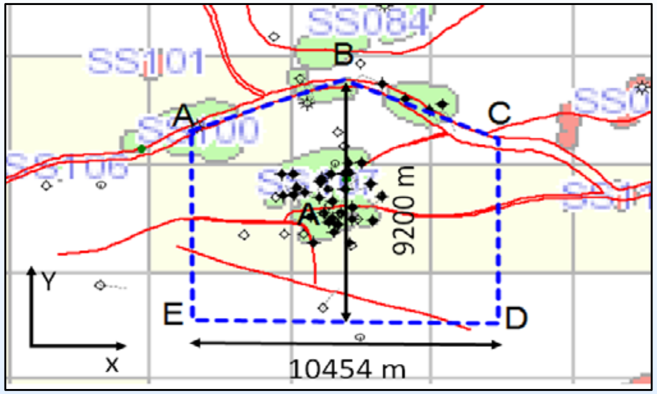
Field 107 Lithology Model

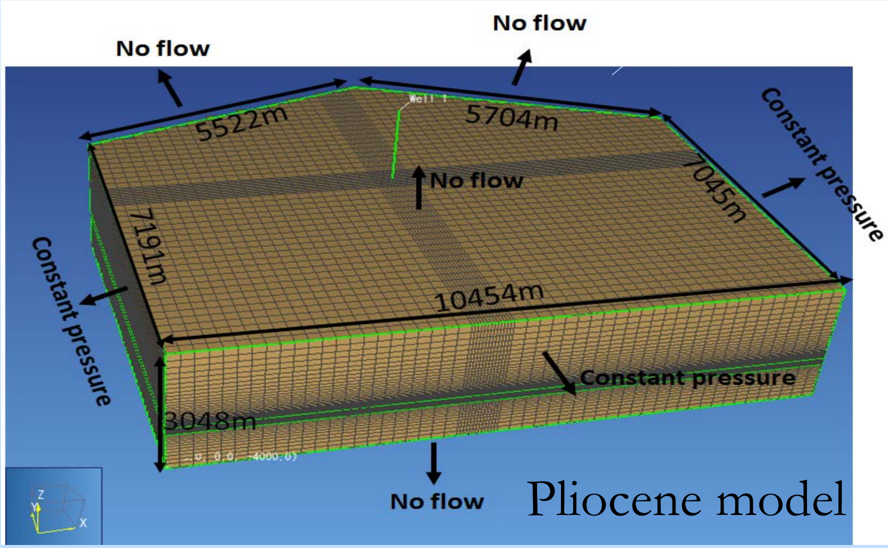


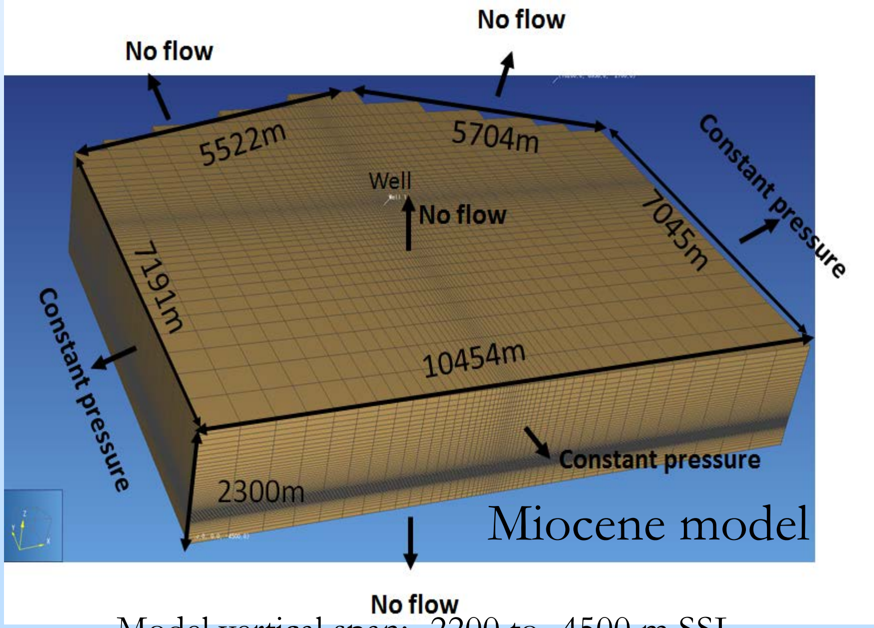


Technical Status

Field 107 Injection and Migration Modeling







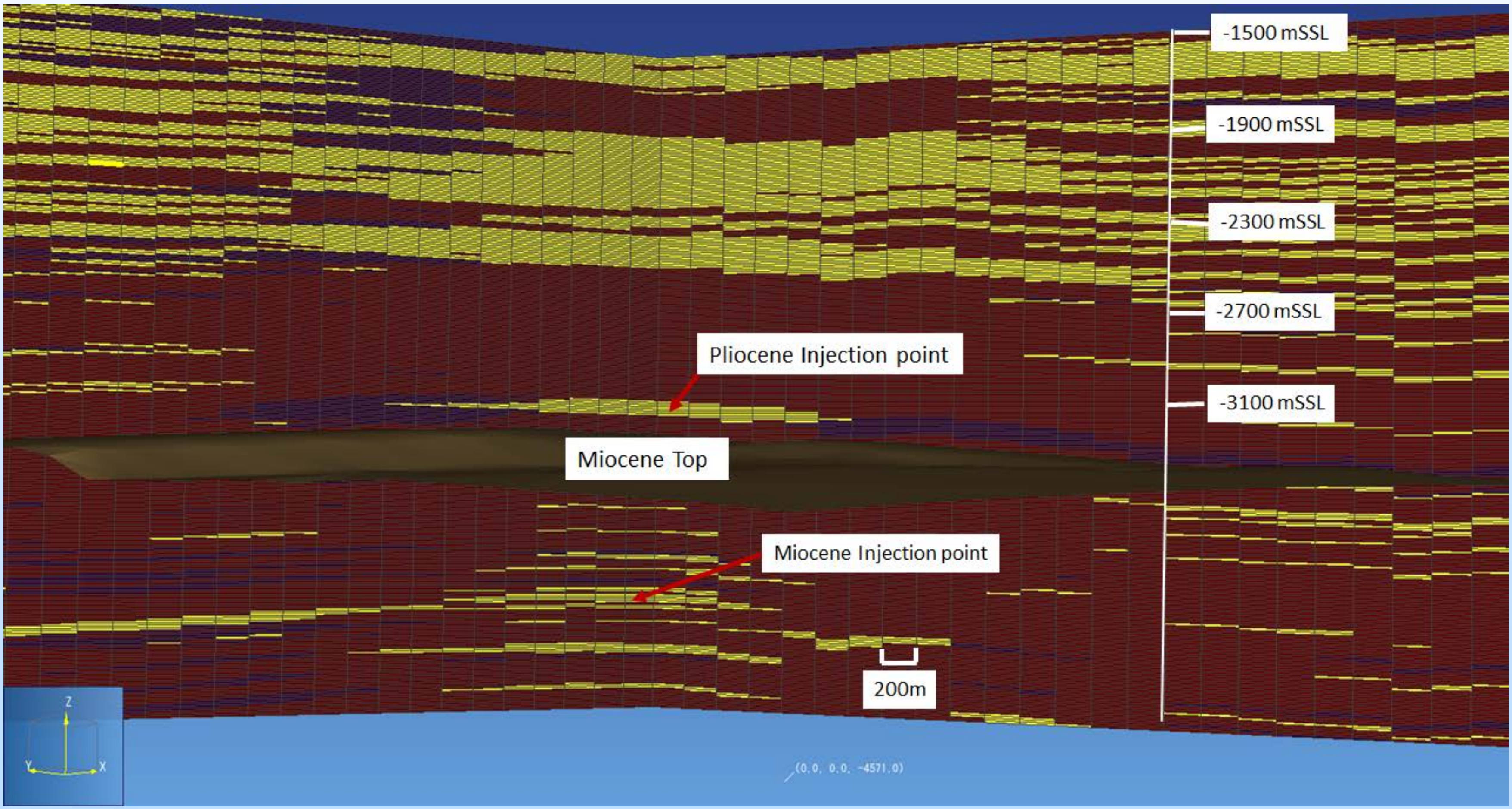
Model vertical span: -1500 to -4500 m SSL

Model vertical span: -2200 to -4500 m SSL

Technical Status

Field 107 Injection and Migration Modeling

Perforation interval for Pliocene model in Block 107: -3150 to -3200 m SSL
Perforation interval for Miocene Model in Block 107 : -4070 to -4080 m SSL



Technical Status

Field 107 Injection and Migration Modeling

- Field 107 Fluid Flow- Pliocene Model Result Summary

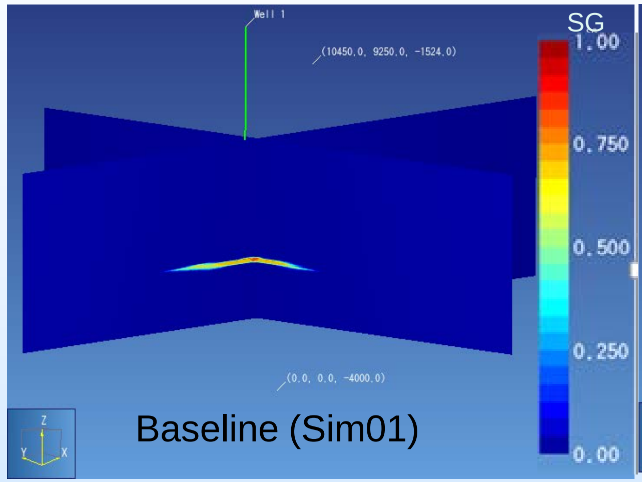
		Input			Result			
Model	Scenarios	Relative Permeability for Sand	Capillary Pressure	PP Gradient (psi/ft)	CO_2 Lateral Migration Radius after 30 Years Injection (mile)	CO_2 Plume Top after 30 Years Injection (m SSL)	CO_2 Migration after 30 Years of Observation (m SSL)	Leaking?
Pliocene	Sim01 (Baseline)	Based on Berea Sandstone	Yes	0.435	1.5	-3115	-3115	Contained
	Sim02 (Different Relative Permeability for Sand)	Based on Usira Sandstone	Yes	0.435	1.4	-3115	-3115	Contained
	Sim03 (Different PP Gradient)	Based on Berea Sandstone	Yes	0.3	1.4	-3115	-3115	Contained
	Sim04 (No Salt)	Based on Berea Sandstone	Yes	0.435	1.5	-3115	-3115	Contained
	Sim05 (Non-isothermal)	Based on Berea Sandstone	Yes	0.435	1 mile after 10 years injection	NA	NA	Contained
	Sim06 (No capillary pressure)	Based on Berea Sandstone	No	0.435	1	-2500	-1675	Contained

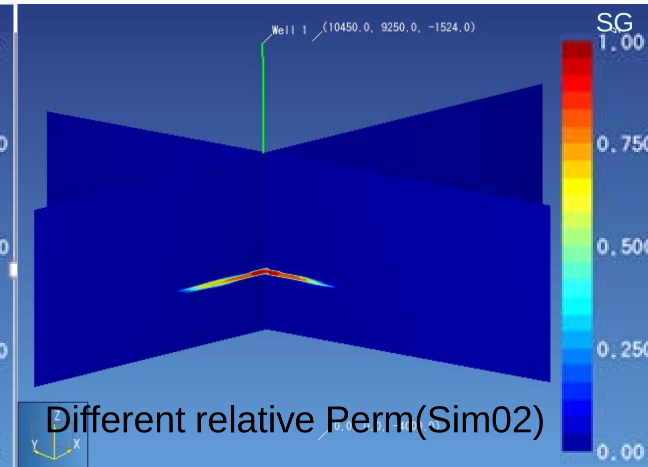
Technical Status

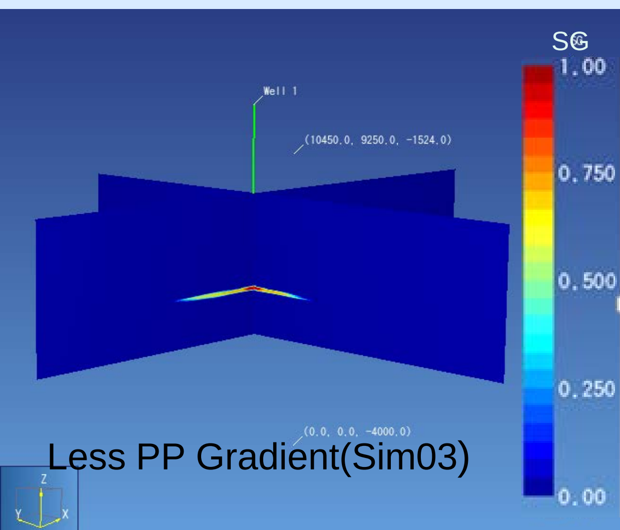
Field 107 Injection and Migration Modeling

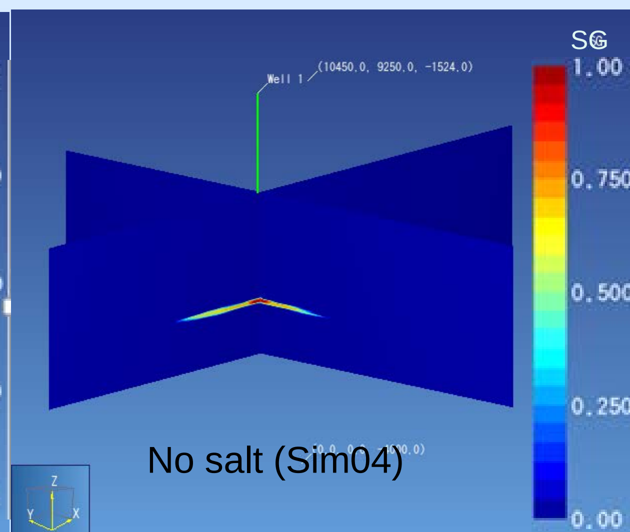
- Field 107 Fluid Flow- CO2 Saturation after 30 Years Injection

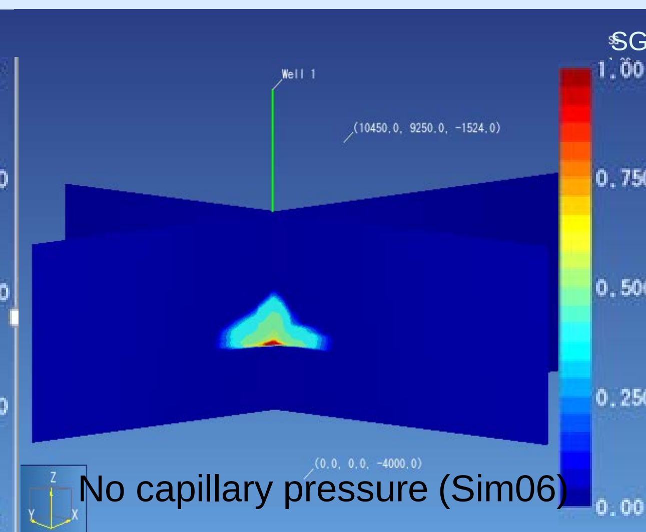
<u>Pliocene Model</u>











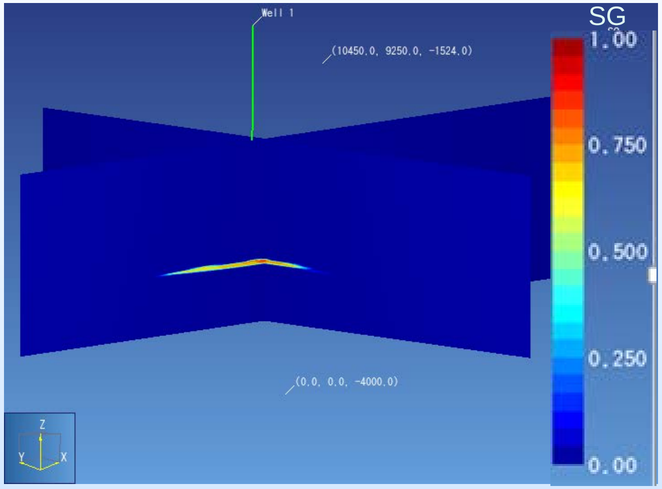
Technical Status

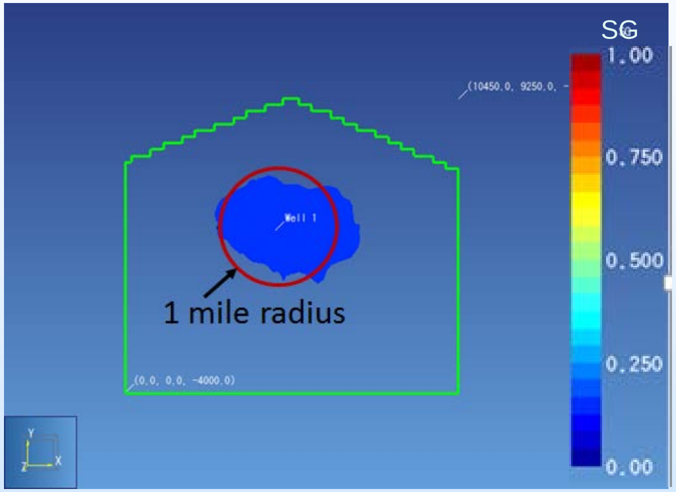
Field 107 Injection and Migration Modeling

- Field 107 Fluid Flow- CO2 plume after 30 Years Observation

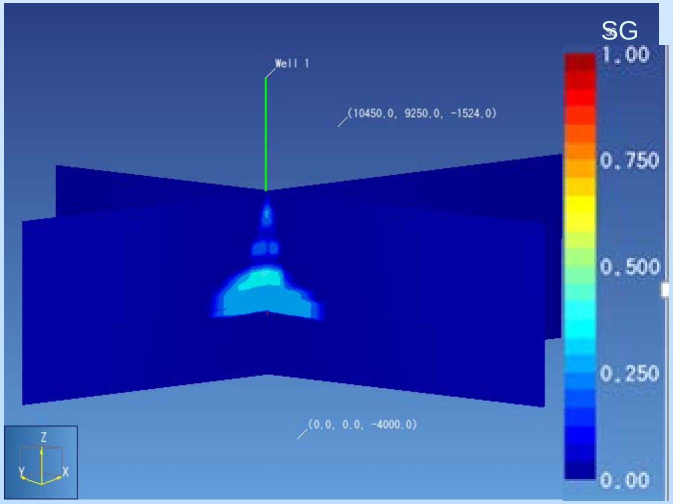
Pliocene Model

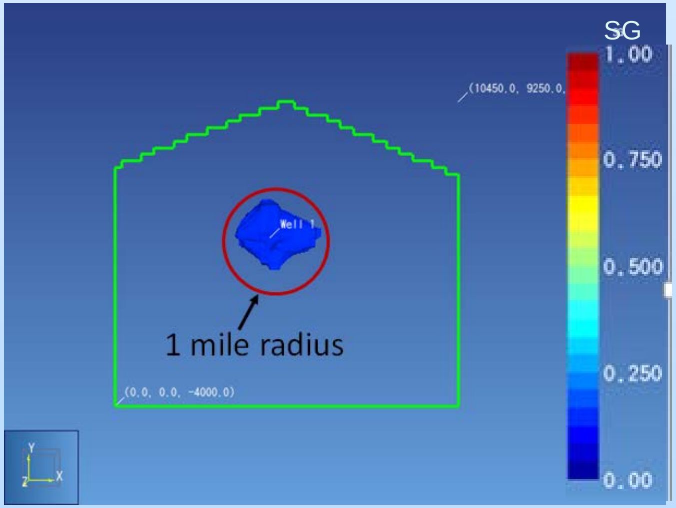
Baseline case (Sim01)





No capillary pressure case (Sim06)





Technical Status

Field 107 Injection and Migration Modeling

- Field 107 Fluid Flow- Miocene Model Result Summary

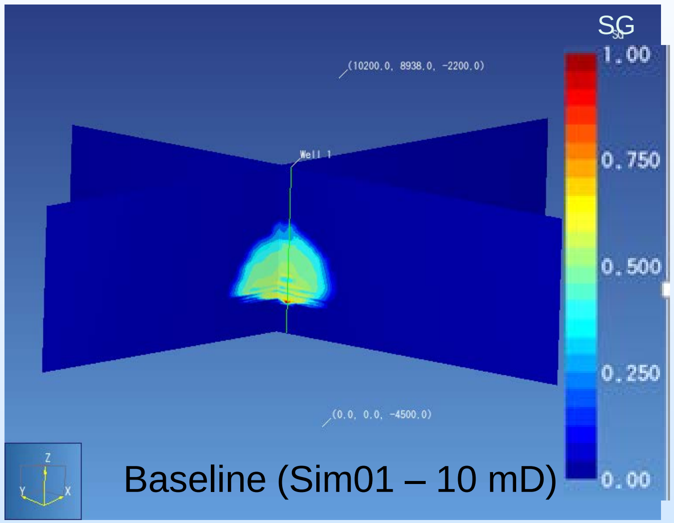
		Input			Result			
Model	**Scenarios**	**Shale/Silt Permeability**	**Capillary Pressure**	**Injection Rate (million ton/y)**	**CO2 Lateral Migration Radius after 30 Years Injection (mile)**	**CO2 Plume Top after 30 Years Injection (m SSL)**	**CO2 Plume Top after 30 Years of Observation (m SSL)**	**Leaking?**
Miocene	Sim01 (Baseline)	Set minimum to 10md	No	1	0.5	-3075	-2575	Contained in Pliocene
	Sim02 (Different Permeability for silt and shale)	Use original value from log correlation (around 1 md)	No	1	1	-3625	-3415	Contained in Miocene
	Sim03 (Different injection rate)	Set minimum to 10md	No	0.5	0.4	-3075	-2595	Contained in Pliocene
	Sim04 (With capillary pressure)	Set minimum to 10md	Yes	1	1.2	-3975	-3975	Contained in Miocene

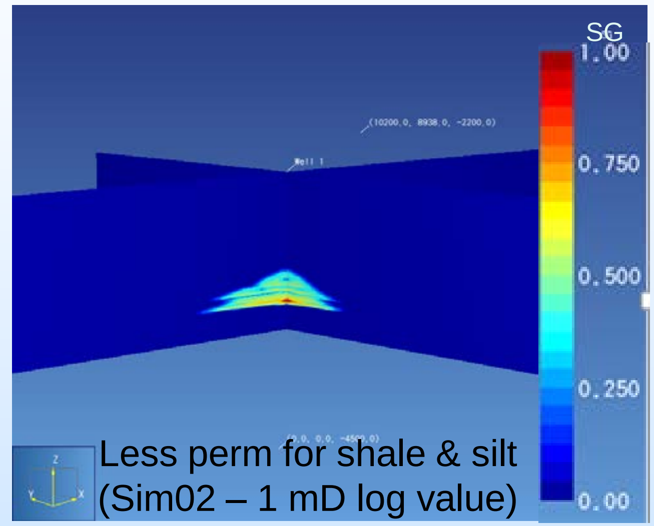
Technical Status

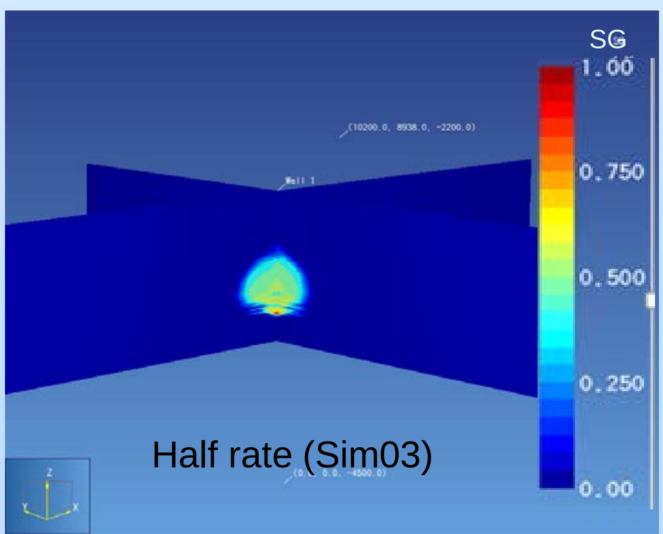
Field 107 Injection and Migration Modeling

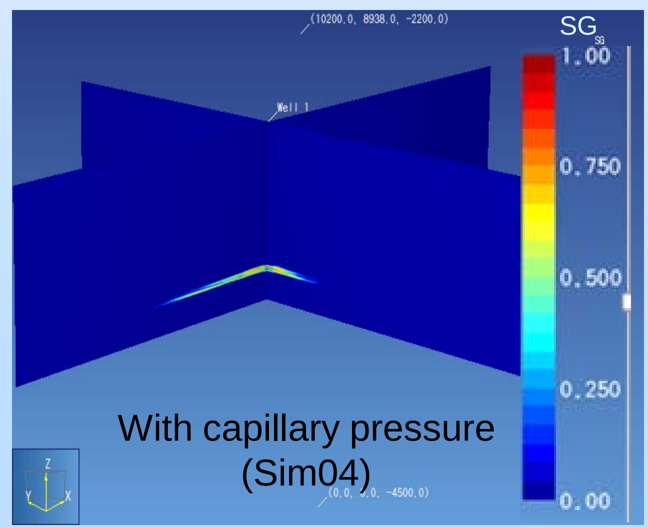
- Field 107 Fluid Flow- CO_2 Saturation after 30 Years Injection

Miocene Model









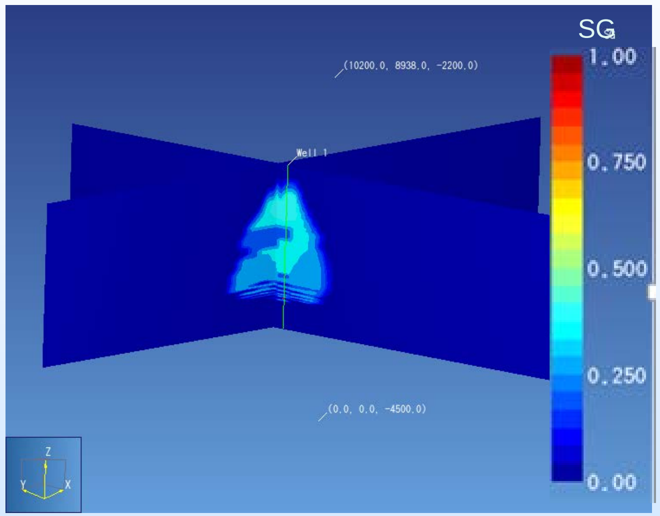
Technical Status

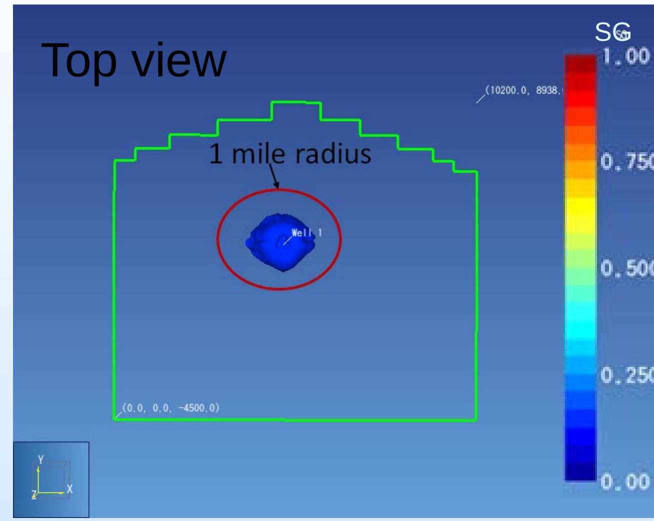
Field 107 Injection and Migration Modeling

- Field 107 Fluid Flow- CO_2 plume after 30 Years Observation

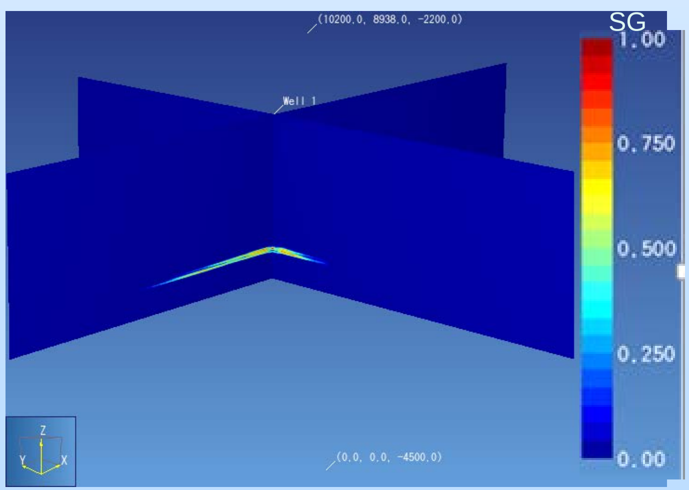
Miocene Model

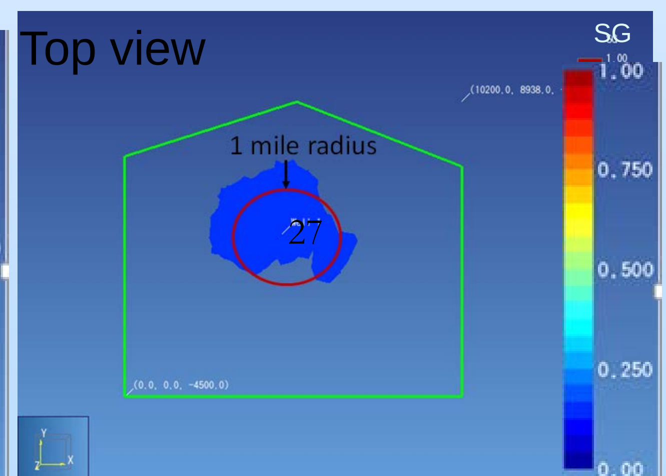
Baseline case (Sim01 – 10 mD)





With capillary pressure case (Sim04)

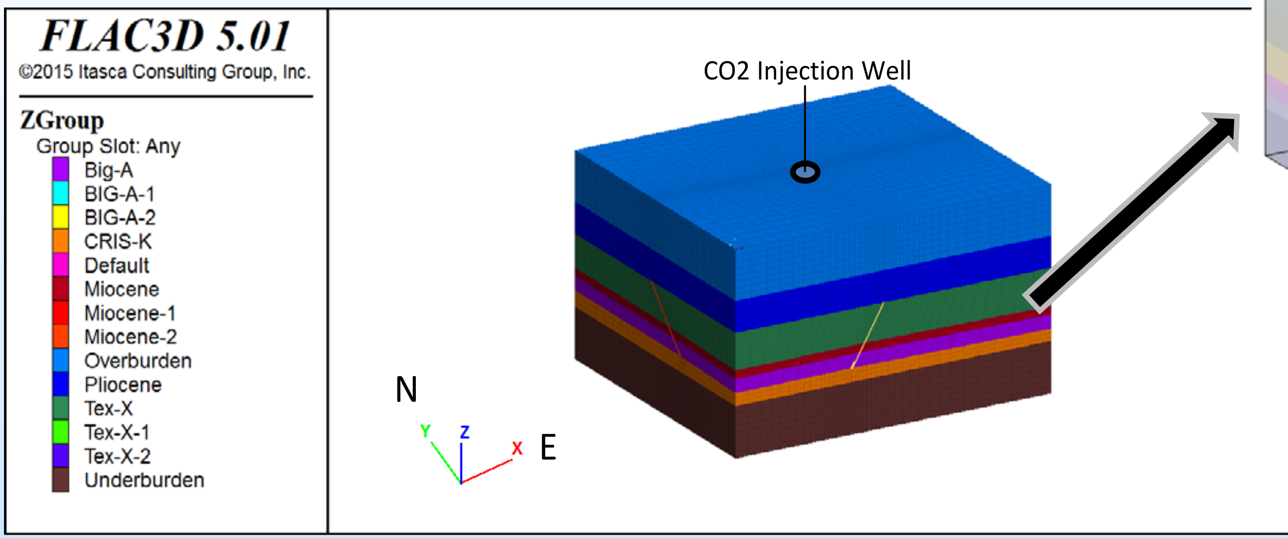


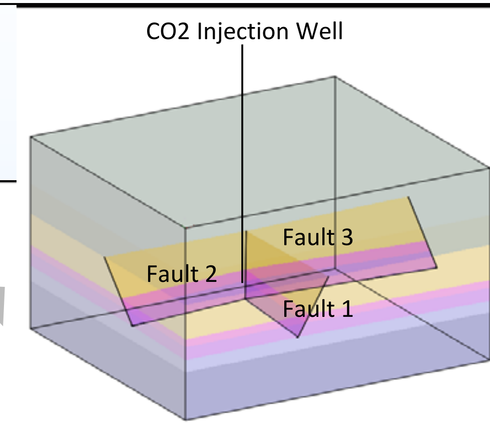


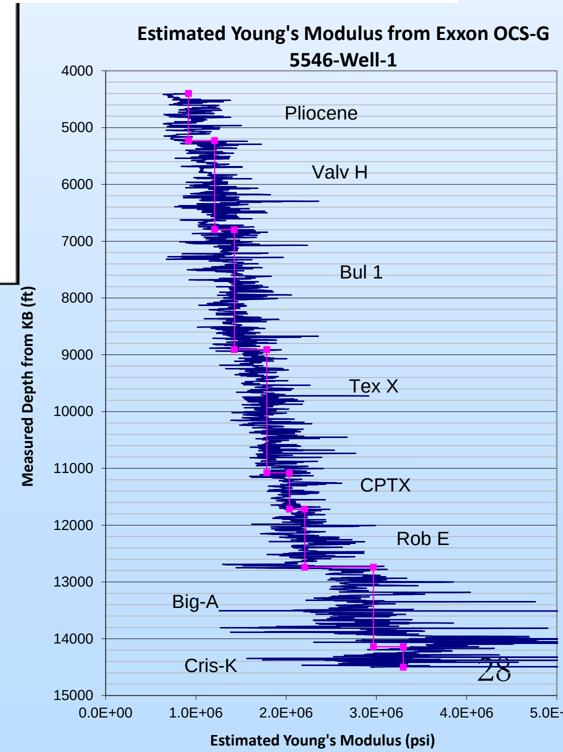
Technical Status

Field 107 Geomechanical Modeling

3D-GeoMechanical Model to Assess Induced Displacement & Stresses and Potential Fault Activation





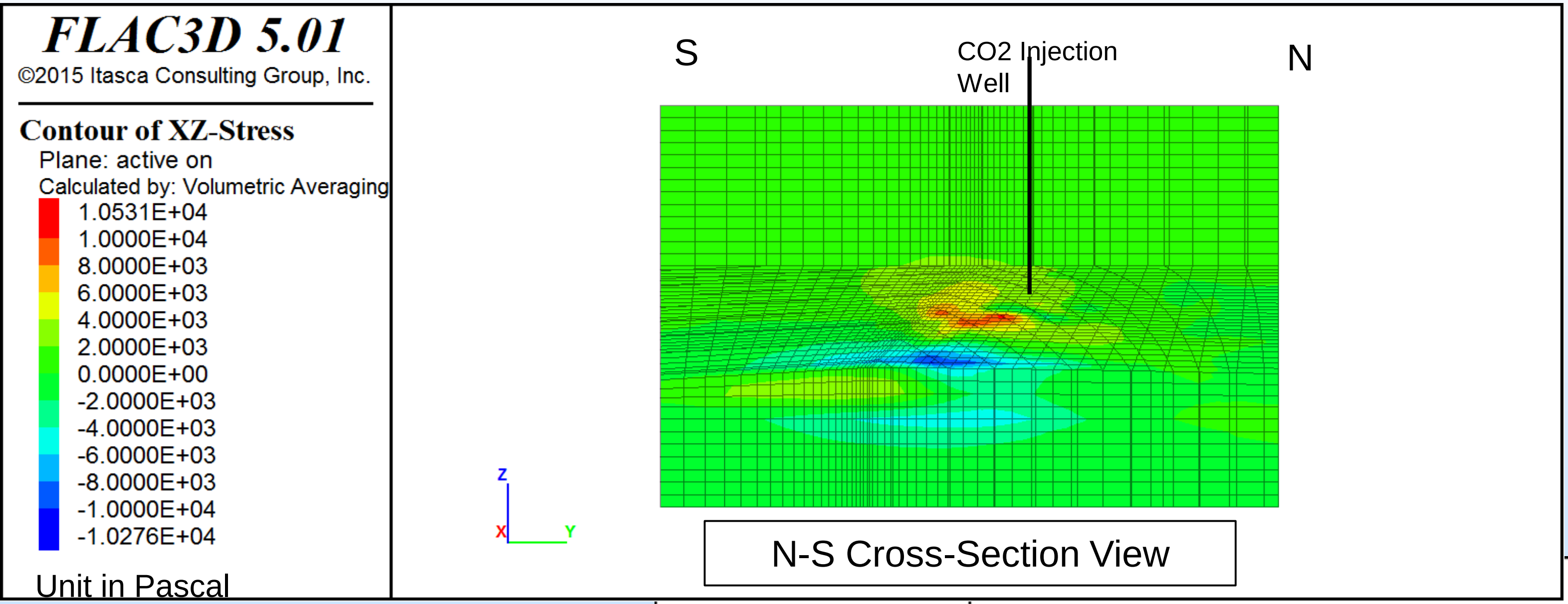


With pressure & temperature distribution results from fluid flow simulations and estimated mechanical properties from available well logs, core data, formation test data, etc., the 3D-geomechanical model can estimate the changes in displacement & stress, and evaluate fault activation risk.

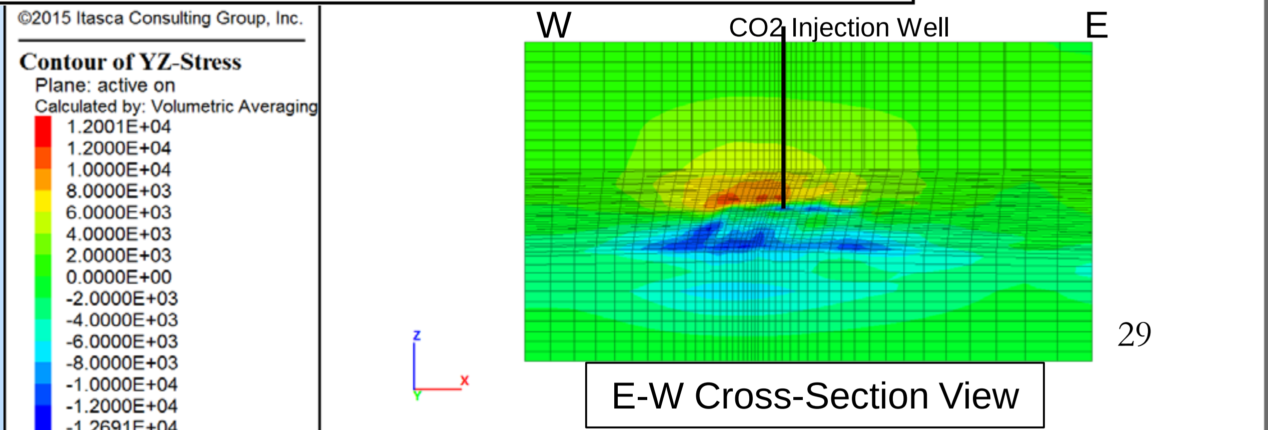
Technical Status

Field 107 Geomechanical Modeling

Estimated Induced Subsurface Shear Stresses due to CO_2 Injection at Base Pliocene Target Zone (Pliocene Baseline Scenario).



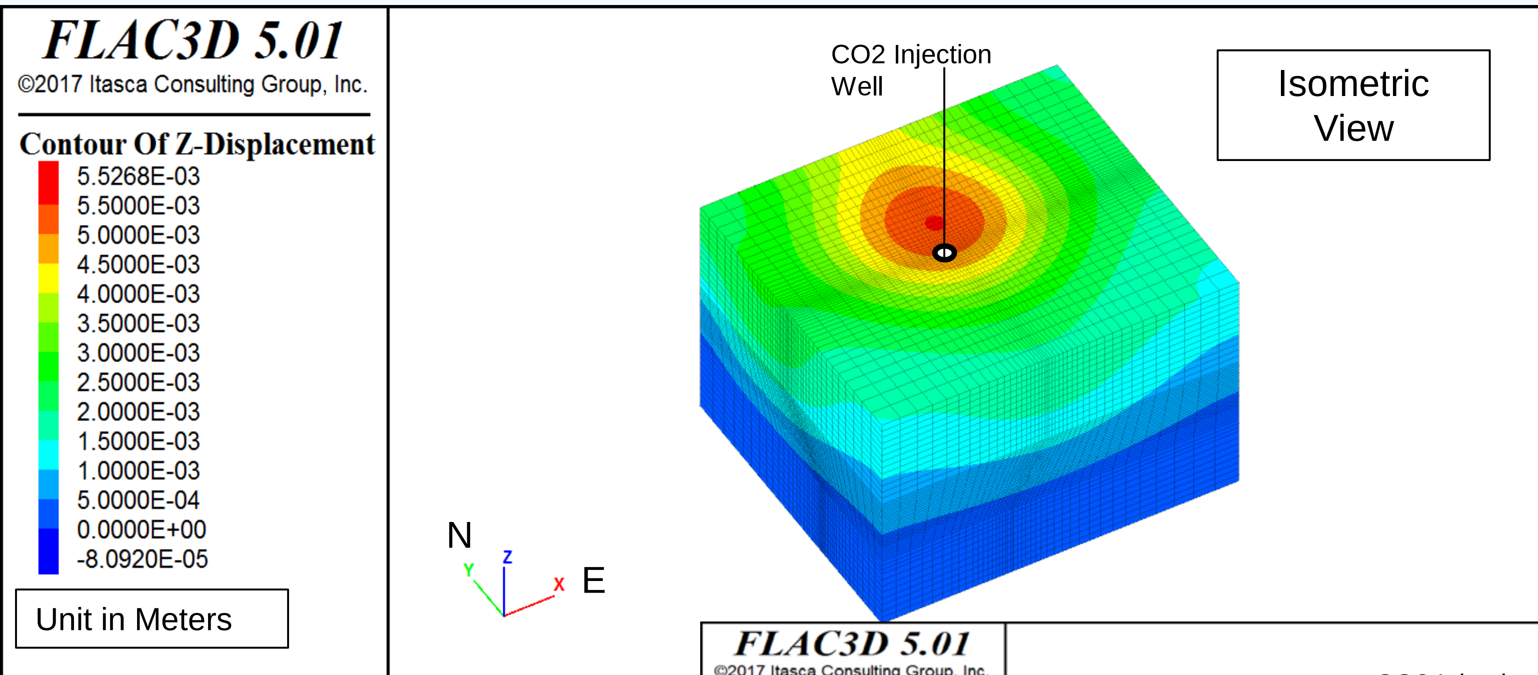
Maximum induced shear stresses are less than 2E4 Pa (3 psi) for various injection and input parameter scenarios evaluated. There is very low risk of potential fault activation.



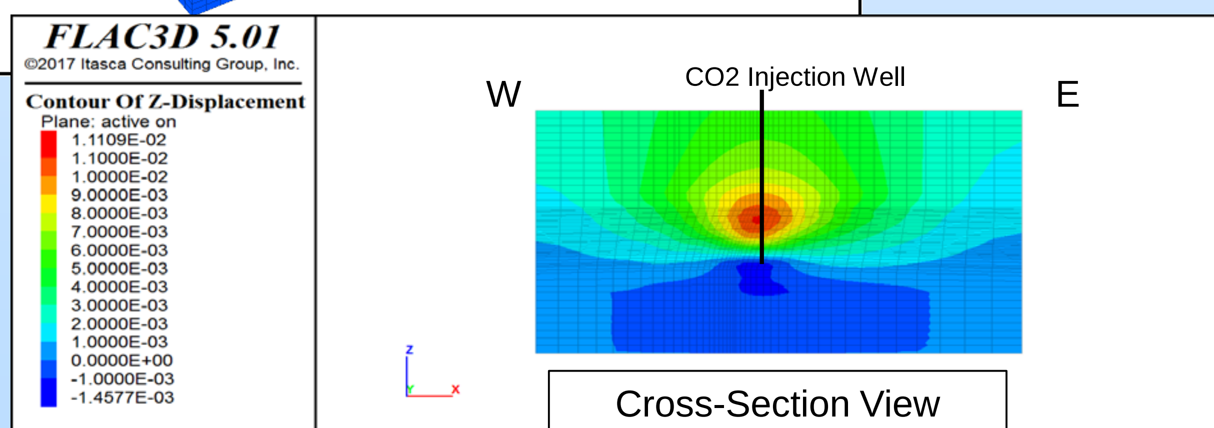
Technical Status

Field 107 Geomechanical Modeling

Estimated Induced Displacement due to CO_2 Injection at Upper Miocene Target Zone (Miocene Baseline Scenario).



Maximum induced seafloor displacements are less than 1 cm (0.4 inch) for various injection and input parameter scenarios evaluated.



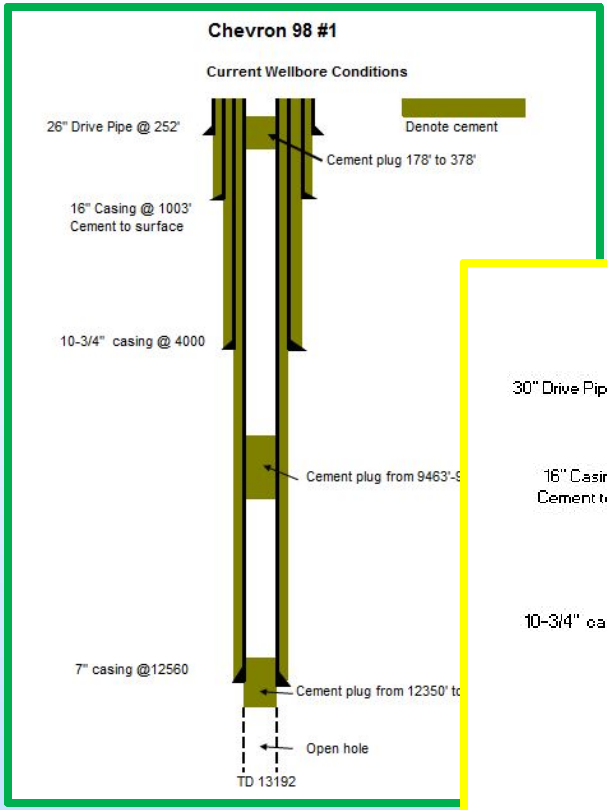
Technical Status

Risk Assessment and Characterization

Risk Assessment

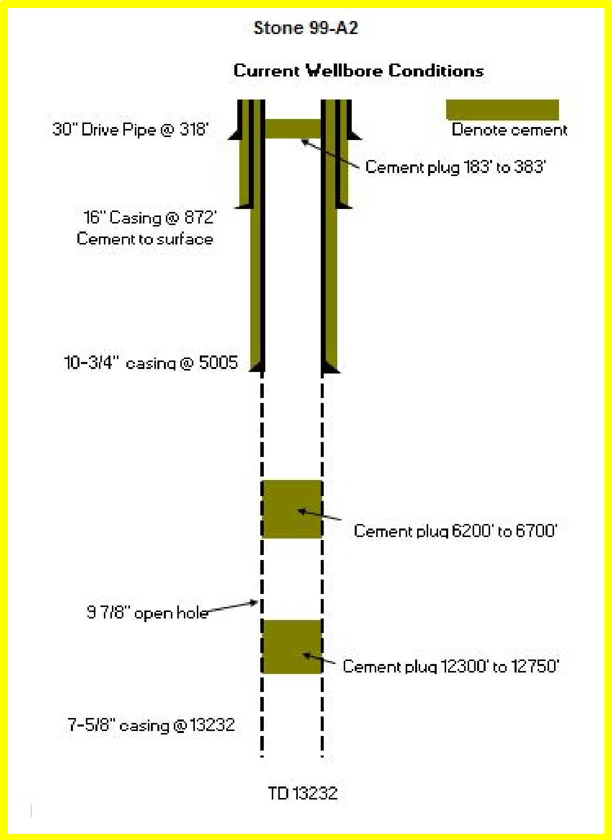
Well Integrity- 77 well schematics

Good Integrity		Moderate Integrity
Chevron 98-1	Energy XXI 108-13	Stone 99-A2
Stone 99-1	Energy XXI 108-14	Chevron 99-2
Stone 99-1 ST1	Energy XXI 108-15	Chevron 99-4
Stone 99-1 ST2	Energy XXI 108-16 ST1	Chevron 99-5
Stone 99-3	Energy XXI 108-17	Chevron 107-B1
Stone 99-A1	Energy XXI 108-19	Chevron 107-5
Stone 99-A1 ST1	Energy XXI 108-22	Energy XXI 108-1
Stone 99-A2ST1	Energy XXI 108-23	Energy XXI 108-2
Stone 99-E1	Energy XXI 108-24	Energy XXI 108-3
Stone 99-E2	Energy XXI 108-26	Energy XXI 108-4 ST1
Chevron 99-1	Energy XXI 108-29	Energy XXI 108-7
Chevron 99-3	Energy XXI 108-30	Energy XXI 108-18
Chevron 99-6	Energy XXI 108-31	Energy XXI 108-20
Chevron 99-7	Energy XXI 108-32	Energy XXI 108-21
Chevron 99-8	Energy XXI 108-33	Energy XXI 108-25
BoisDarc 107-1	Energy XXI 108-34	Energy XXI 108-27
Chevron 107-1	Energy XXI 108-34ST1	Energy XXI 108-28
Chevron 107-2	Energy XXI 108-36	Energy XXI 108-35
Chevron 107-3	Energy XXI 108-37	Energy XXI 108-40
Chevron 107-4	Energy XXI 108-38	
Chevron 107-6	Energy XXI 108-39	
Chevron 107-7	Energy XXI 108-41	
Energy XXI 108-5	Energy XXI 108-41ST1	
Energy XXI 108-6	Energy XXI 108-41ST2	
Energy XXI 108-8	Energy XXI 108-41ST2BP	
Energy XXI 108-9	Energy XXI 108-42	
Energy XXI 108-10	Energy XXI 108-42ST1	
Energy XXI 108-11	Energy XXI 108-43	
Energy XXI 108-12		



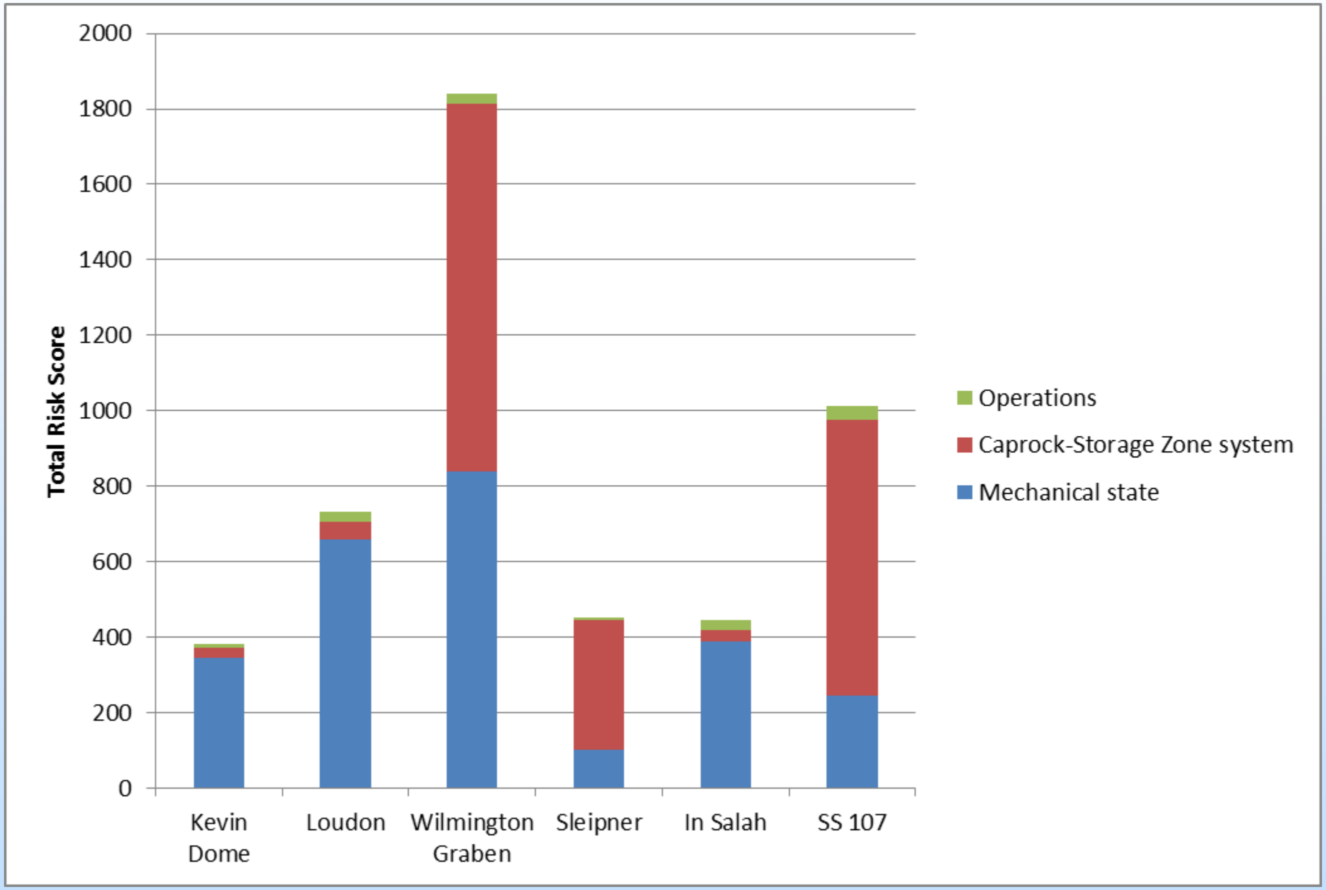
Good Integrity

Moderate Integrity



Technical Status

Risk Assessment and Characterization



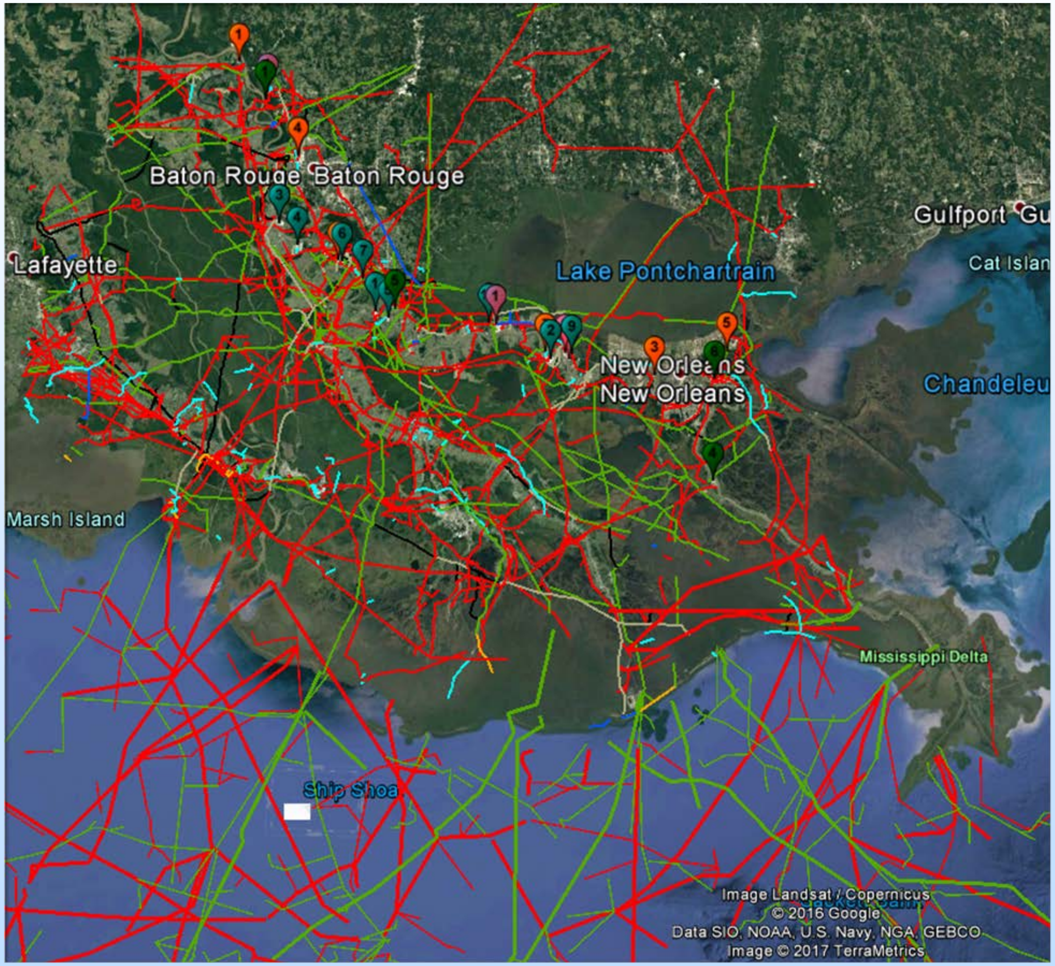
We completed a risk assessment on SS Block107 field considering 3 primary leakage mechanisms: tensile fracturing of the caprock, fault activation, and well damage. Will apply the same assessment to SS Block 84 field.

Technical Status

Analysis of Existing Infrastructure

Interactive map showing top 25 industrial sources and existing pipelines surrounding SS Block 107 field (shown as white square).

GeoMechanics Technologies will be adding this map to our website by mid-September 2017.



Technical Status

Analysis and Interpretation

Storage Capacity Estimation

NETL approved CO2 Storage Resource Estimate:

$$G_{CO2} = A_t h_g \emptyset_{tot} \rho E_{saline}$$

Using BOEM reservoir data, the existing oil/gas fields in northern Ship Shoal have the potential to store:

P10= 12 million tons,

P50= 47 million tons, and

P90= 127 million tons of CO2

Technical Status

Analysis and Interpretation

Estimated storage resource for the Pliocene and Miocene for SS Block 84 field based on BOEM depleted oil and gas reservoir data:

Low/P10	(metric tons)	Medium/P50	(metric tons)	High/P90	(metric tons)
Miocene	8.06E+04	Miocene	3.16E+05	Miocene	8.53E+05

Estimated storage resource for the Pliocene and Miocene for SS Block 84 field based on volumes derived from geologic modeling:

Low/P10	(metric tons)	Medium/P50	(metric tons)	High/P90	(metric tons)
Pliocene	1.33E+07	Pliocene	5.22E+07	Pliocene	1.41E+08
Miocene	4.72E+06	Miocene	1.85E+07	Miocene	5.00E+07

The estimated storage capacity results are greater when using the sand volumes derived through geologic modeling versus the BOEM depleted oil and gas reservoir data. Also, the storage capacity is underestimated for the Pliocene since there are no hydrocarbon reservoirs found within the Pliocene formations.

Technical Status

Analysis and Interpretation

Estimated storage resource for the Pliocene and Miocene for SS Block 107 field based on BOEM depleted oil and gas reservoir data:

Low/P10	(metric tons)	Medium/P50	(metric tons)	High/P90	(metric tons)
Pliocene	1.47E+05	Pliocene	5.78E+05	Pliocene	1.56E+06
Miocene	8.16E+04	Miocene	3.20E+05	Miocene	8.64E+05

Estimated storage resource for the Pliocene and Miocene for SS Block 107 field based on volumes derived from geologic modeling:

Low/P10	(metric tons)	Medium/P50	(metric tons)	High/P90	(metric tons)
Pliocene	1.56E+07	Pliocene	6.12E+07	Pliocene	1.65E+08
Miocene	2.44E+06	Miocene	9.56E+06	Miocene	2.58E+07

Again, the estimated storage capacity results are greater when using the sand volumes derived through geologic modeling versus the BOEM depleted oil and gas reservoir data. The difference is due to the depleted oil and gas reservoir data not accounting for the water-flooded sand located below the oil/gas-water contact. Using only the depleted reservoir information, a large quantity of the storage resource is missed. However, the sand volume obtained through geologic modeling may overestimate the storage capacity as the model accounts for all sand within the formation, not just the interconnected sand.

Accomplishments to Date

- Geologic data review completed.
- Geologic models for SS Block 84 and 107 fields developed and used as input for fluid flow modeling.
- Finalizing the injection and migration models to test various injection scenarios and confirm secure storage permanence.
- Completed baseline geomechanical modeling to determine the level of risk associated with large-scale CO2 injection at SS Block 84 and 107 fields.
- Finished a risk assessment for SS Block 107 field and will apply the same assessment to SS Block 84 field for comparison.
- Completed analysis of existing infrastructure of oil and gas for CO_2 transportation. An interactive map showing sources and pipelines will be added to our website.
- Estimated the storage resource for all oil and gas fields for the Ship Shoal Area based on BOEM reservoir data and the NETL calculation.
- Calculated and compared the estimated storage resource for the Pliocene and Miocene for SS Block 84 and 107 fields using volumes derived from modeling compared to the depleted oil and gas reservoir volumes.

Lessons Learned

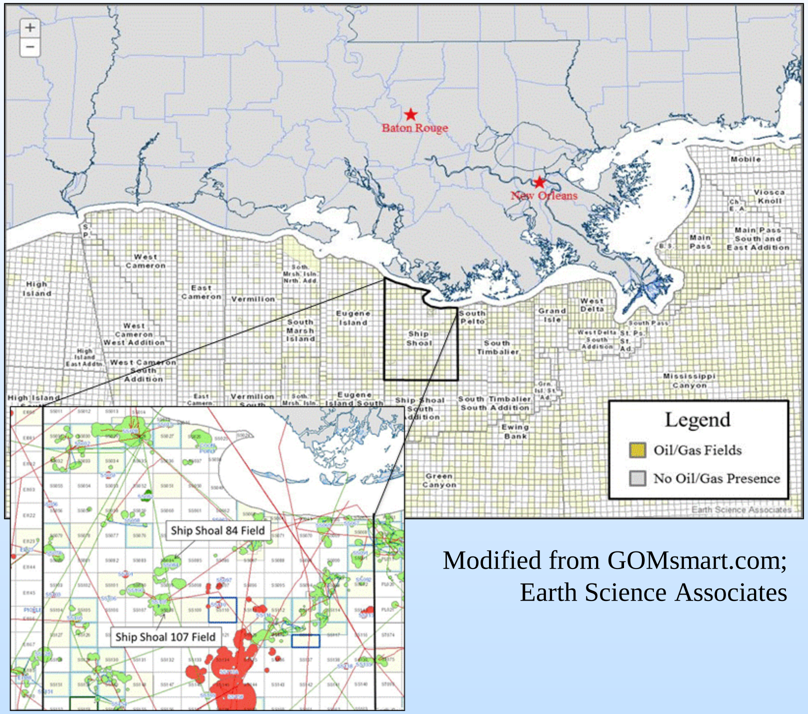
- We were able to obtain an NDA with BOEM to access structure maps produced by field operators for Ship Shoal oil and gas fields.
- BOEM and Pipelines and Hazardous Materials Safety Administration (PHMSA) were very helpful with providing excellent geologic and pipeline transportation data, respectively.
- We tested the use of polygon mesh versus rectangular mesh for fluid flow migration modeling, which reduced the number of cells thereby decreasing model run time without sacrificing accuracy.

Synergy Opportunities

Our work is complementary to the offshore Gulf of Mexico work performed by UT Austin and NITEC. A comparison of the estimated storage resource in depleted oil and natural gas reservoirs would be beneficial. Also, it would be interesting to learn how evaluating regional saline formations has increased the estimated storage capacity. Additionally, it would be important to review with them how our fluid flow and geomechanical modeling results have affected our capacity estimations.

Project Summary

- The Gulf of Mexico presents an excellent combination of high need and significant opportunity for large-scale geologic storage of CO_2.
- GeoMechanics Technologies is completing a detailed geological characterization and integrated fluid flow and geomechanics assessment of SS Block 84 and 107 fields to simulate long-term injectivity, migration, storage permanence and induced fault reactivation risk.
- Findings-to-date indicate high confidence that Pliocene and Miocene targets and seals are sufficient to store high volumes of CO_2 within the depleted oil and gas fields of the Ship Shoal area.



Modified from GOMsmart.com; Earth Science Associates

Appendix

- Benefit to the Program
- Project Overview
- Organization Chart
- Gantt Chart
- Bibliography

Benefit to the Program

<u>The anticipated benefits to the OSRA program of the proposed project include</u>:

- ❖ Providing a more extensive and detailed geologic review and analysis of the Ship Shoal Area in the northern GOM. The improved prediction of CO_2 storage capacity for this near-shore region may allow it to be considered as a potential commercial sequestration site by the 2025-2035 timeframe.
- ❖ The development and analysis of a combined CO_2 migration model and geomechanical simulation approach will allow for the evaluation of plume migration, induced stresses and potential fault reactivation due to CO_2 injection. The results of the modeling will be useful for the research community to inform, compare, and validate future CO_2 sequestration developments.

This project addresses program goals to estimate CO_2 storage capacity of the Ship Shoal area to within $\pm$30% accuracy and to ensure 99% storage permanence, ensuring containment effectiveness.

Project Overview
Goals and Objectives

The primary goals are to identify storage capacity in Plio-Miocene structural traps throughout the Ship Shoal Area and to determine the risks associated with high volume CO2 storage.

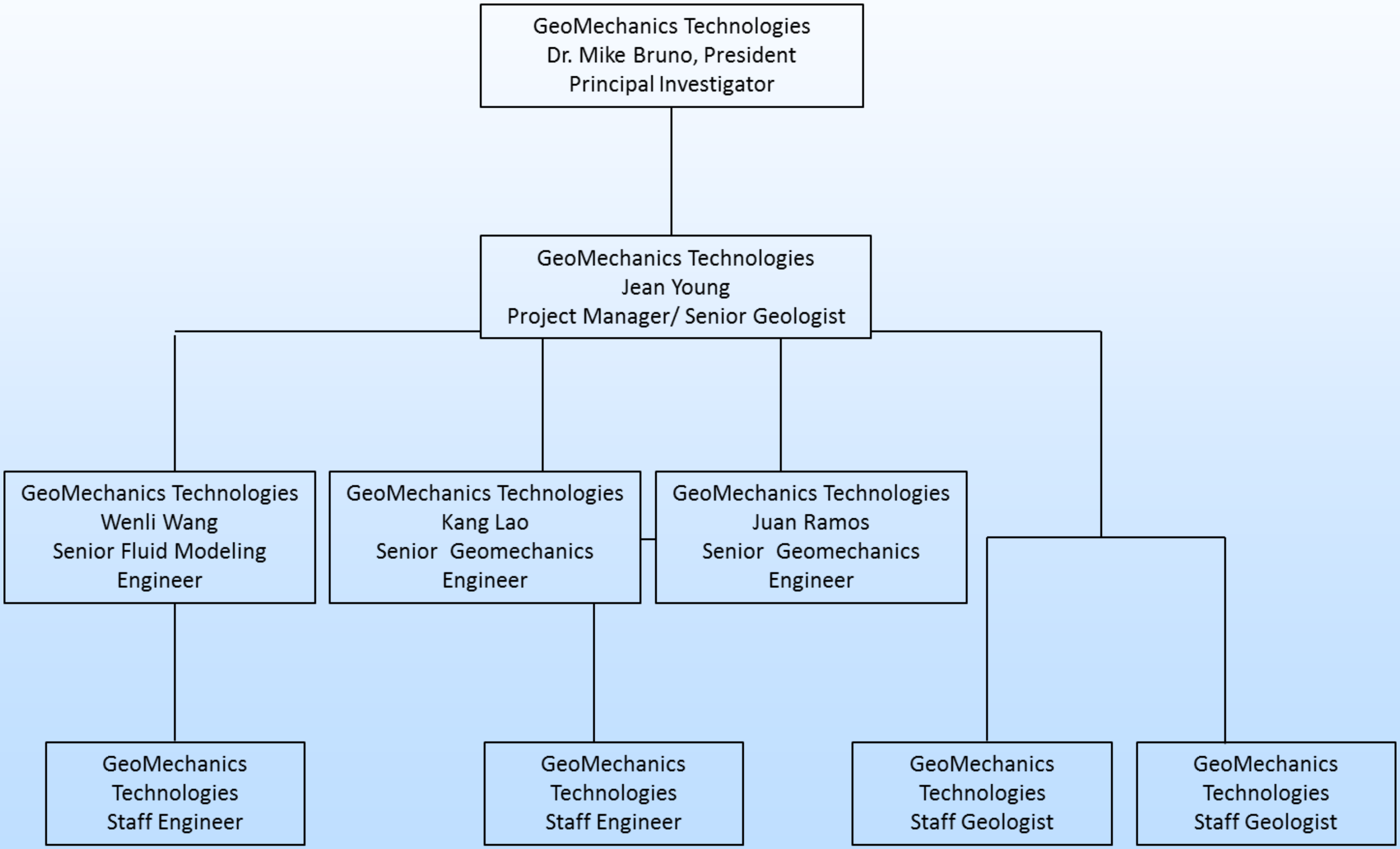
Phase I

- Geologic data review;
- Geologic modeling;
- Storage capacity estimation; and
- Preliminary risk assessment.

Phase II

- Fluid flow and geomechanical modeling;
- Risk assessment;
- CO2 transportation; and
- Refined storage capacity estimation.

Organization Chart



Gantt Chart

	Project Plan and Schedule															
	Period 1 (Year 1) 2015												Period 2 (Year 2) 2016			
Task Description & Milestones	1	2	3	4	5	6	7	8	9	10	11	12	Q1	Q2	Q3	Q4
Task 1. Project Mgmt & Planning																
Subtask 1.1: Kick off meetings and discussions with DOE																
Subtask 1.2: Update Project Management Plan																
Subtask 1.3: Project Coordination																
Task 2. Formation Evaluation							COMPLETED									
Task 3. Geologic Model Development												COMPLETED				
Go/No Go Decision														COMPLETED		
Task 4. CO2 Injection and Migration Modeling																
Subtask 4.1: Design and Assemble TOUGH2 CO2 Injection Model																
Subtask 4.2: Simulate Varying Injection Scenarios																
Task 5. Geomechanical Modeling																
Subtask 5.1: Develop Geomechanical model and Import Mechanical Properties																
Subtask 5.2: Simulate CO2 Injection to Estimate Induced Geomechanical Response																
Task 6: Risk Assessment and Characterization																
Task 7. Analysis of Existing Infrastructure of Oil and Gas for CO2 Transport																
Task 8: Storage Capacity Calculation																
Task 9. Reports, Documentation and Technology Transfer																

Milestone

Go/No Go Decision

*currently near the end of Period 2 (Year 2) requesting a six month no cost time extension.

Bibliography

- Lao, K., 2016, Assessment of CO_2 Storage Resources in Depleted Oil and Gas Fields in the Ship Shoal Area, Gulf of Mexico, International Workshop on Offshore Geologic CO_2 Storage, May 2016, Austin, Texas

- Bruno, M., White, N., Wang, W., Young, J., Lao, K., 2016, Assessment of CO_2 Storage Resources in Depleted Oil and Gas Fields in the Ship Shoal Area, Gulf of Mexico, Mastering the Subsurface Through Technology Innovation and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting, August 16-18, 2016, Pittsburgh, Pennsylvania

- Bruno, M., Young, J., Oliver, N., Wang, W., Xiang, J., Lao, K., Ramos, J., Diessl, J., 2017, Assessment of CO_2 Storage Resources in Depleted Oil and Gas Fields in the Ship Shoal Area, Gulf of Mexico, Carbon Management Technologies Conference, July 18-20, 2017, Houston, Texas