(ARRA Site Characterization) – Geologic Characterization of the Triassic Newark Basin of Southeastern New York and Northern New Jersey

(DE-FE0002352)

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U.S. Department of Energy

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Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

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- **Key Project Team Members:**

  Sandia Technologies, LLC; Conrad Geoscience/PVE-Scheffler, New York State Museum, Lamont Doherty Earth Observatory, Rutgers University, Schlumberger, Lawrence Berkeley National Laboratory

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Presentation Outline

- Project Benefits to the Program
- Project Overview - Objectives, Goals
- Project Accomplishments
- Technical Status
  - Shallow Core Hole Test Well at Lamont Doherty Earth Observatory
  - LBL Modeling Results
- Summary
  - Key Findings, Lessons Learned
- Future Plans
  - Final Data Integration

Benefit to the Program

- Program Goals
  - Provide geologic characterization of potential reservoir storage and confining formations in the Northern Newark Basin

- Project Benefit Statement
  - Evaluate and assess CO_2 storage and reservoir capacity in the under-explored Newark Basin in the northeast U.S. corridor

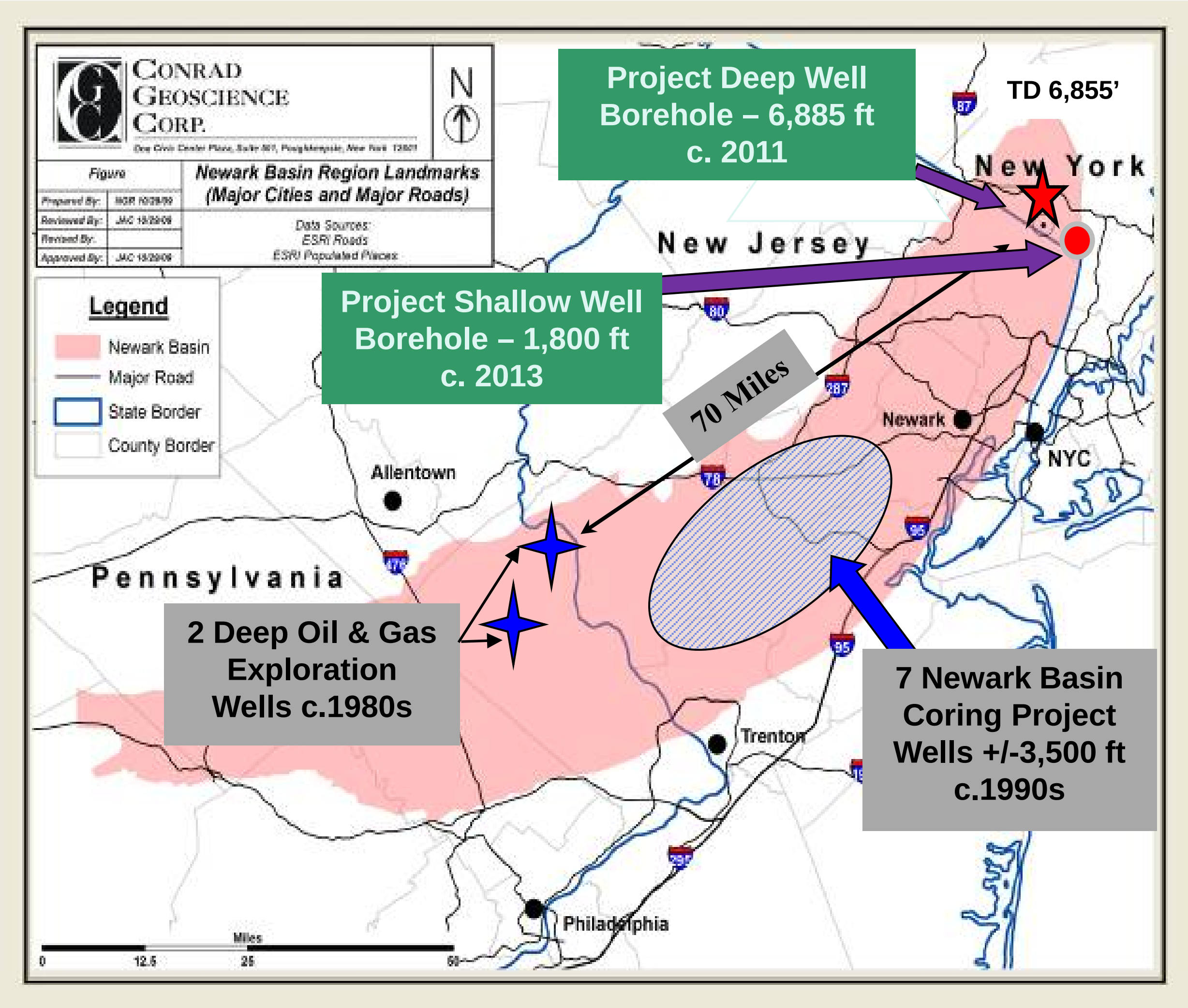
Project Overview:
Goals and Objectives

- **<u>Primary Objective</u> -** Demonstrate that geologic sequestration of CO_2 can offer an effective and viable large-scale mitigation approach to managing greenhouse gas emissions from industrial sources in the northeastern United States

- **<u>Sub-objectives:</u>**
  - **Identify presence/absence of commercial scale reservoirs in the northern end of the basin.**
  - **Identify presence of appropriate confining zone(s) and cap rock layers.**
  - **Evaluate geo-mechanics of potential injection scenarios.**
  - **Characterize hydro-geologic regime of the sedimentary section.**
  - **Perform laboratory based kinetics work and reactive/flow modeling of potential injection scenarios.**

- As an ARRA project, goal was to spur or create the basis for meaningful near-term and long-term employment, building and initiating a foundation for a CCS industry using the Newark Basin geologic formations

Under-Explored Newark Basin



- Newark Basin stretches from Rockland County, New York, southwest across northern New Jersey, and into southeastern Pennsylvania (140 miles long x 32 miles wide)
- Geographic extent ~ 2,700 square miles
- Close proximity to large population areas and a heavily industrialized section of the country (28 MM tons/year CO_2 in closest NY/NJ counties)
- Deep well offsets (mid 1980s) are more than 70 miles away – oil and gas exploration
- Newark Basin Coring Project 7 wells (1990s), central New Jersey ~3,500 ft deep – chrono-stratigraphic focus, only 1 Stockton Fm Well

2-D Seismic Acquisition NYS Thruway, Garden State Pkwy

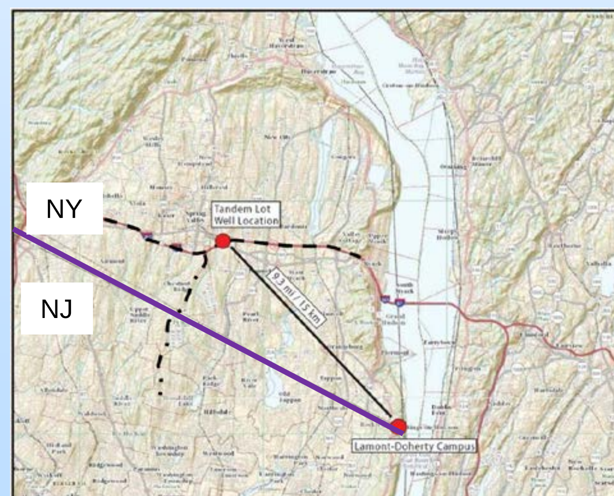
6:30 PM – 6:30 AM one lane shut down for Vibroseis Party
Up to 200,000 Cars per day

'Night Shift'

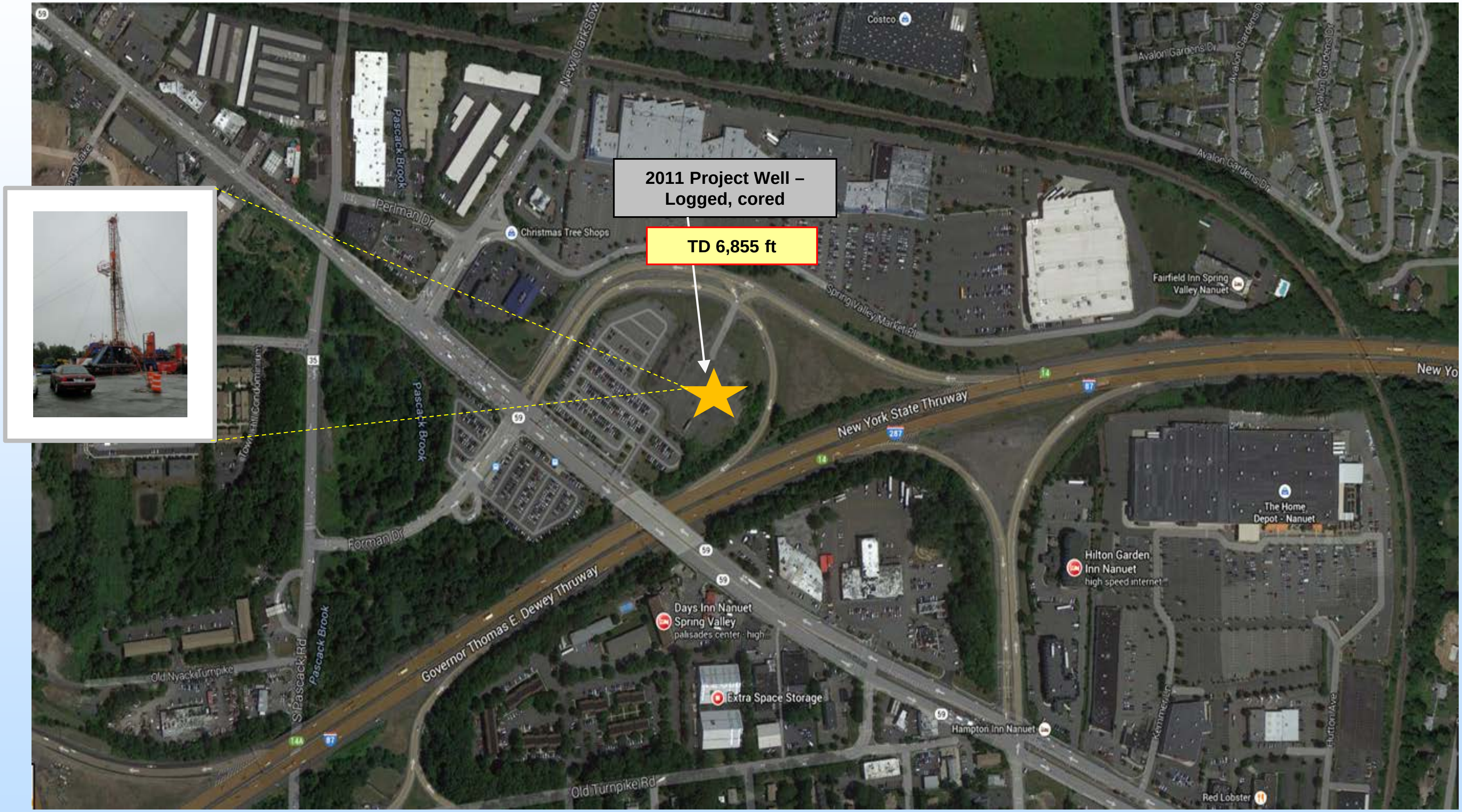
Traffic Control
NYS Troopers

We thank the following for their Courage, Cooperation and Assistance in permitting and access to roadways & shoulder.

~22 miles
Seismic Data

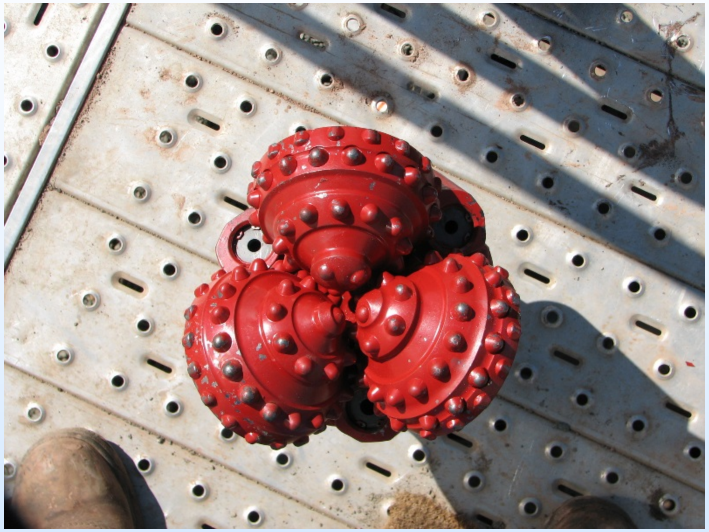


Aerial Photo of NYSTA 1-Tandem Lot Location

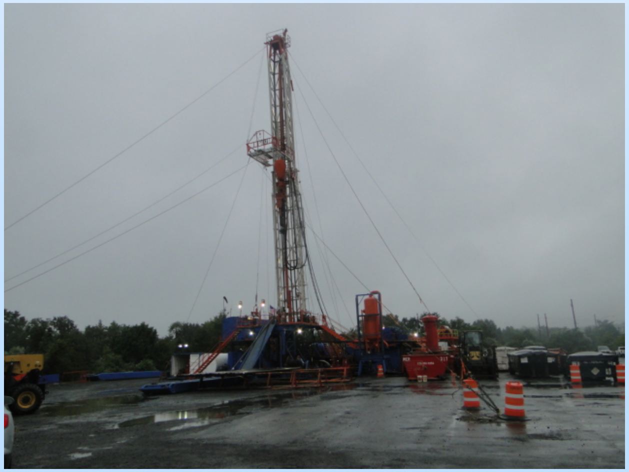


Drilling to 6855 feet at Exit 14-W

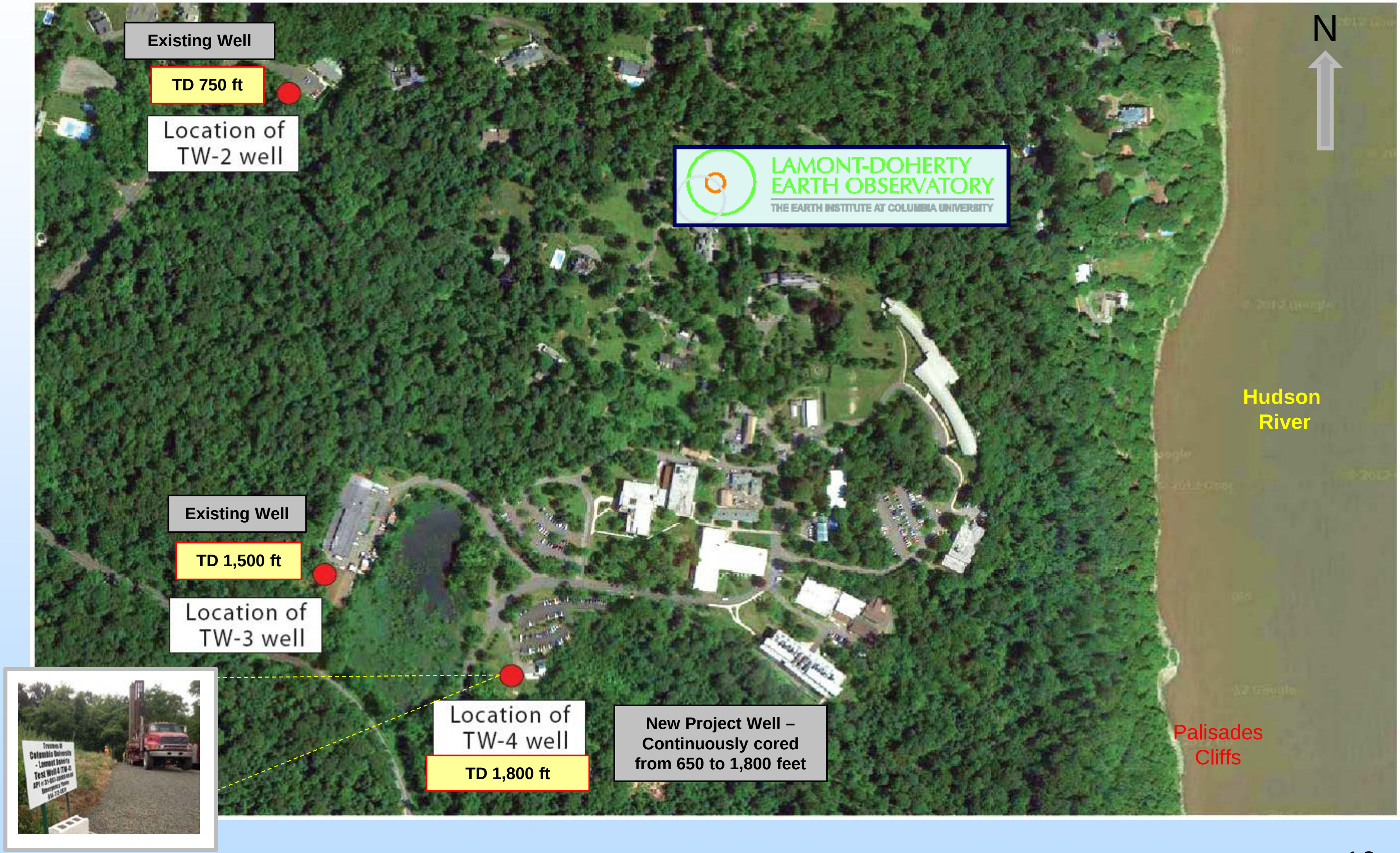
Factory 'Fresh' Drill Bit



'Spent' Drill Bit 48 hrs



Aerial Photo of Lamont Doherty Earth Observatory

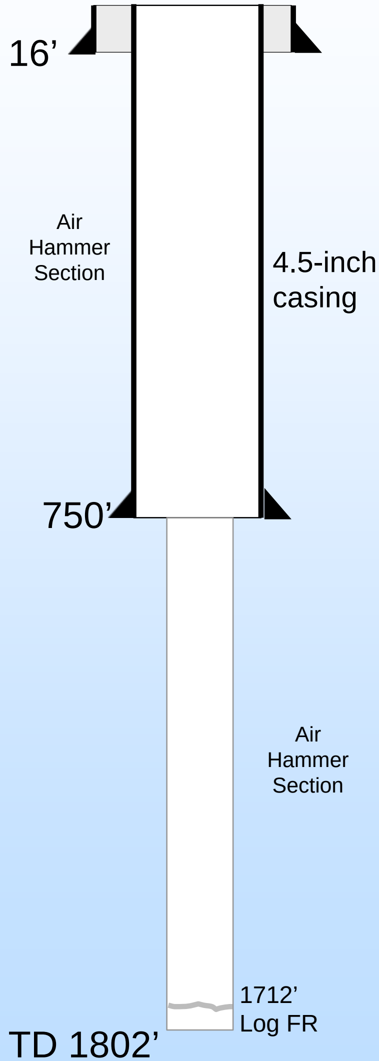


Technical Status

- Second well, TW-4, drilled on Lamont Campus to 1,802 ft, to apparent basement, cored from 600 – TD, logged to 1,712 ft
- Logged offset well TW-3 (TD 1,500 ft) with slim hole tools
- Performed Data Integration – Schlumberger ELAN Log analysis, elemental/mineralogy data on TW-3 and TW-4 wells
- Ran Core Analysis, performed routine and mercury injection capillary pressure specialized data
- LBNL Results
  - Experimental & Numerical Modeling Activities
  - Basin Scale Model for CO_2 Flow
  - Plume and Pressure Model Simulations
  - Geochemical Reaction Modeling
  - Mineralization Predictions

BERKELEY LAB

Shallow Core Hole TW-4 Well –
Air Hammer & Mineral Core Rigs



- Short Conductor Casing set to 16 feet
- **<u>Air Hammer Hole:</u>** A 6-1/8-inch diameter borehole was air hammered to 650 feet between July 15-18 with max penetration rate of 300 feet per day (day-light only). Drill cuttings samples collected by LDEO Staff from surface to 650 feet
- **<u>Coring:</u>** from 650-750 feet, 100 feet of SQ Core (4-inch diameter) from lower Palisades Sill through transition zone into the sedimentary section (set surface casing) and 1,050 feet of HQ Core (2.5-inch diameter) core collected to 1,800 feet basement (>95% recovery)
- **<u>Logging</u>**: Schlumberger Slim-hole tool logging program and RST run for lithology
- **<u>Logging of TW-3</u>**: Larger diameter tools run in existing TW-3 well (Sonic Scanner, CMR, Elemental Capture Sonde, etc.)

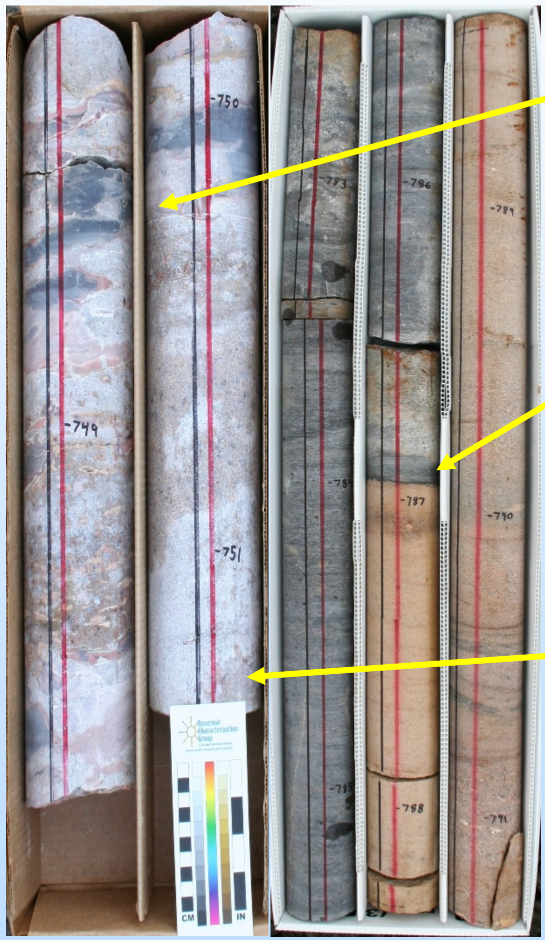
TW-4 Well Shallow Core Hole– Mineral Rig Coring

TW-4 Well Cores (upper borehole)

Base of Palisades Sill
& Meta-Sediment Zone

Lockatong Fm

SQ 4-in core



Altered
Meta-sediments
725-780 ft

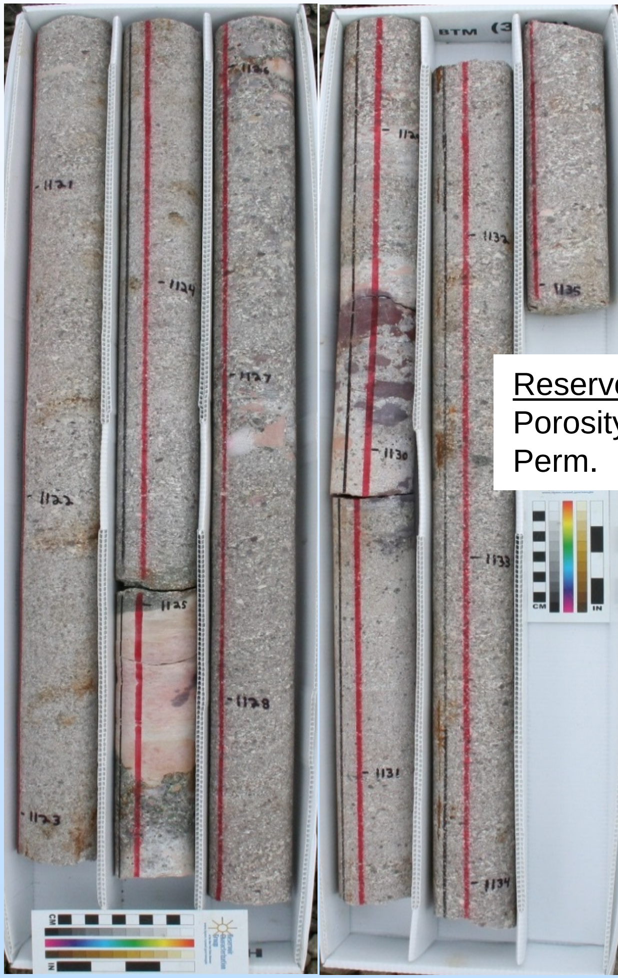
Lake sediments, red-beds
playa silts
787 ft

Base of Meta-sediments
at ~ 751 ft.

HQ 2.5-in core

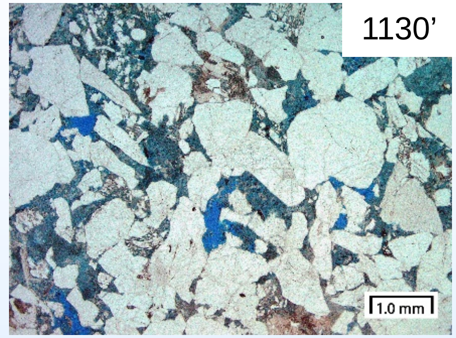
TW-4 Well Cores (lower borehole)

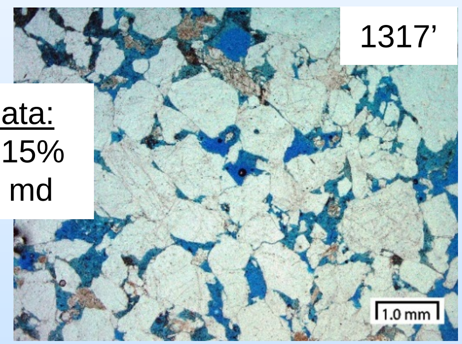
Stockton Fm

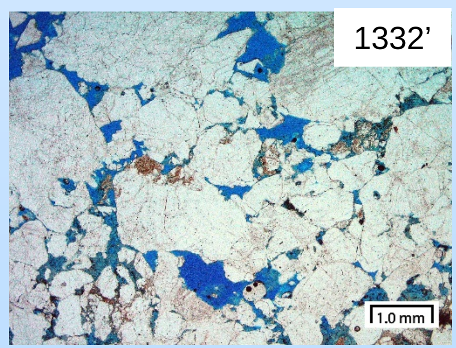


Reservoir Data:
Porosity 11-15%
Perm. 1-50 md

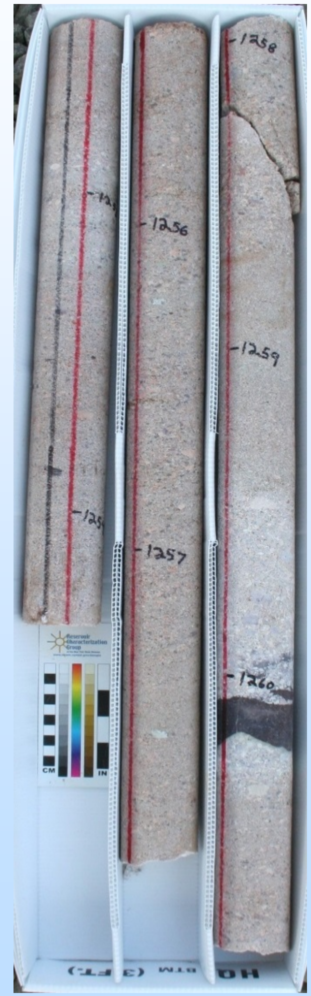
Thin Sections

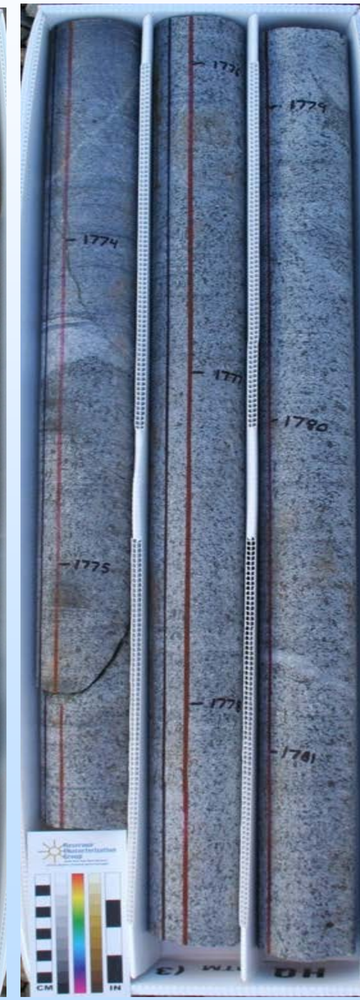






Granitic Basement





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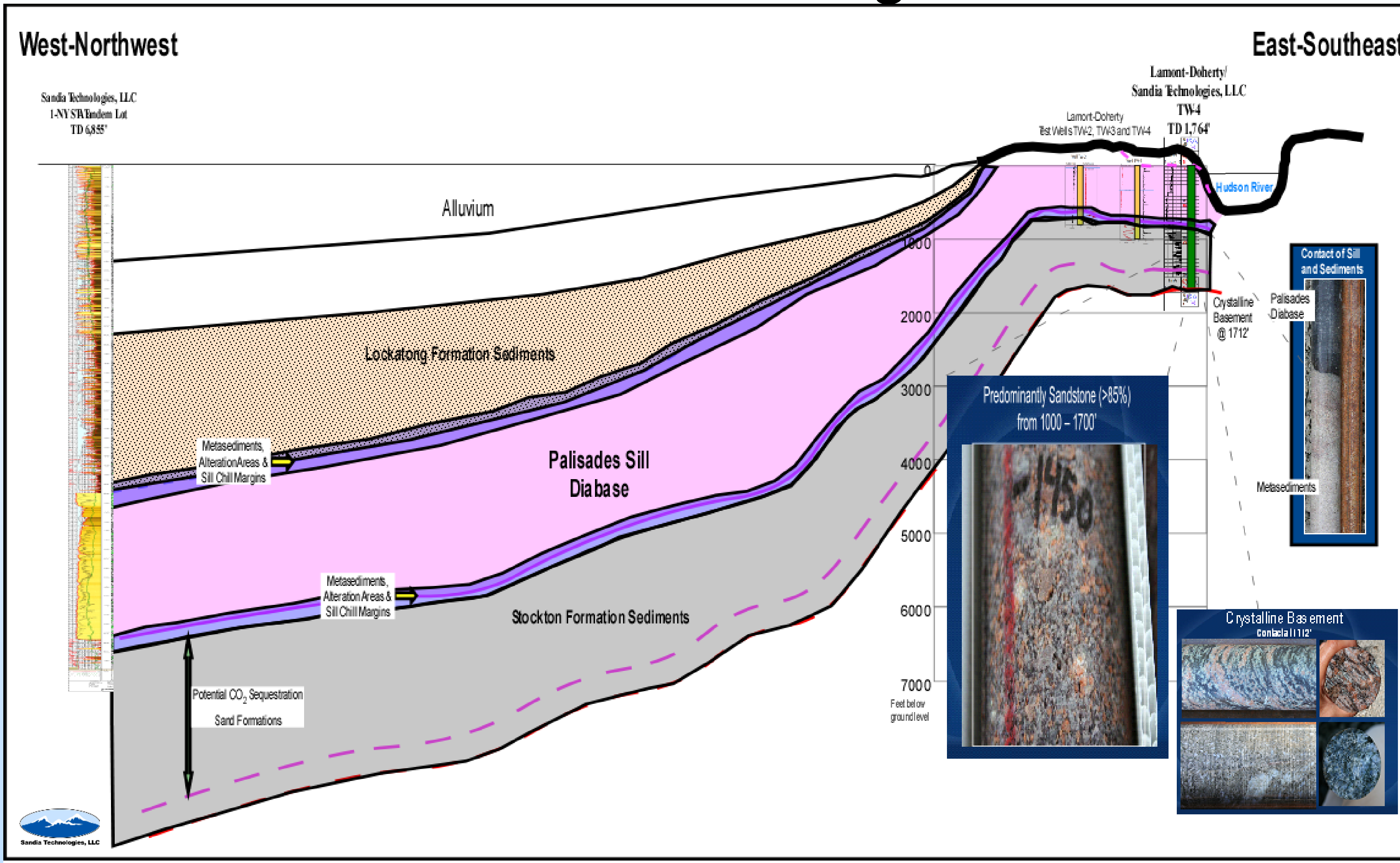
NYS M NEW YORK State Museum

Generalized W-E Geologic Section



Depiction of Stratigraphy in Northern Portion of Newark Basin from Project Test Wells

Experimental and Numerical Modeling Activities for the Newark Basin

- Objectives
  - Preliminary assessment of suitability of potential reservoirs for storage of significant quantities of CO_2 within the Newark Basin
  - Performed laboratory experiments to assess the rate of dissolution of CO_2 in formation brine and rate of mineralization
  - Performed reactive transport modeling to predict the fate of the injected CO_2 plume based on available site characterization data and laboratory geochemical observations.

- Approach
  - Reactive transport modeling
    - ECO2N module (Pruess and Spycher, 2007) of the TOUGHREACT (Xu et al., 2012) geochemical transport simulator
  - Basin-scale flow and CO_2 transport simulations
    - Assess fate of the injected CO_2 plume, e.g., estimation of the plume shape and
    - Expected migration distance; prediction of expected pressure buildup and injectivity.
  - Geochemical simulations without transport
    - Determine likely reaction pathways between formation water, sediments, and injected CO_2, with complex reactive transport simulations assessing impact of geochemical reactions on CO_2 plume migration

Basin-Scale Model for CO_2 Flow in Newark Basin

- A 3D Basin-scale 'Simple' model developed, predicting extent of plume migration.
  - A Model domain 16 km in the x-direction, 8 km in y-direction (due to symmetry).
  - Assume Injection formation was 150 m thick, with injection in the lower 60 m.
  - Initial Model domain design guided by analytical solutions from the literature and modelers.

- The Numerical grid was refined near the injection well
  - A Model domain 16 km in the x-direction, 8 km in y-direction (due to symmetry).
  - Grid coarsened laterally, Grid size = 57,600 blocks.

- The two side boundaries of the model domain were open to flow, all other boundaries, including the top and bottom boundaries, were no-flow.
  - Initial pressure distribution was hydrostatic; isothermal conditions were assumed.
  - Presence of salt was ignored

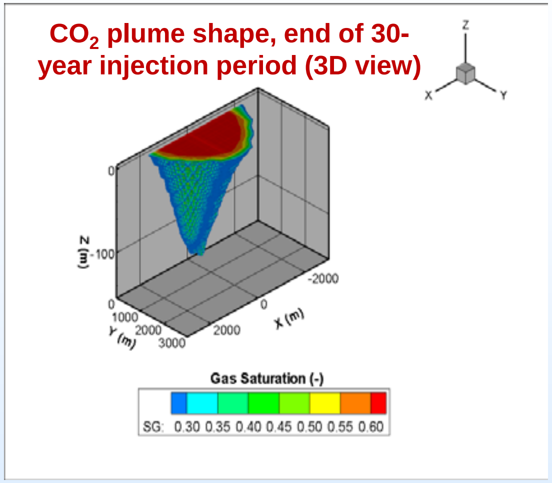
- A Base case hydrologic property set was developed based on core samples obtained from the Tandem Lot Well No. 1.
  - Flow and transport simulations were initially performed with Base case properties.

- Sensitivity of predictions
  - Parameters were varied by changing values in the Base case properties, one at a time.

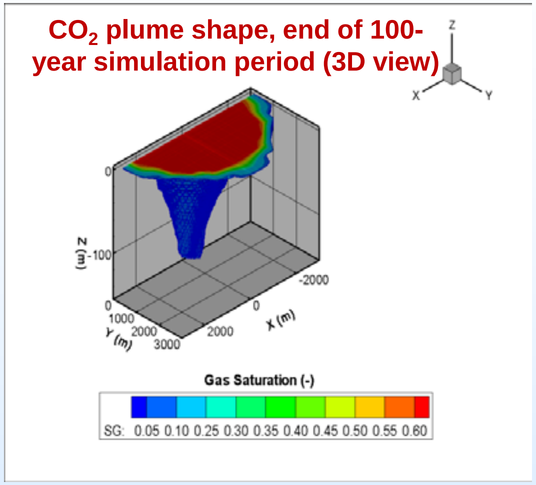
- A 30 year injection period, followed by a 70 year observation period, was simulated.

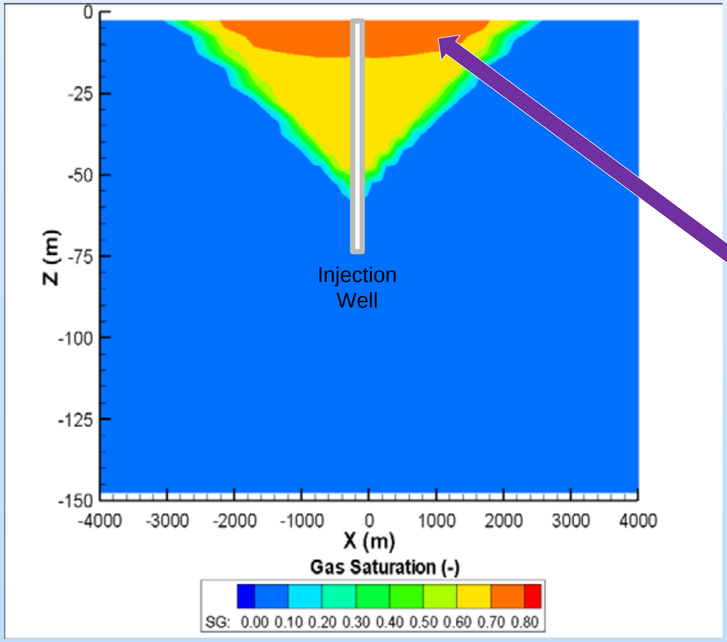
Plume Model Results for CO_2 Flow in Newark Basin

Post-30-yr injection, predicted plume migration ~2,000 m



Post-100-yr injection, predicted plume migration ~3,000 m

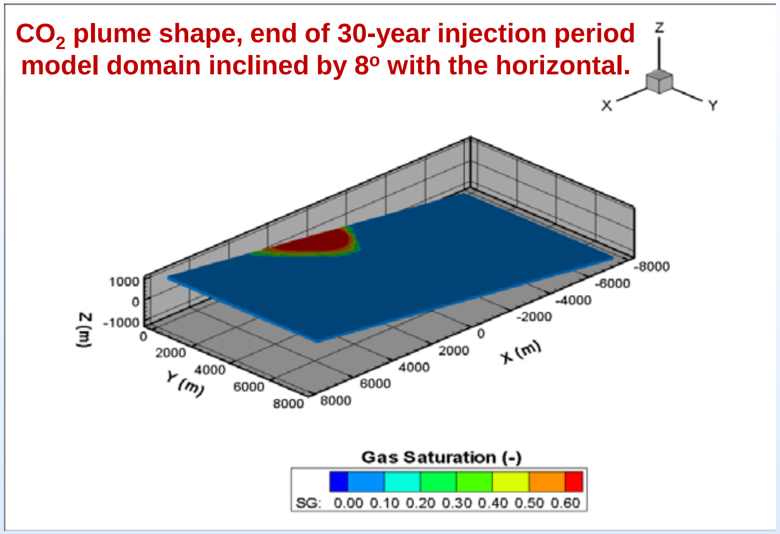


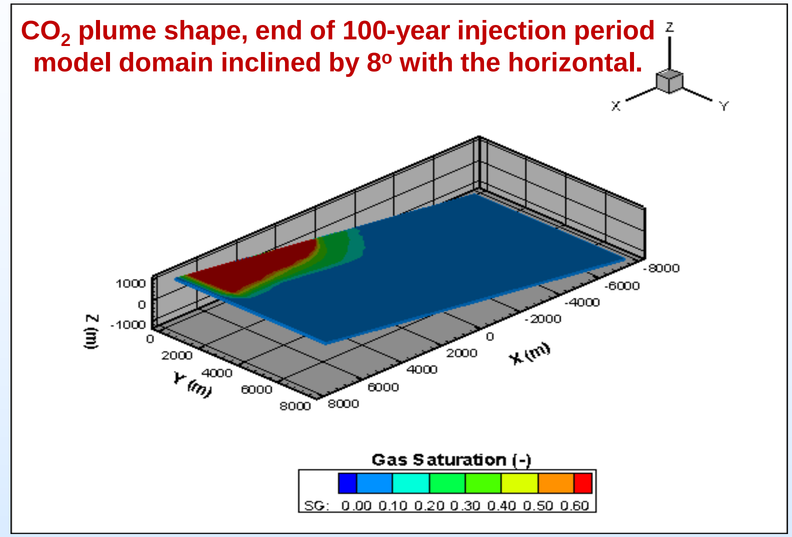


Vertical cross-section of CO_2 plume shape, end of 100 years (2D view)

Model predicted buoyancy effect showing highest CO_2 plume saturations localized in upper 10-15 m of 50 m injection interval

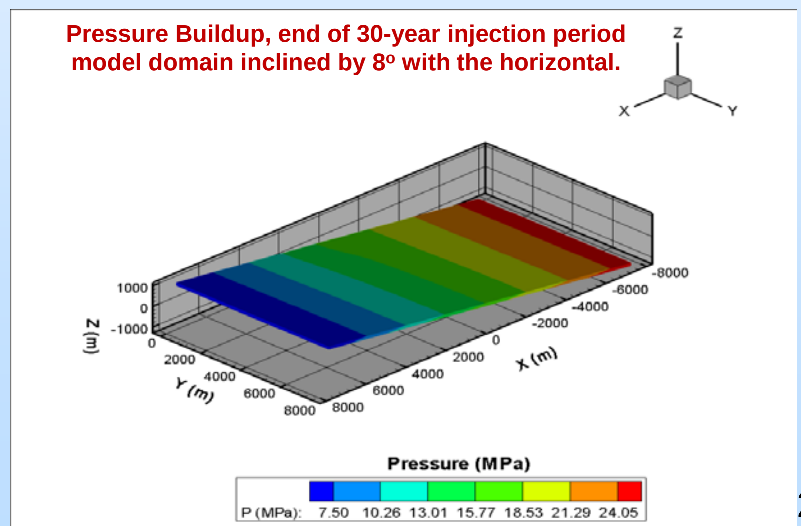
Plume Drift Model Results for CO_2 Flow in Newark Basin





Results

- Geologic formation dip (tilt) has a significant impact on plume shape and location
- Model domain tilt (dip) by 8º, plume extent in excess of 6,000 m in the up-gradient direction at the end of the 100-year observation period.
- Migration in the down-gradient direction is limited



Mineral Reaction Model Results for CO_2 Flow in Newark Basin

- Reactive transport modeling performed using 2D radial model and inclined Cartesian (x-y) model
- pH -- predicted to drop to values near 5.0 within most of the two-phase region *(Figure 1)*
- Most reactive primary minerals are predicted to be plagioclase and Fe-chlorite.
- Calcite is predicted to dissolve throughout the two-phase plume. Anhydrite precipitates from calcite dissolution. Fe-chlorite dissolves resulting in the precipitation of ankerite and kaolinite.
- Overall, these reactions result in a very small volume increase, resulting in a maximum absolute porosity drop of only about 0.3 % *(Figure 2)*
- Formation inclination does not alter the geochemical transport predictions in any significant way, although plume migrates much farther up-gradient

CO_2 Saturation & pH

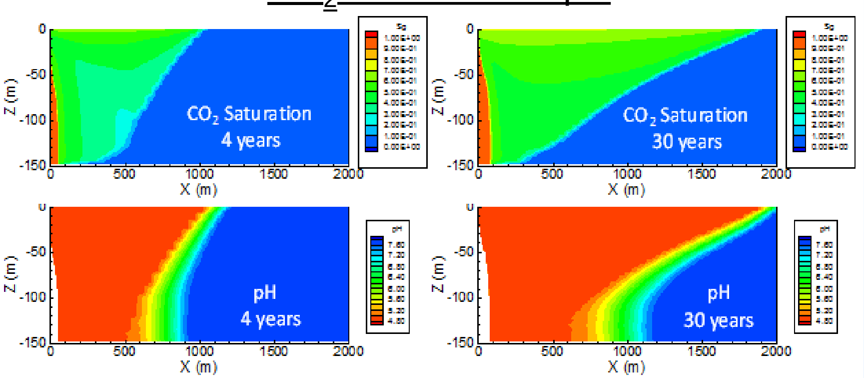


Figure 1. Predicted CO_2 saturation and plume pH after 4 and 30 years of injection. Simulations performed with 2D radial model including reactive transport

Mineralization & Reactions

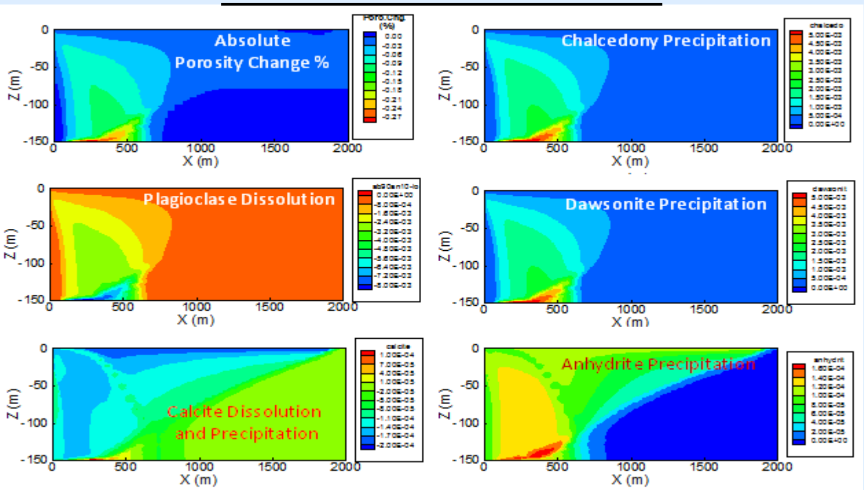


Figure 2. Predicted absolute porosity change (computed porosity - initial porosity, in percent) and computed volume fraction change of main dissolving and precipitating minerals after 30 years.

Other Observations/Predictions

- Approximately 85% of the injected CO_2 exists as a free gas phase, even after 100 years since injection started, with remaining 15% is dissolved in water.
  - Implications -- takes a long (very long) time to completely dissolve the injected CO_2 in formation brine.
  - Mineralization and reactions are predicted to be extremely slow.

- The Base case simulations performed with low values of residual gas saturation (S_{gr} = 0.01) to conservatively estimate plume migration distance.
  - An increased S_{gr} of 0.2 (a more realistic value), ~73% of the injected CO_2 remains in the gas phase after 100 years.

- Increasing S_{gr} has no noticeable impact on extent of geochemical reactions.

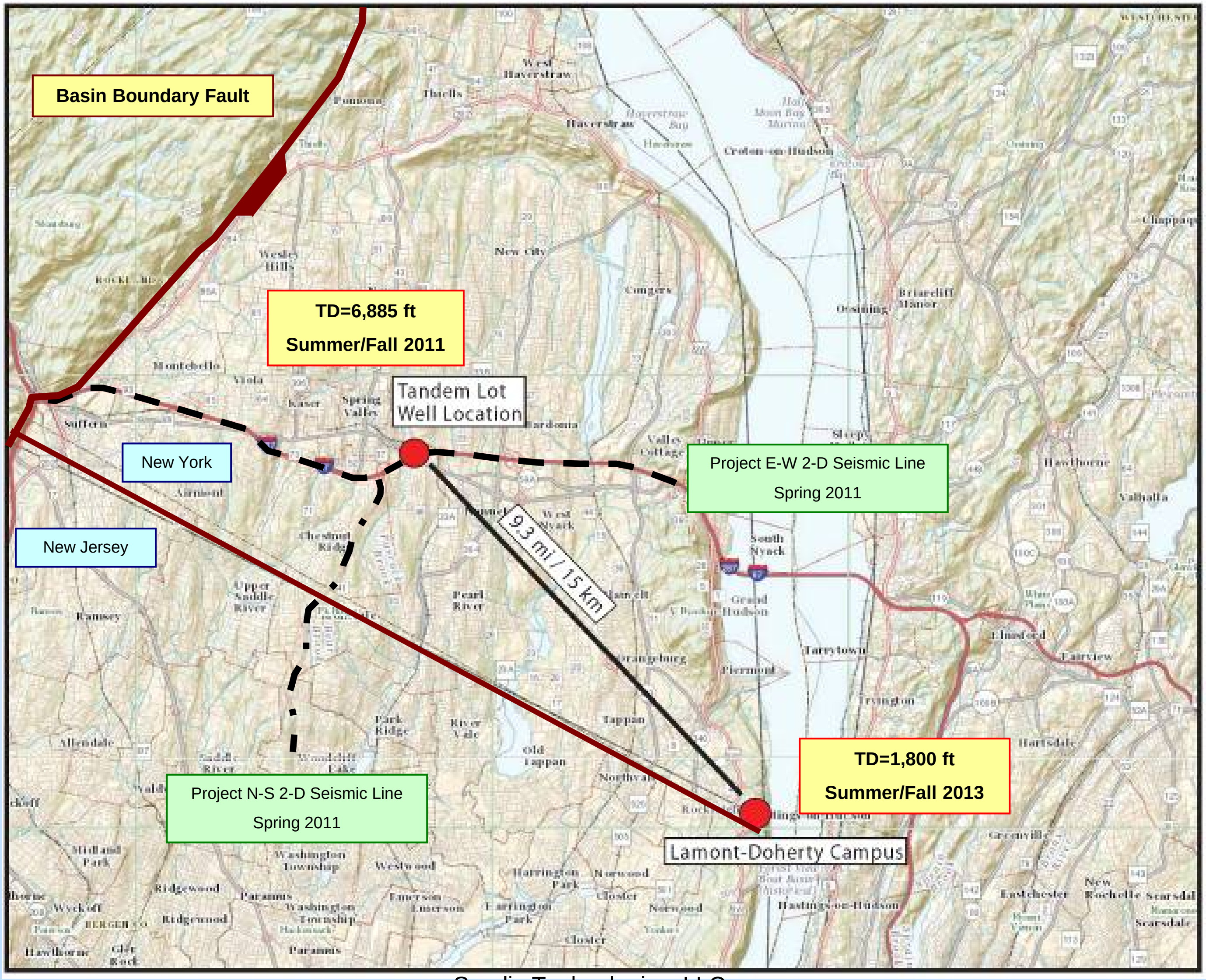
- Base case simulations run with homogeneous formation properties used mean permeability of 50 mD.
  - Real world expectations are that vertical permeability will be considerably smaller than horizontal permeability.
  - When the vertical permeability is reduced by an order of magnitude (i.e., anisotropy ratio = 0.1), the up-gradient plume migration distance is predicted to be ~5,000 m after 100 years (angle of inclination 8^o), considerably smaller than the Base case predictions.

- Pressure buildup values of > 8 Mpa was observed near the injection well for Base case simulations.
  - Values can be even greater if salt precipitation is included and/or formation permeability is lower. This can have significant consequences for injectivity and formation integrity.

Accomplishments to Date

- Cut new whole and rotary core plug analyses, with baseline review of earlier Newark Basin cores – ***Completed Summer 2010***
- Acquisition, processing and interpretation of high resolution 2-D Seismic lines, W-E Line 101 12.3 miles; N-S Line 201 8.6 miles (New York State Thruway, Garden State Parkway ROWs) and integration of site Vertical Seismic Profile (VSP) data – ***Completed March-June 2011***
- Drilling, coring, & logging of a deep NYSTA Exit 14 Well (6,885 ft) stratigraphic test boring – ***Completed July-October 2011***
- Completed extensive routine, advanced whole, rotary core plug analyses and fluid analyses from NYSTA Exit 14 Well – ***Completed Spring 2013***
- Drilled and cored LDEO Shallow Core Hole (TW-4) through sedimentary section (+/-1,712 feet) – ***Completed September 2013***
- Completed routine, advanced whole, rotary core plug analyses & calibrated ELAN Log analyses (TW-4 and TW-3) – ***Completed June 2014***
- LBNL completed reactive and kinetics experiments and modeling runs using basin core data and materials – ***Completed June 2014***
- Integration of previous Newark Basin well data with NYSTA well and data TW-4, TW-3 logs using ELAN Log analysis and core description – ***Completed August 2014***
- Database of wellbores in Newark Basin ***-- to be completed August 2014***
- ***Final report to be completed October 1, 2014***

Newark Basin Project Major Field Accomplishments – 2 D Seismic Lines & Characterization Well Locations



Summary – Key Findings (1)

Tandem Lot 6855' Well

- At the deep test well location, sandstone development decreases with depth, however, three shallower Reservoir Flow Units are identified (Unit 1 ~2,100 to 2,500 ft, Unit 2 ~ 2,800 – 3,200 ft, Unit 3 ~ 3,650 – 4,250 ft) – limited sandstone development below 4,250 feet due to Sill
- Measured formation pressures indicate a freshwater gradient, placing the supercritical CO_2 window below a depth of 2,500 feet
- Recovered MDT Formation water samples from 3,058 feet in deep well indicate brackish waters only (<10,000 ppm NaCl) i.e. flow units classified as "underground source of drinking water".
- Deep test well confirmed presence of abundant lithified, low permeability mudstones/siltstones that can act as confining caprock layers. Minifrac testing of confining intervals were run up to tool limits of +/-5,500 psi (3,055 feet and 3,510 feet) without formation breakdown, indicating >1.55 psi/ft fracture pressure.
- Additional potential trapping mechanism occurs where flow units are cross-cut by the Palisades Sill
- Intra-basin faulting may add more potential localized reservoir traps

Summary – Key Findings (2)

<u>LDEO TW-4 1802' well</u>

- Normal faulting observed from Seismic lines across Palisades Sill and beneath in apparent Stockton Sand bedding and potential flow unit layers.
- At TW-4 well, most of formation units (beneath the Sill) from 1100 – 1700 feet consisted of 85% sand, with coarse grains, and matrix cement;
- ELAN log analysis of TW-4 and TW-3 indicate multiple Stockton Sand reservoirs with hundreds of feet of thickness, porosity values ranging from 11 – 16%, and core and ELAN permeability ranging from 1-50 md
- Core analysis corroborates findings of thick sections of Stockton Sand with reservoir porosity values obtained of 10-17% and average of 15 md in developed sands
- Porosity, permeability influence by Palisades Sill effects and rifting
- Deeper Basin sediments will exhibit more reservoir quality and thicker section
- Mineral core HQ, SQ diameters can provide good reasonable cost options for obtaining core samples

Summary – Lessons Learned

- Local Rule -- County regulatory concerns/requirements trump (may not agree) with state Permit requirements
  - May result in increased well construction costs, i.e. local request for additional surface casing
- Research Field Work can be accomplished in an urban-suburban “developed” setting
  - However, costs will be higher than budgeted, i.e. seismic on NYS Thruway, permitting charges, traffic, access
- Early Public Outreach effort smoothed project ‘bumps’
  - Efforts to local Rockland Co., NY officials helped facilitate educational outreach to key stakeholders and wider public
- Northern end of the basin is more complex than originally anticipated
  - Intra-basin faulting, igneous dikes and sills, and altered metasediments above and below the Palisades Sill
- Palisades Sill was thicker than estimated (+/-1,575 feet) in deep well
  - Halo zones of meta-sediments, altered intervals above-below diabase.
- Defined Potential Reservoir Flow zones
  - Indicated from Logs, Cores, MDT fluids, integrated ELAN analyses
- Integrated Seismic-Geologic structure, thickness information show effect of the sill on sediments, faulting, thinning
  - Intrusions, dikes, Faulting, discontinuity have reduced reservoir quality, destroyed it in places
- Deeper wedges of “sediments” are likely present to 13,500 feet in southern NY
  - Potential sediment wedge of remnant Paleozoic formations may be present
- Fresh water connate fluids in upper Basin area formations will get more saline with depth in NJ
  - Unknown of reservoir continuity or sand quality can extend to central NJ, among Newark Basin Coring Wells

Summary – Future Plans

- Final DOE Project report and NATCARB data integration complete by September 30, 2014.
- Continue to work with researchers on Newark Basin to supply data, respond to inquiries.

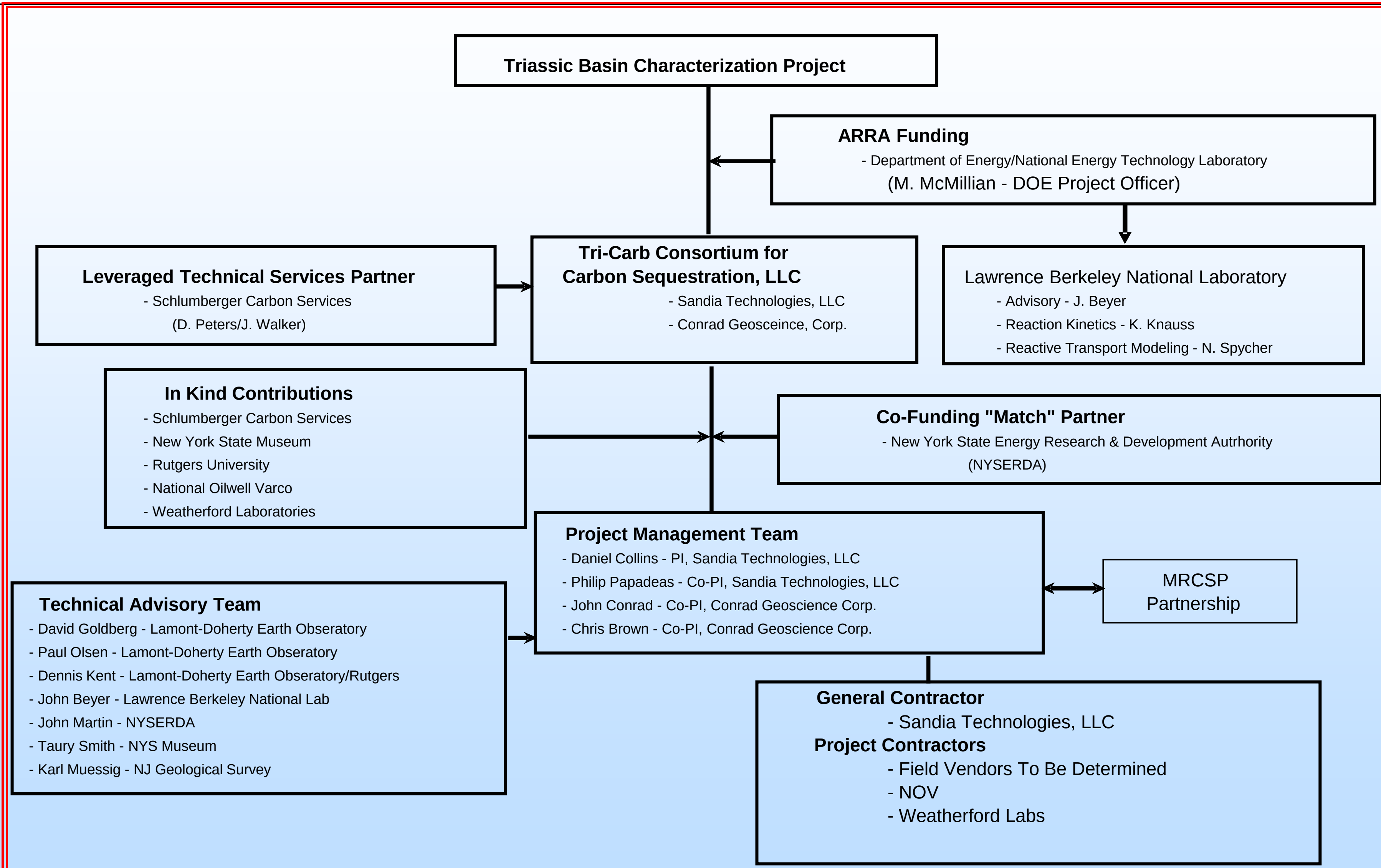
- *New Award:*
  - DE-FE0023334 – Geomechanics of Mesozoic Basins: Applications to Geosequestration

Questions?

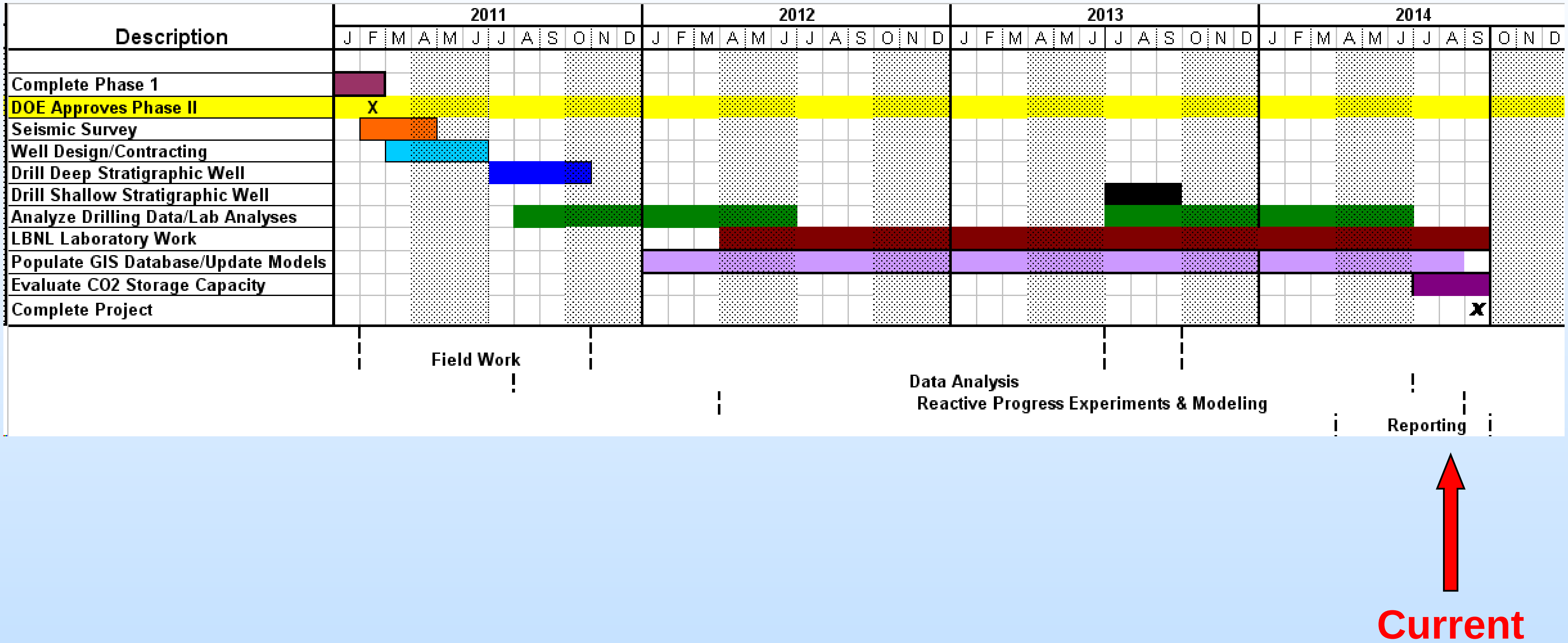
Appendix

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

Organization Chart-UPDATE



Gantt Chart


Description
2011
2012
2013
2014
J F M A M J J A S O N D
Complete Phase 1
DOE Approves Phase II
X
Seismic Survey
Well Design/Contracting
Drill Deep Stratigraphic Well
Drill Shallow Stratigraphic Well
Analyze Drilling Data/Lab Analyses
LBNL Laboratory Work
Populate GIS Database/Update Models
Evaluate CO2 Storage Capacity
Complete Project
X
Field Work
Data Analysis
Reactive Progress Experiments & Modeling
Reporting
Current

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