# SECARB Phase III ANTHROPOGENIC TEST:

## Risk Management through Detailed Geologic Characterization and Modeling

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## SECARB Stakeholders' Briefing

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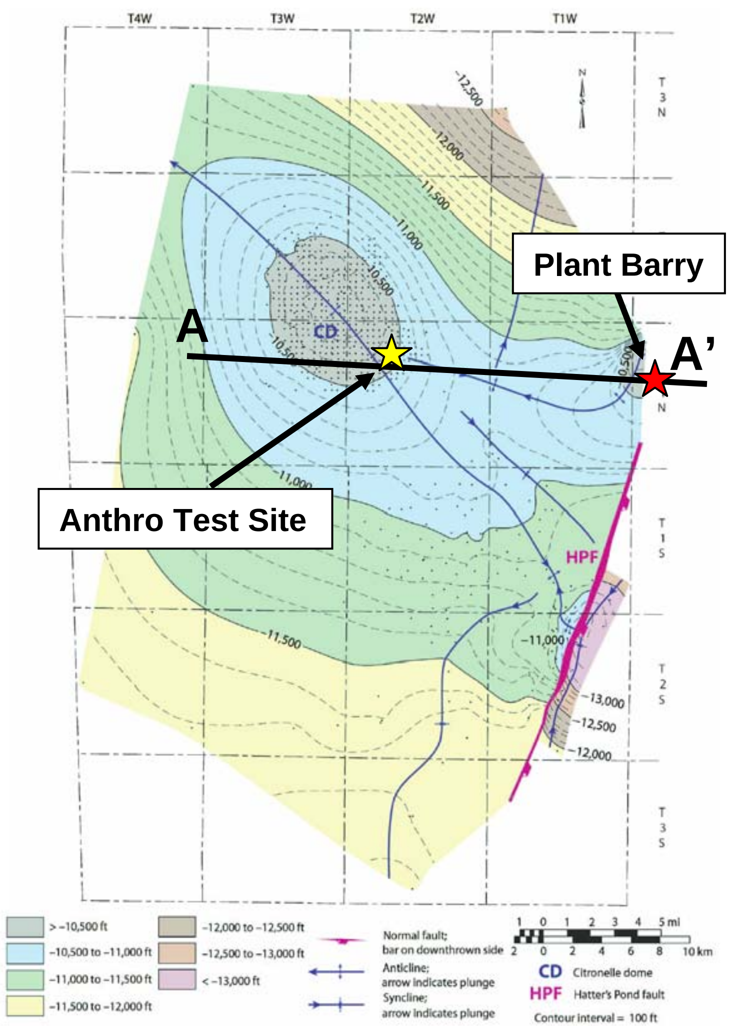
# How Do We Address Storage Risks (prior to drilling a well)?

1. **Storage permanence**
   - Select a site with 4-way geologic closure (i.e. structural trap)
   - Multiple confining units and secondary storage compartments
2. **Adequate reservoir injectivity and storage capacity**
   - Conduct detailed reservoir characterization using existing log and core data
   - Reservoir simulation
3. **Existing wellbore leakage risk**
   - Survey of existing deep penetrations in the project area
   - Working relationship with existing well operator(s)
4. **New wellbore leakage risk**
   - Construct project wells to underground injection control (UIC) Class I non-hazardous standards

Structural Contour Map of the Top of the Rodessa Formation




*Source: Esposito et al., 2008*

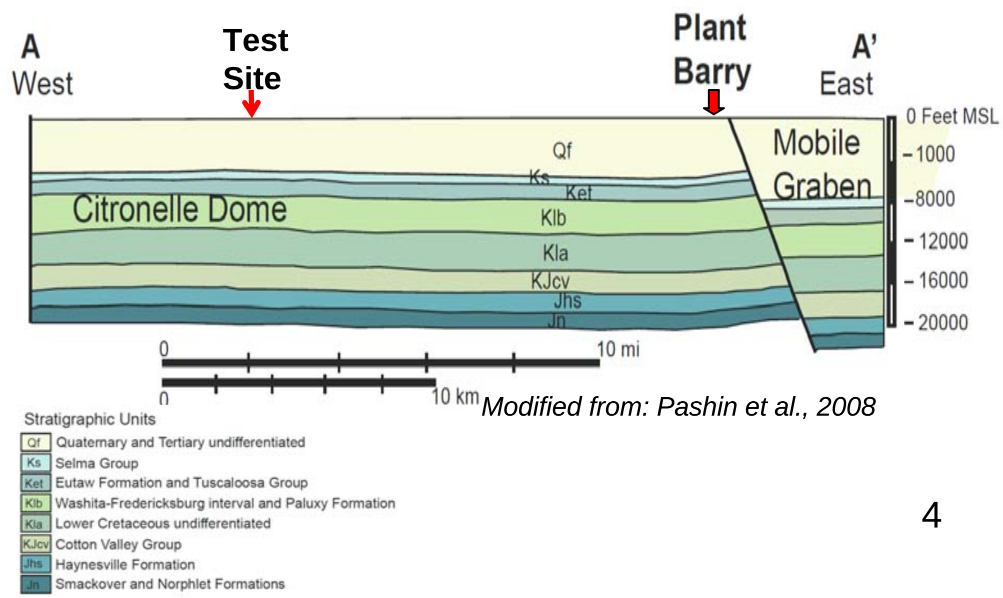
# 1. Storage Permanence

Regional data and studies show that the Citronelle Dome is:

- A subtle open fold
- Limbs dipping less than 1 degree
- Four-way structural closure

*Sources: Pashin et al., 2008; Cottingham, 1988; Esposito and others, 2008*

## Cross Section from Plant Barry to Citronelle Dome



# 1. Storage Permanence (Cont.)

## Southeast Alabama Saline Reservoirs and Seals

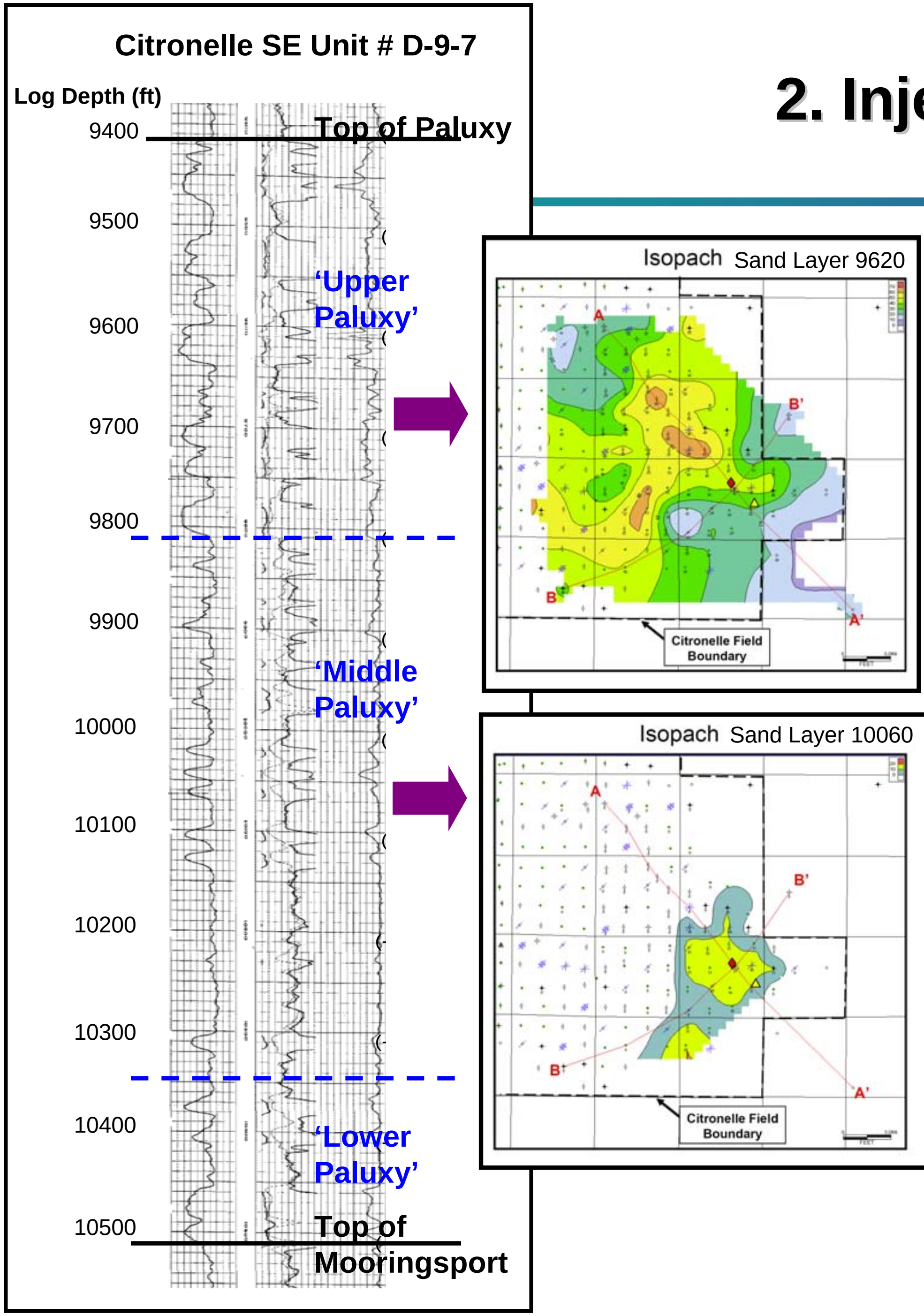
| System | Series | Stratigraphic Unit | Major Sub Units | Potential Reservoirs and Confining Zones |
|---|---|---|---|---|
| Tertiary | Plio-Pliocene | | Citronelle Formation | Freshwater Aquifer |
| Tertiary | Miocene | Undifferentiated | | Freshwater Aquifer |
| Tertiary | Oligocene | | Chicasawhay Fm. | Base of USDW |
| Tertiary | Oligocene | Vicksburg Group | Bucatunna Clay | Local Confining Unit |
| Tertiary | Eocene | Jackson Group | | Minor Saline Reservoir |
| Tertiary | Eocene | Claiborne Group | Talahatta Fm. | Saline Reservoir |
| Tertiary | Eocene | Wilcox Group | Hatchetigbee Sand | Saline Reservoir |
| Tertiary | Paleocene | | Bashi Marl | Saline Reservoir |
| Tertiary | Paleocene | | Salt Mountain LS | Saline Reservoir |
| Tertiary | Paleocene | Midway Group | Porters Creek Clay | Confining Unit |
| Cretaceous | Upper | Selma Group | | Confining Unit |
| Cretaceous | Upper | Eutaw Formation | | Minor Saline Reservoir |
| Cretaceous | Upper | Tuscaloosa Group | Upper Tusc. | Minor Saline Reservoir |
| Cretaceous | Upper | Tuscaloosa Group | Mid. Tusc. — Marine Shale | Confining Unit |
| Cretaceous | Upper | Tuscaloosa Group | Lower Tusc. — Pilot Sand, Massive sand | Saline Reservoir |
| Cretaceous | Lower | Washita-Fredericksburg | Dantzler sand | Saline Reservoir |
| Cretaceous | Lower | Washita-Fredericksburg | Basal Shale | Primary Confining Unit |
| Cretaceous | Lower | Paluxy Formation | 'Upper' 'Middle' 'Lower' | Proposed Injection Zone |
| Cretaceous | Lower | Mooringsport Formation | | Confining Unit |
| Cretaceous | Lower | Ferry Lake Anhydrite | | Confining Unit |
| Cretaceous | Lower | Donovan Sand | Rodessa Fm. 'Upper' | Oil Reservoir |
| Cretaceous | Lower | Donovan Sand | 'Middle' | Minor Saline Reservoir |
| Cretaceous | Lower | Donovan Sand | 'Lower' | Oil Reservoir |

← Confining Zone (Primary Confining Unit)

← Injection Zone (Proposed Injection Zone)

## The Anthropogenic Test's $CO_2$ Storage Site

- Target reservoir is the Lower Cretaceous Paluxy Fm (at 9,400').
- 1,100 foot interval of stacked sandstones and shales.
- Numerous reservoir seals and confining units (at least 5).
- No evidence of faulting or fracturing, based on reinterpretation of existing 2D seismic lines.



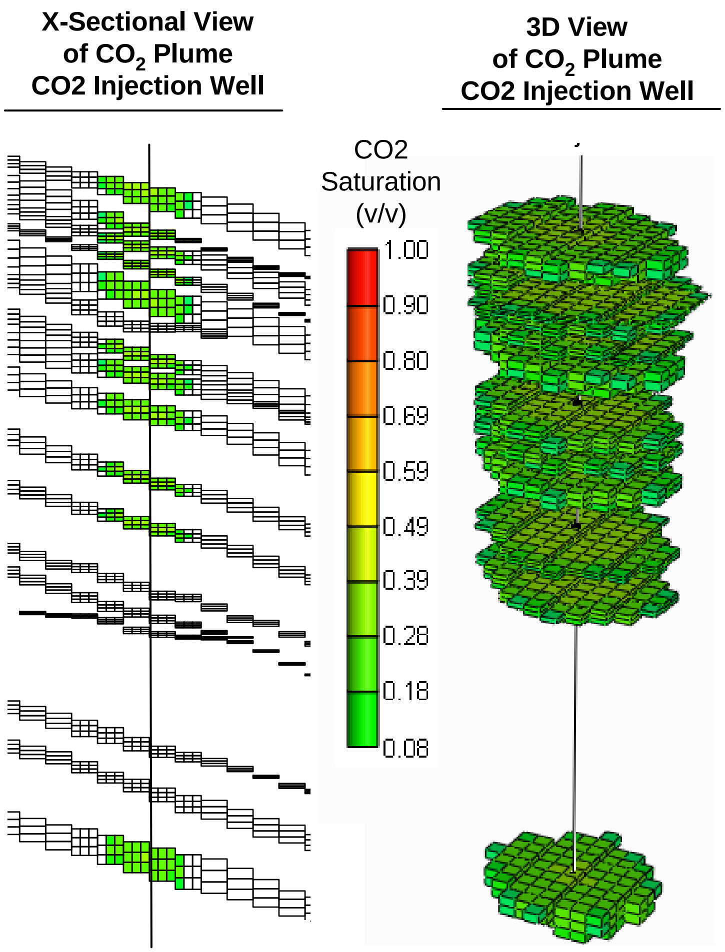

# 2. Injectivity and Capacity

## Establishing Reservoir Properties for Paluxy Saline Formation

- Sand continuity mapping to determine "open" or "closed" sand intervals.
- Detailed analysis of over 80 well logs for porosity and depositional style.
- Regional core data for porosity and permeability.
- 340 net feet of sand at injector
- Average porosity of 19%
- Average permeability of 90 md

# 2. Injectivity and Capacity (Cont.) Reservoir Simulation

## Modeling the $CO_2$ Plume



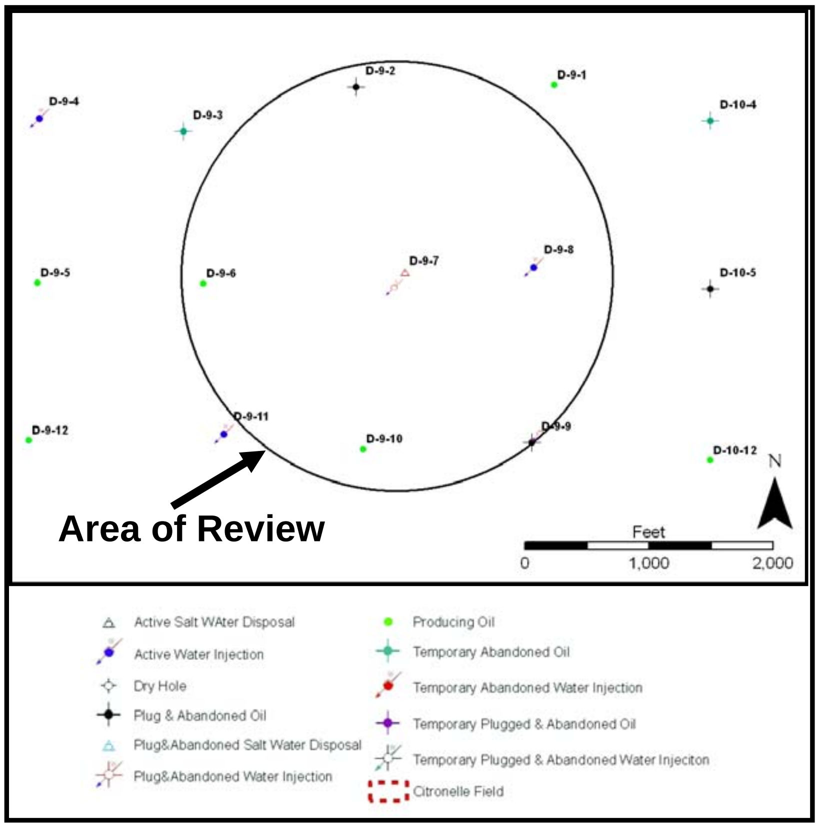

## Understanding $CO_2$ Flow and Optimizing Storage Capacity

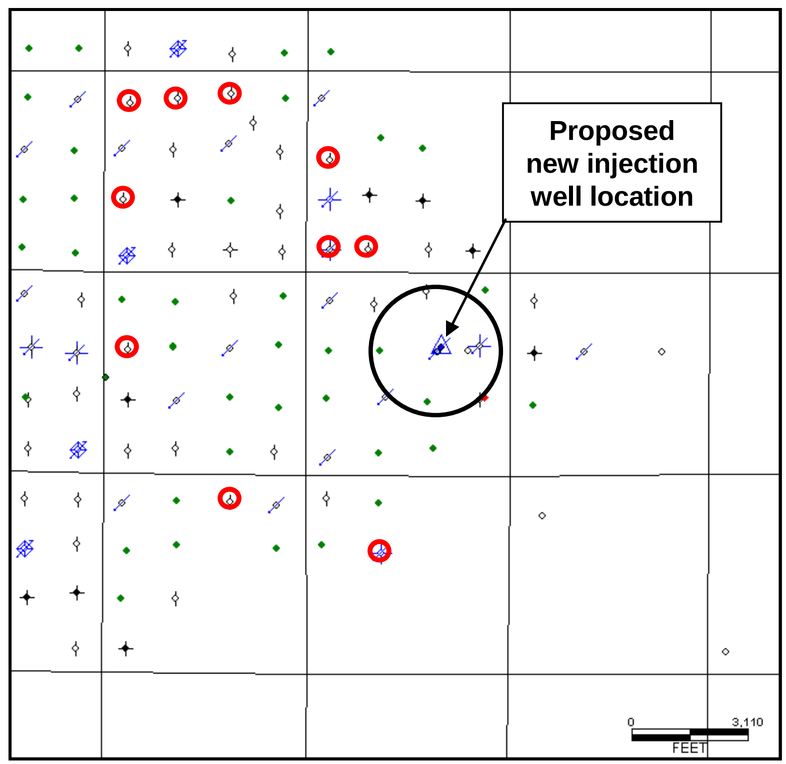
The information from detailed reservoir characterization was used to model and optimize the $CO_2$ plume:

- Areal extent of $CO_2$ will be limited (~1,000 ft) by injection into multiple sand layers.
- Low dip results in a near-circular plume and little post $CO_2$ injection up-dip migration.

# 3. Existing Wellbore Leakage Risk

- Catalog of data for wells within estimated plume area (Area of Review)
- Oil field operator maintains active MIT program for the field
- Ran cement bond logs on selected wells in the injection area (highlighted with red circles)
  - Adequate cement bonds observed across injection interval and confining unit in all wells
  - Average top of cement depth is at a depth of 6,800 ft (>2,000 ft above top of confining unit).



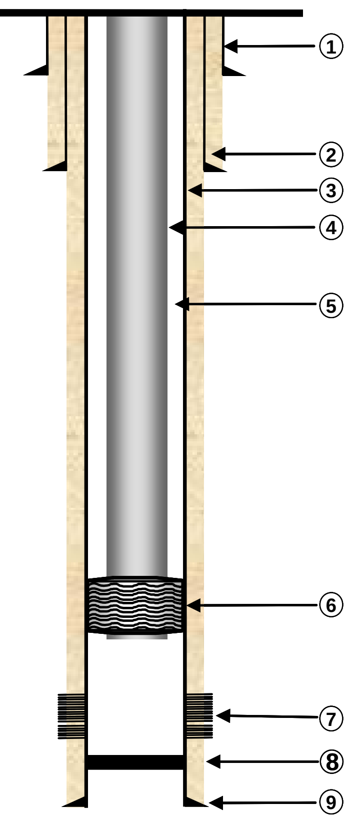
# 4. New wellbore leakage risk: Design for new Project Wells

- Using accepted UIC well construction standards (Class I non-hazardous) to construct all wells
- Surface casing run to below base of USDW and cemented to surface
- Long string casing to TD
- Cemented into surface casing
- Injection through tubing and packer
- Monitoring well-head and down-hole pressure throughout injection period

## Completion Well Diagram

**COMPLETION DETAIL**

1. 16” Conductor Pipe set at 60’.
2. 10-3/4” Surface Casing @ 2,500’, set in 13 1/2” hole; 45.5 lb/ft J-55 STC; Cemented to surface.
3. 7” Protection Casing @ 11,800’, set in 9-7/8” hole; 26.0 lb/ft L-80 LTC; Cemented to surface (2 stage).
4. 2-7/8” Injection Tubing @ 9,300’; 6.5 lb/ft L-80 EUE 8rd.
5. Annular Fluid: 8.4 lb/gal inhibited fresh water.
6. Injection Packer @ 9,300’; 7” x 2 7/8” Ni-plated full-bore lockset packer
7. Perforations: 9,400’ to 10,500’.
8. Cast Iron Bridge Plug and Cement Cap at Ferry Lake
9. Total Depth @ 11,800’.



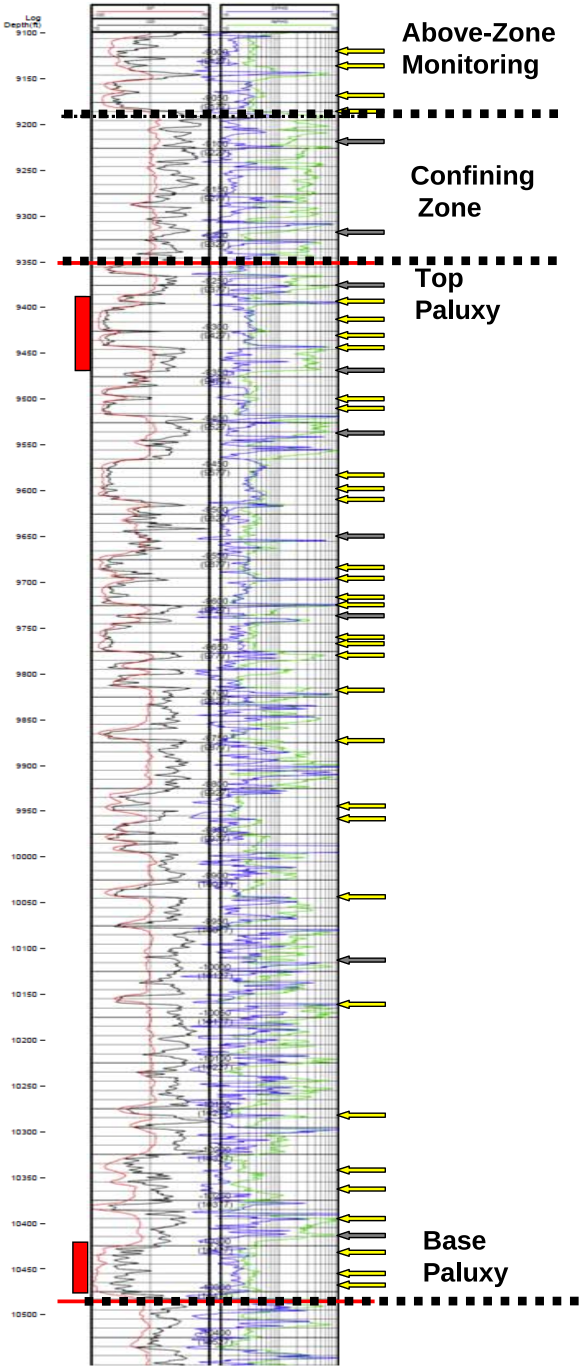
# How Does Drilling a Characterization Well Further Address These Risks?

1. **Storage Permanence**
   - confirm properties of the confining units with core and log data
2. **Adequate reservoir injectivity and storage capacity**
   - confirm properties of the confining units with core, log and fluid data
3. **Existing wellbore leakage**
   - update reservoir simulation using new characterization data to reassess the project AoR
4. **New wellbore leakage risk**
   - Well construction requirements

# Anthropogenic Test Characterization Well (D-9-8 #2)

At the end of December 2010, we began drilling the Anthropogenic Test characterization well

- Well drilled to 11,800’ TD (spud to TD) in 30 days and under budget.
- Well was cased and cemented in January 2011.
- Whole and sidewall cores, geophysical well logs
- Well will be used as an observation/monitoring well

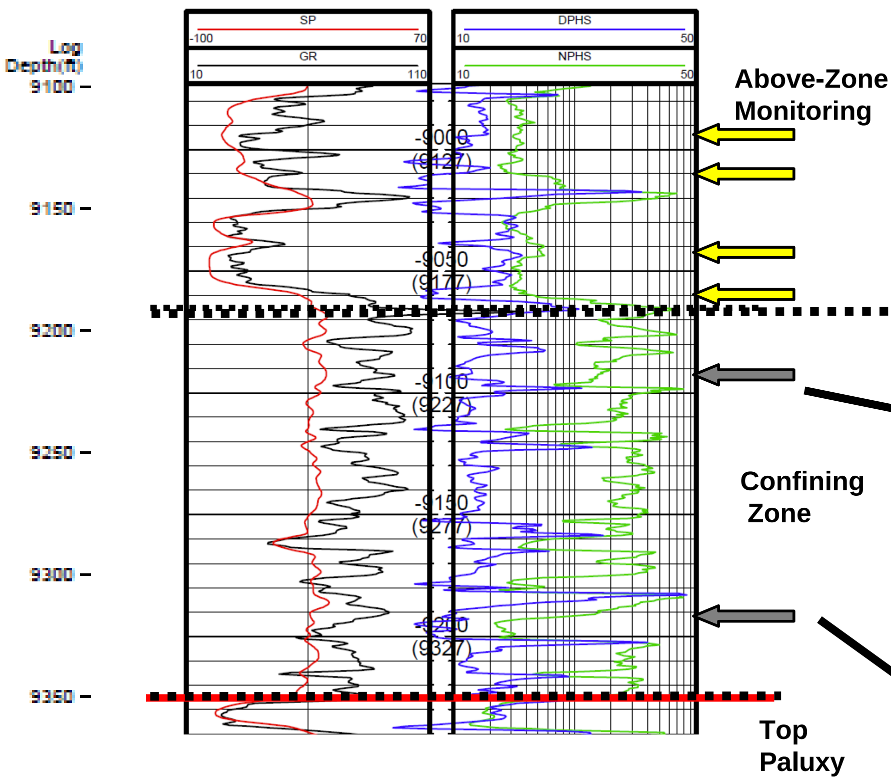



# Data Collection at D-9-8#2

- Recovered extensive Paluxy Formation whole core (98 feet in two intervals)
- 62 Whole core plugs tested
- Recovered a total of 45 percussion sidewall cores from:
  - Overlying confining units,
  - Overlying saline reservoirs
  - Paluxy Formation
- Ran full set of well logs (quad combo, array gamma, MRI, mineralogy, dipole sonic, etc.).

# D-9-8#2 Sidewall Core Data

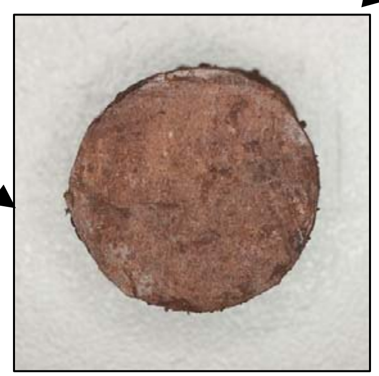
**Sidewall cores can be used to acquire reasonable porosity values for sandstone intervals and confirm lithology for shales. Unreliable for permeability.**




### Above-Zone Monitoring Sand Properties

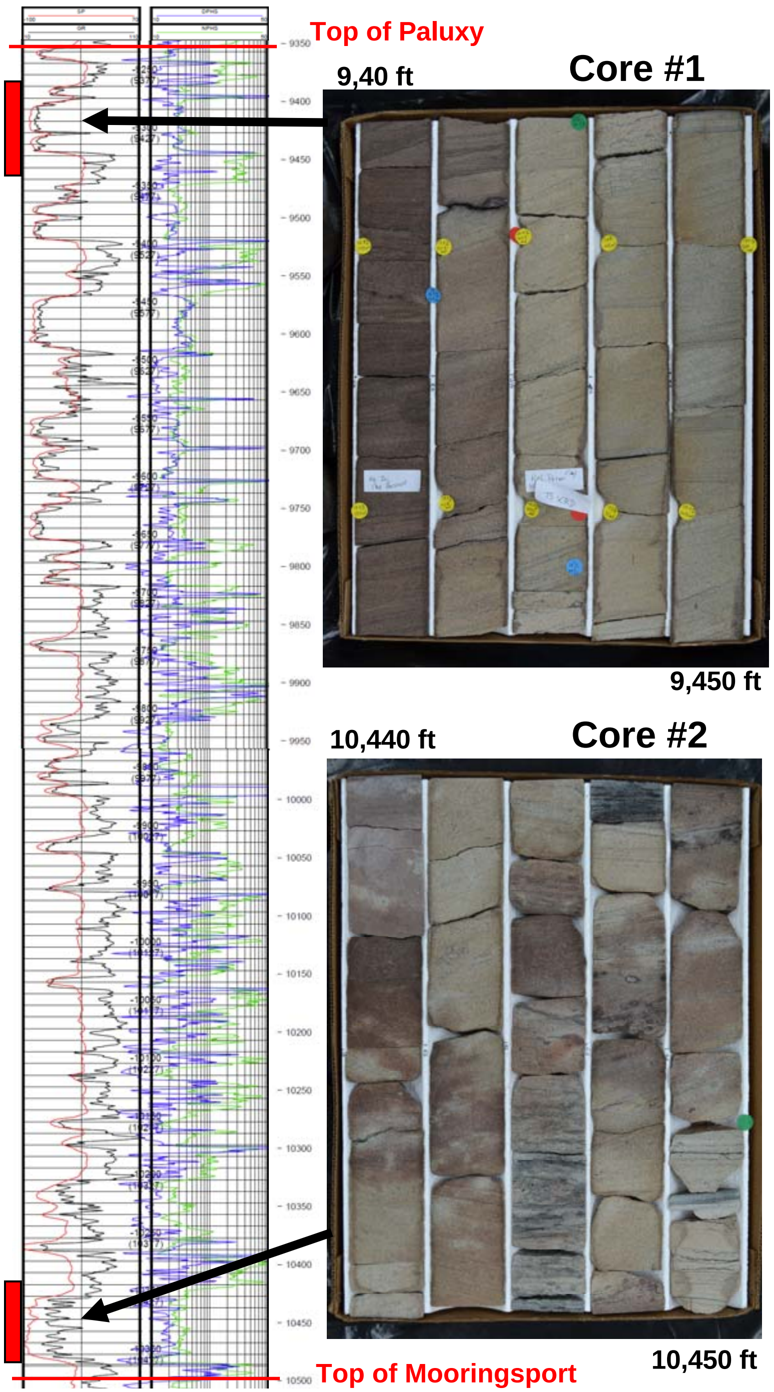
| Sample Depth (ft) | Porosity (%) | Lithology |
|---|---|---|
| 9,120 | 23.5 | SS, fine-grained |
| 9,160 | 21.0 | SS, fine-grained |
| 9,170 | 21.8 | SS, fine-grained |
| 9,180 | 23.4 | SS, fine-grained |

### Confining Zone Lithology



**9,318 ft**
**Siltstone-Shale**

**9,210 ft**
**Shale**



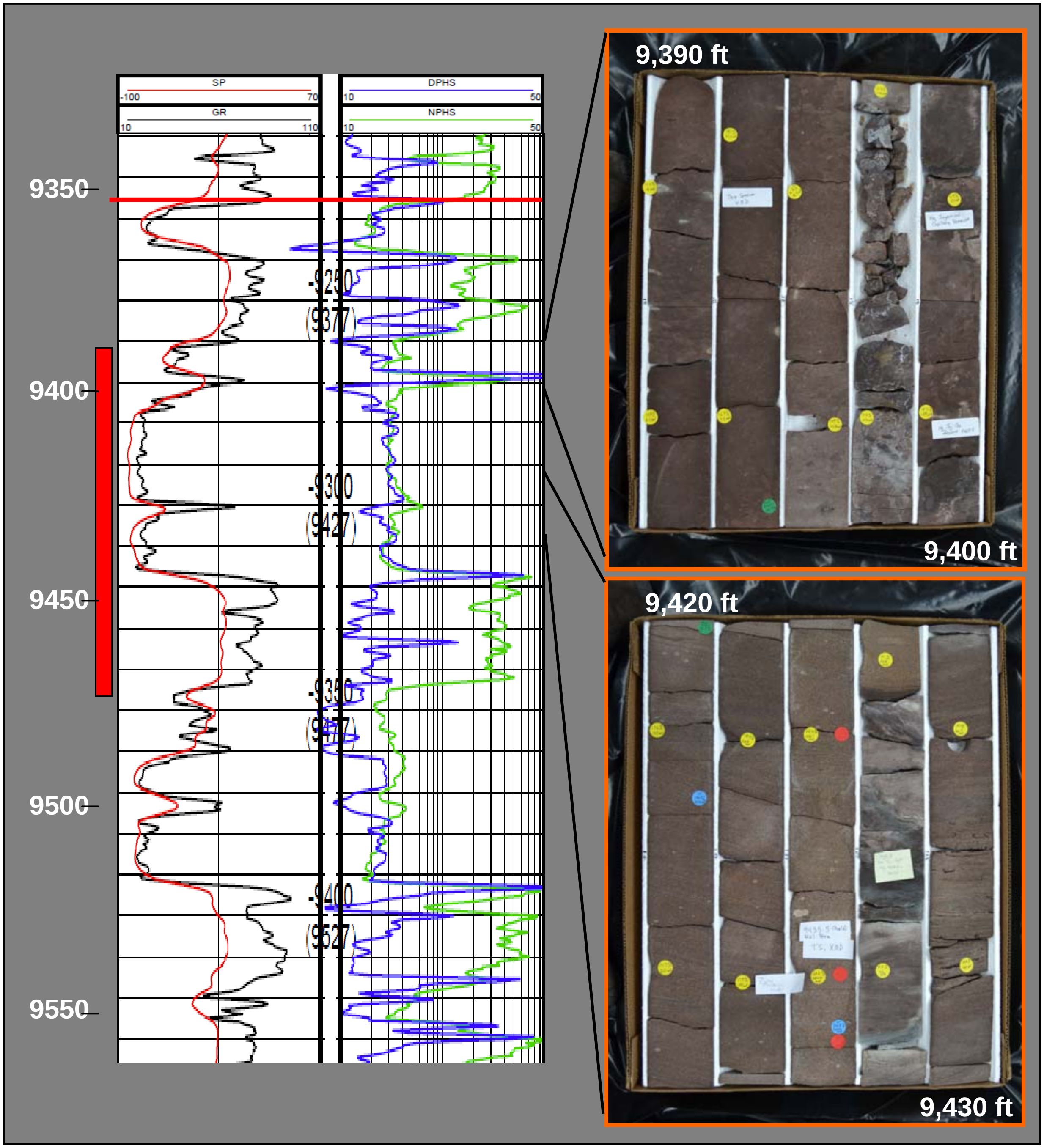

# Paluxy Whole Core

**Cored Top and Basal Paluxy Sands**:

- Fluvial System: sand and shale sequence in both upper and lower core
- Fining upward units suggest channel fill
- ‘Sandy’ intervals are typically between ~ 2-10 ft
- Sharp base of medium- coarse grained sand grading upward to finer sand and then shale.

**Prior to this project no core of the Paluxy Formation had been collected regionally**

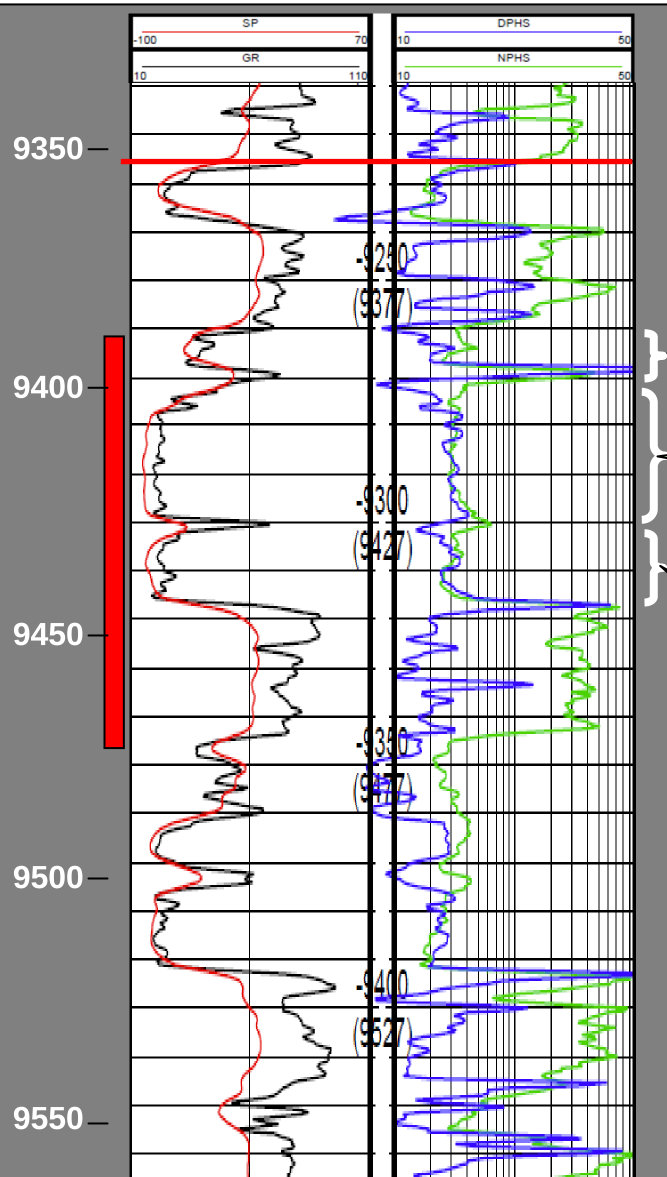
# Paluxy Core #1




**Notable Features**:

- Heavily burrowed
- Rip-up clay pebbles
- Root zones
- Trough cross beds
- Multiple soil horizons
- Upper sands in Core # 1 were oxidized (red color)
- Lower sands are not oxidized

# Porosity and Permeability Ranges, Core #1




**Porosity Range: 6-18%**
**Permeability Range: 1 – 50 md**

**Porosity Average: 13 %**
**Permeability Average: 8 md**

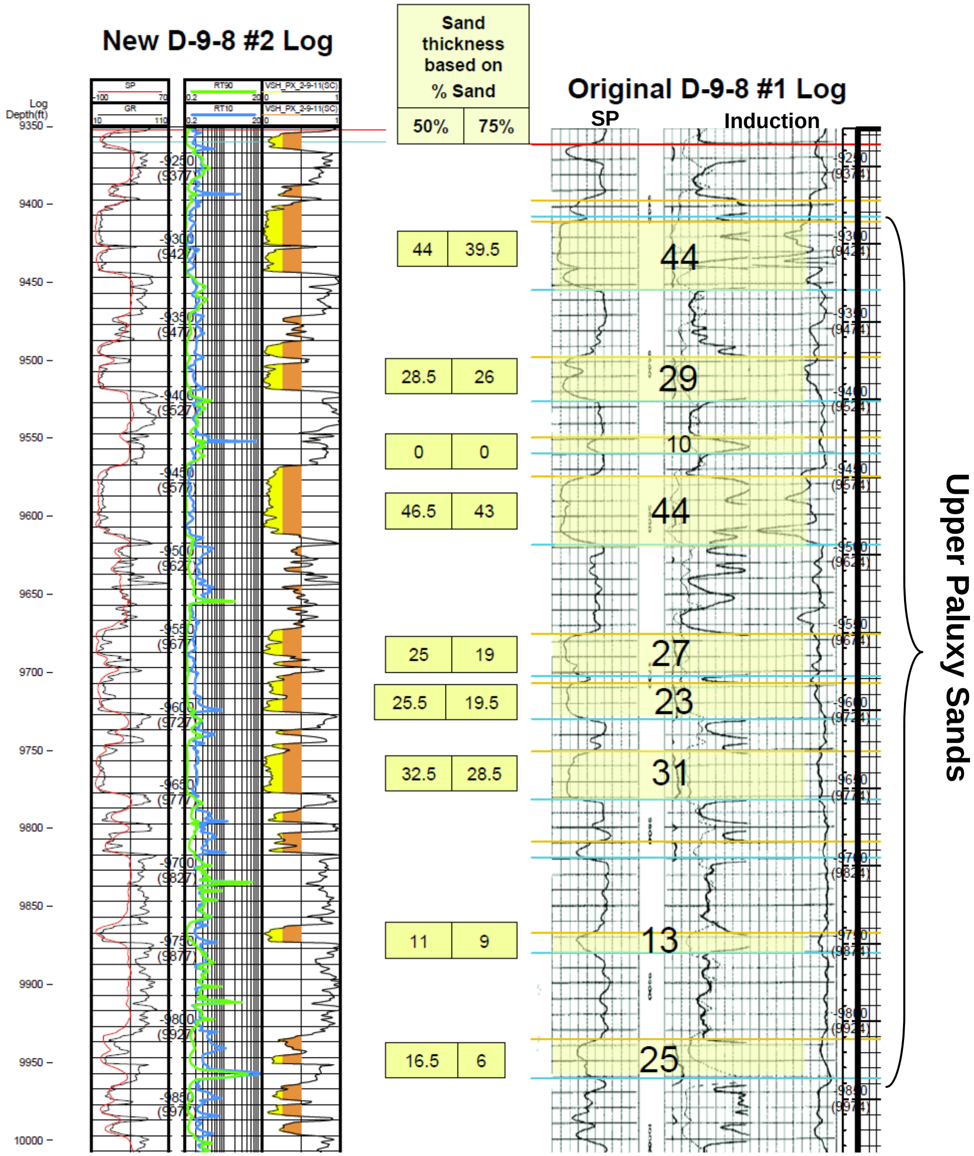
**Porosity Range: 6-23%**
**Permeability Range: 1 – 3,800 md**

**Porosity Average: 18%**
**Permeability Average: 440 md**

**Porosity Range: 8-22%**
**Permeability Range: 1 – 1,900 md**

**Porosity Average: 18%**
**Permeability Average: 500 md**

# Confirming Storage Capacity (Thickness)



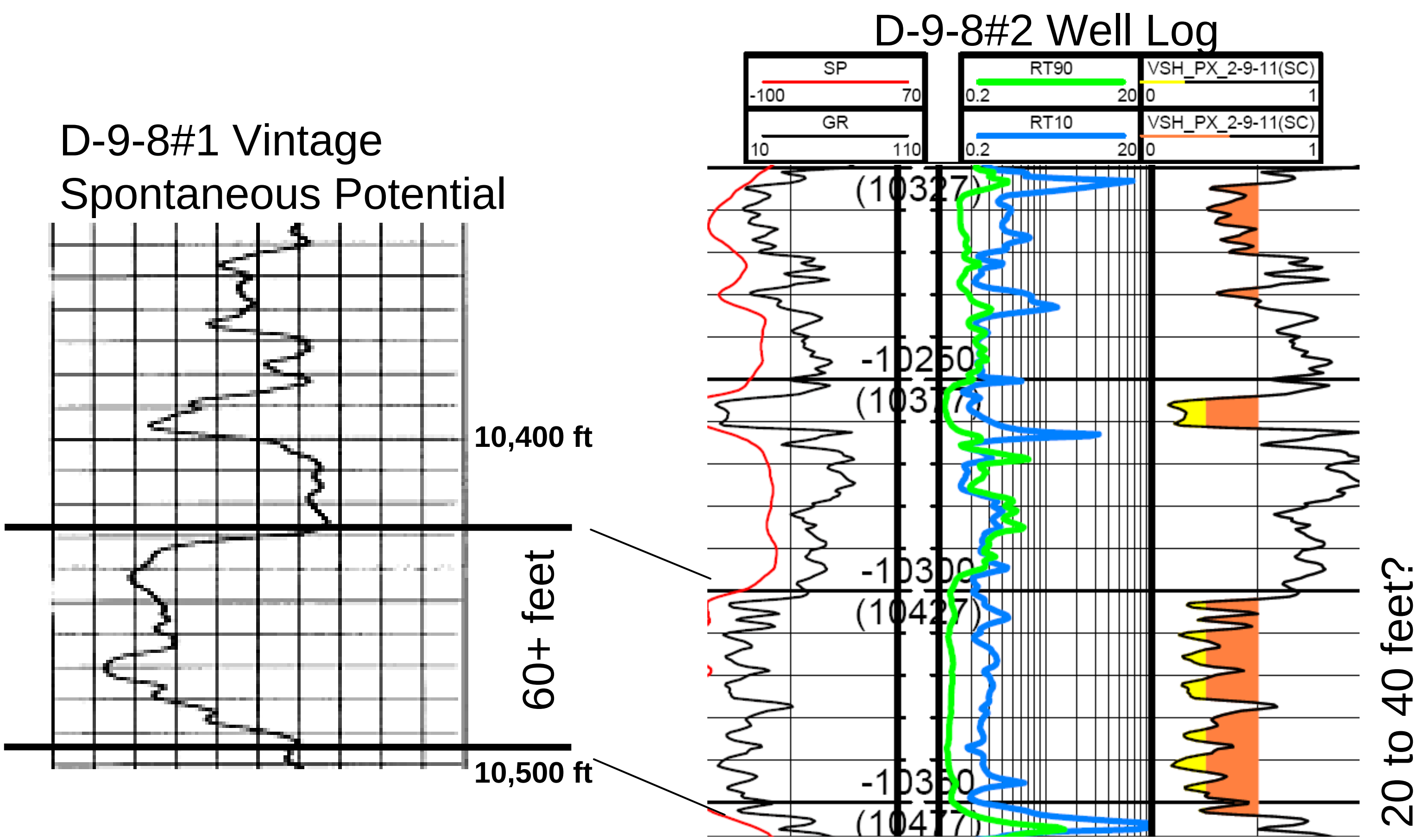

Note: thickness values are in feet

- Calculated sand thickness using new log data.
- New results suggest Paluxy reservoir thickness of:

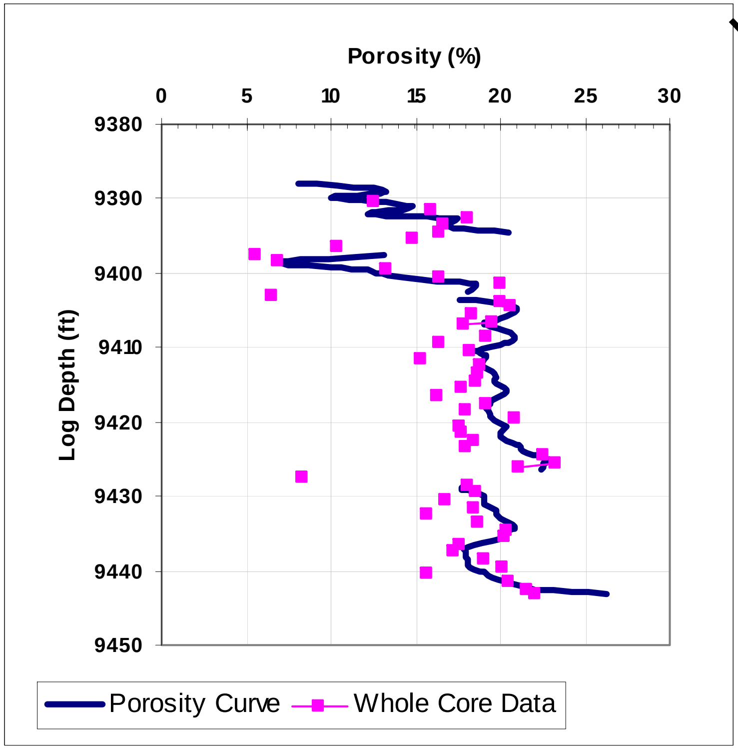
  **278.5 ft** of **50%** clean sand
- Sand thickness estimates made using old logs (310 ft) appear to be acceptable
- However there were notable individual exceptions

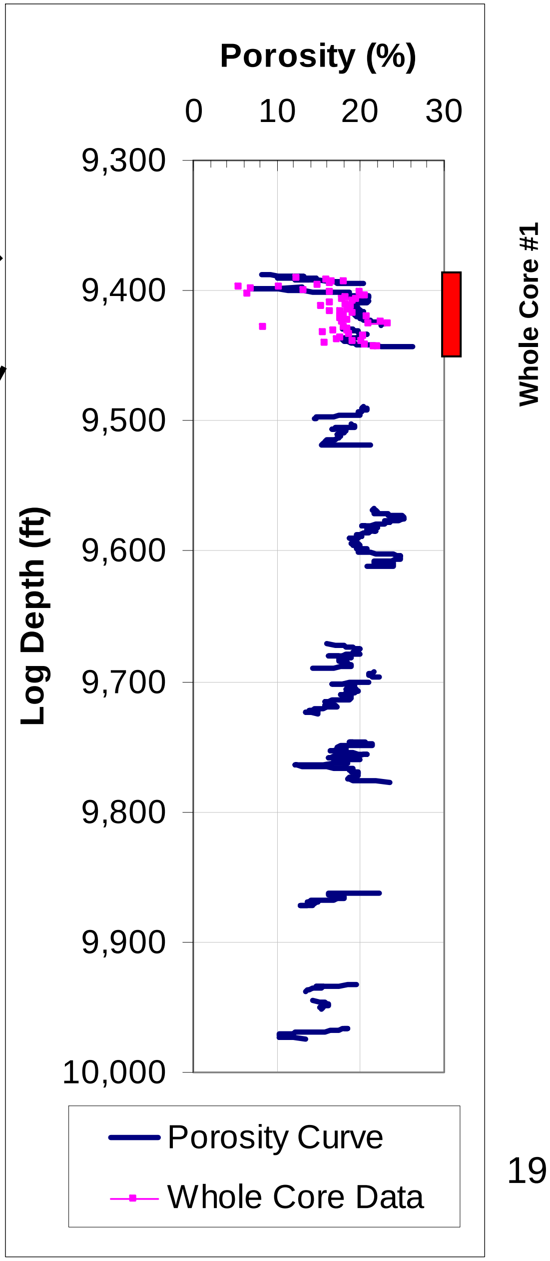
# Confirming Storage Capacity (Thickness)

- Previous slide showed comparison of vintage and new logs for the Upper Paluxy
- The basal Paluxy sandstone (one of our whole core targets) appears to be of lower quality (thickness and vertical continuity) than the old log would indicate



# Confirming Storage Capacity (Porosity)



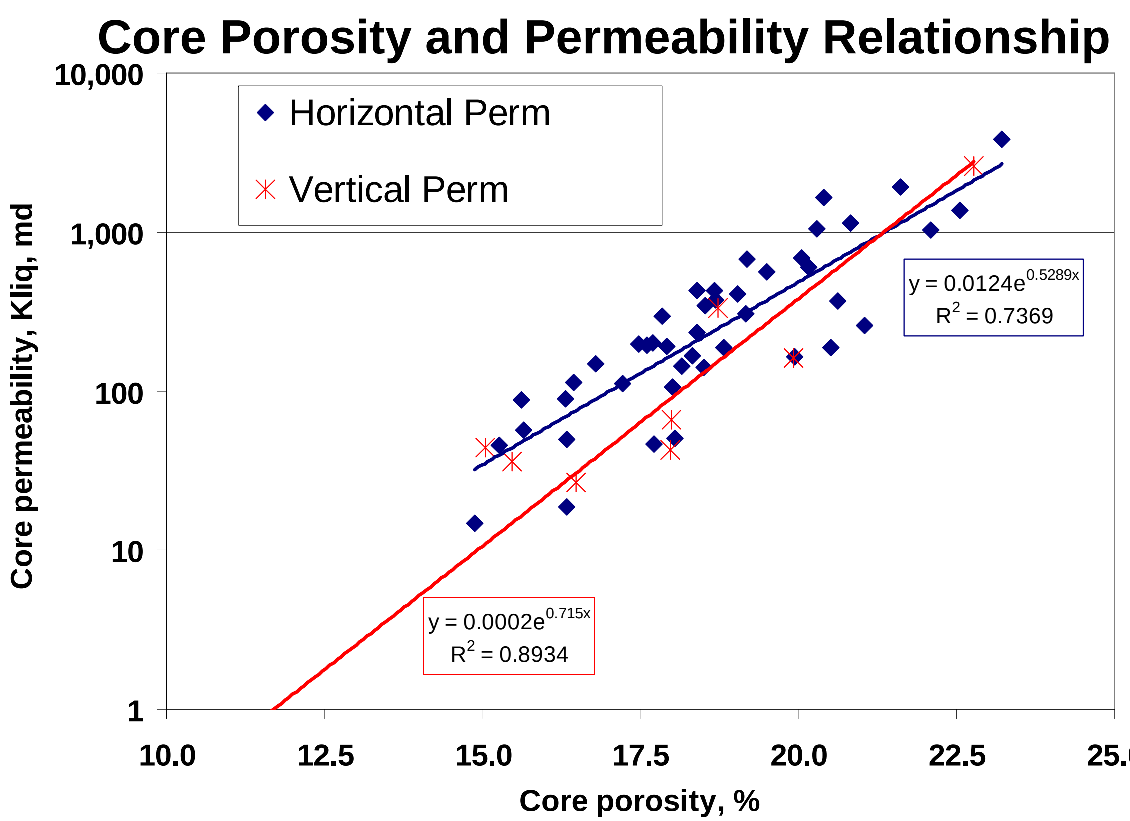




**Porosity log data and core data were used to develop a Paluxy sandstone porosity curve**

- Averaged porosity of the Paluxy Formation sandstones using this approach is 18.9 %
- This estimate compares quite well with the prior sandstone estimate of 19%

# Confirming Reservoir Injectivity (Permeability)

Core tests demonstrated exceptional reservoir permeability

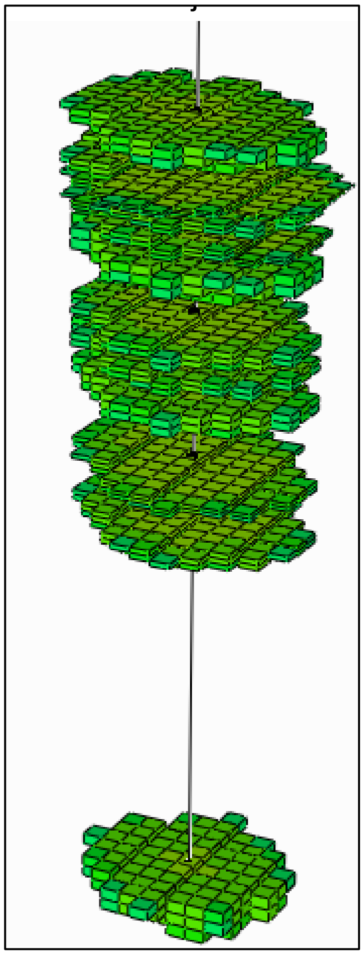



| Phi (%) | Hz Perm (md) | Vt Perm (md) |
|---|---|---|
| 24 | 4,040 | 5,670 |
| 22 | 1,400 | 1,360 |
| 20 | 490 | 320 |
| 18 | 170 | 80 |
| 16 | 60 | 20 |
| 14 | 20 | 4 |
| 12 | 7 | 1 |
| 10 | 2 | 0 |

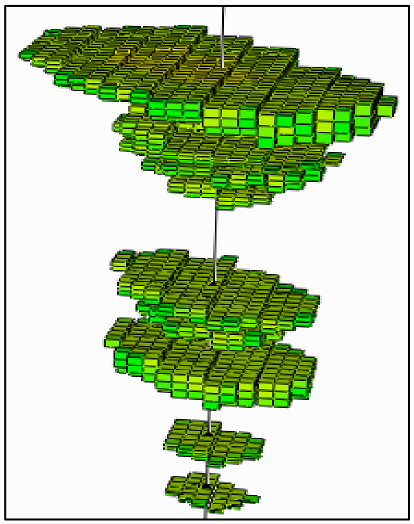
# Updating the Geocellular Model

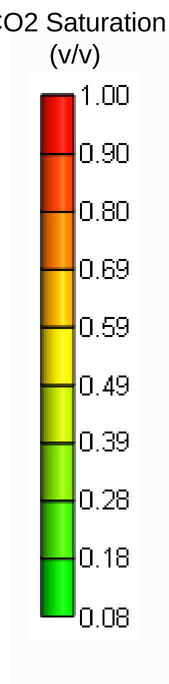
## 3D View of $CO_2$ Plume End of Injection

**Original Model**



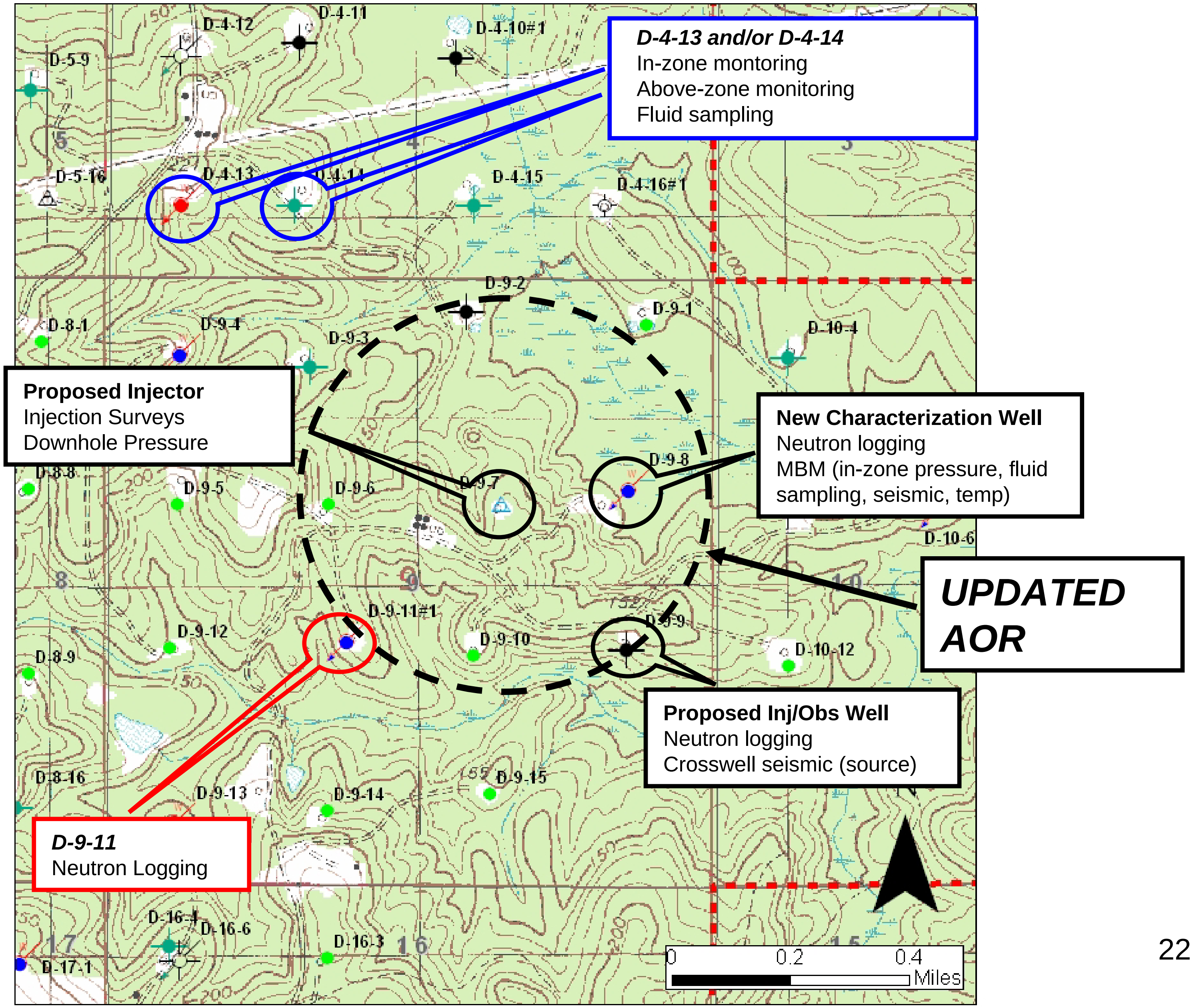
**Updated Model**






- Model plume extent was 1,000 ft radius in original model
- New model now shows plume extent nearly 1,700 ft
- Due to higher permeability in upper Paluxy sandstones
- Necessitates updated Area of Review
- MVA plan appears to be adequate
- Next step incorporate permeability variation within each sandstone – how does that affect the plume behavior?

# Monitoring within and Beyond the Updated AoR



# Conclusions (1)

Site characterization using existing geologic and well data defined project risks to an acceptable level to move forward with characterization well drilling

**1. Storage permanence**

- Geologic closure, no faults or major fracture zones.
- Confining units and seals.

**2. Adequate reservoir injectivity and storage capacity**

- Reservoir thickness, porosity and permeability appeared to be adequate to accept $CO_2$ volume.
- Stacked sand/shale package appears to confine plume extent.

**3. Existing wellbore leakage risk**

- Condition of deep penetrations in UPDATED project area appear to be adequate to prevent $CO_2$ leakage.

**4. New wellbore leakage risk**

- Wells constructed to UIC Class I standards.

# Conclusions (2)

Data from the new characterization well further addresses these risks

**1. Storage permanence**

- Promising confining unit characteristics.
- Establish mechanical properties (work ongoing)

**2. Adequate reservoir injectivity and storage capacity**

- Reservoir thickness, porosity and permeability as good or better than preliminary estimates. More than adequate to accept $CO_2$ volume.
- Stacked sand/shale package still appears to confine plume extent.

**3. Existing wellbore leakage risk**

- Condition of deep penetrations in the updated project area appear to be adequate to prevent $CO_2$ leakage.

**4. New wellbore leakage risk**

- First project well drilled to UIC Class I standards.