WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP
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Arizona Utilities CO_2 Storage Pilot

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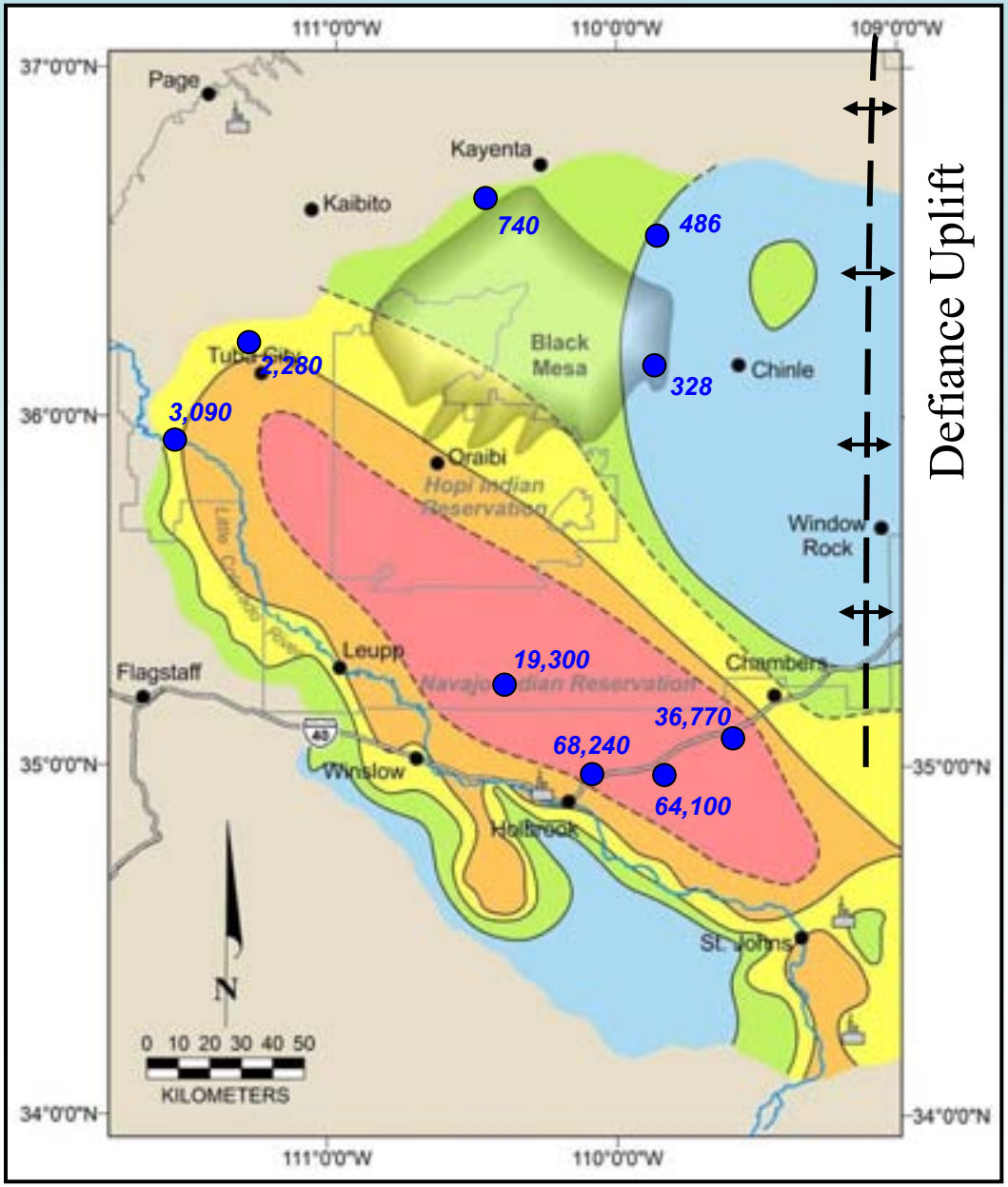
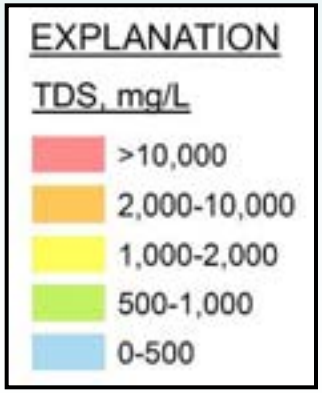
WESTCARB Arizona Utilities CO_2 Storage Pilot

- Objective – evaluate CO_2 opportunities in NE Arizona
- Exploratory – no oil and gas reserves / operations
- Region contains several large coal-fired power plants
- Three sites originally evaluated
- Arizona Public Service Co (APS) property selected
  - Limited, secure access
  - Mineral and surface rights owned by APS

(Source: Google Maps)

Site Selection Constrained by Saline Groundwater and Tribal Lands

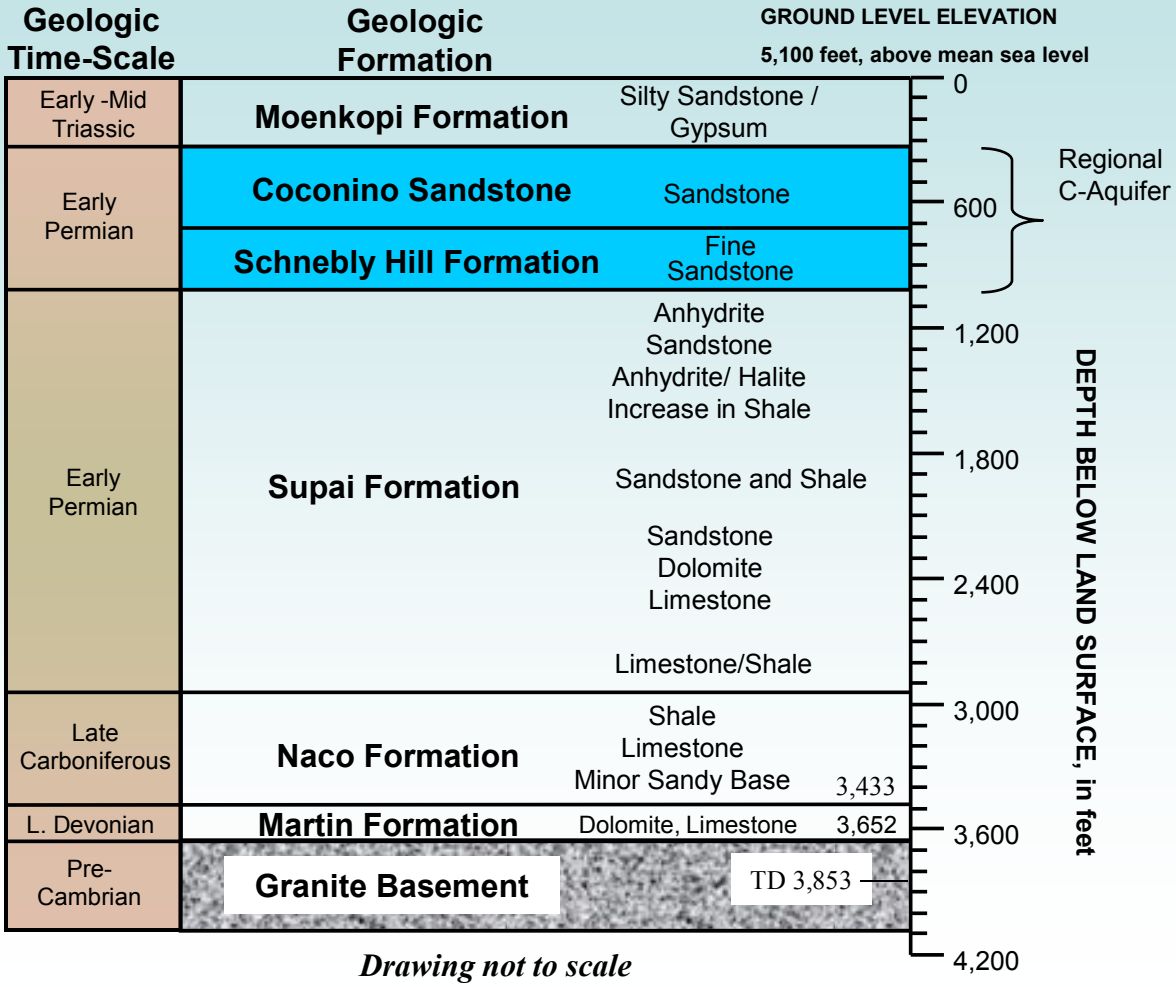




Total Dissolved Solids in Coconino/DeChelly Sandstone

Geologic Section

- General coursing of sediments upward
- Supai Formation
  - Thick seal
  - Alternating layers of anhydrite and shale
- Naco and Martin Formations
  - Marine limestone, dolomite
  - Fractured, vuggy
- Sandstone above basement ?

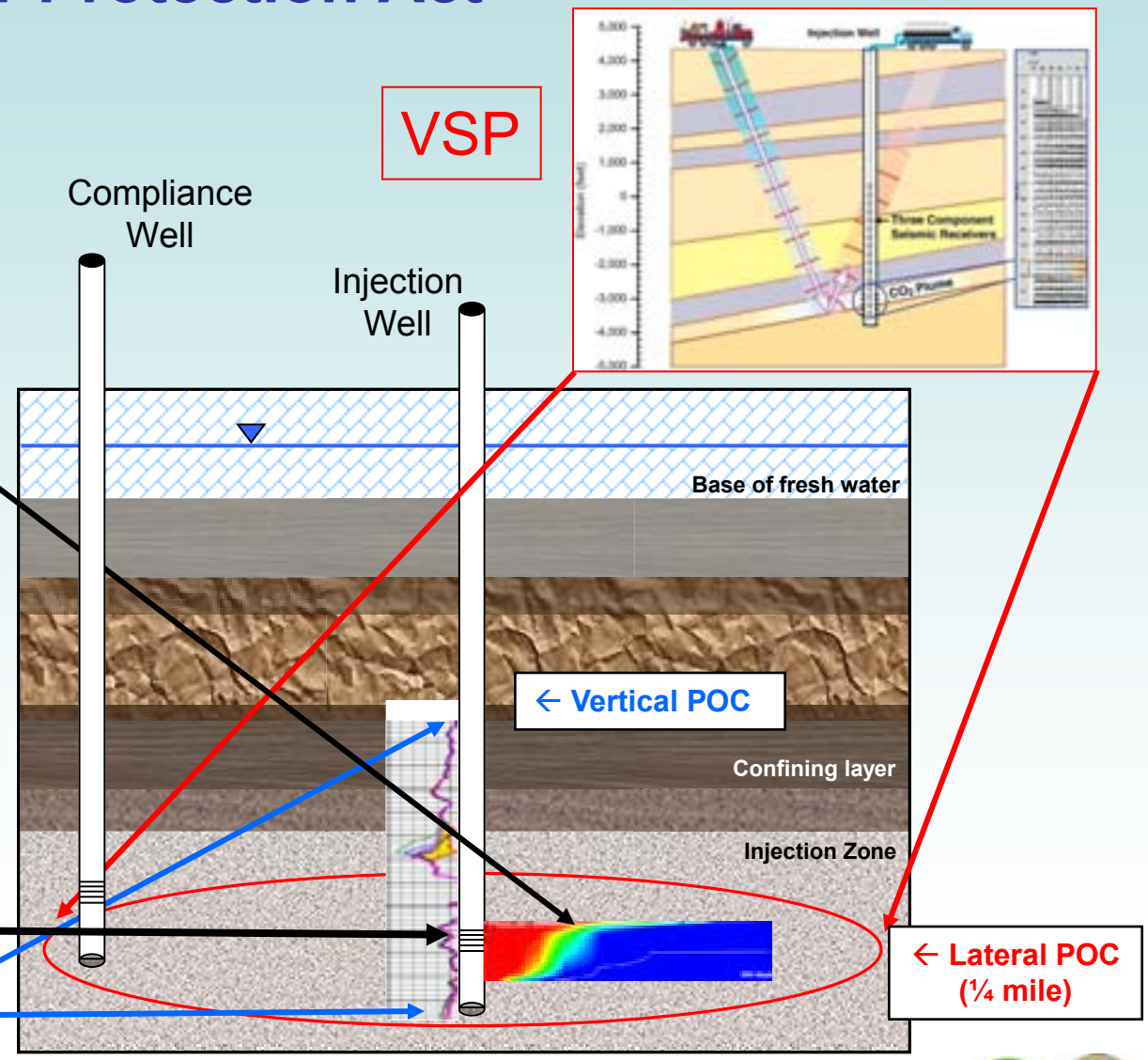


Drawing not to scale

(Source: modified after EM&A cross-section)

Arizona Dual Permitting Experience
UIC and Aquifer Protection Act

- Single-Well Test
- Point of compliance (POC) typically a monitoring well
- Model predictions form basis for POC
- Verification:
  - Lateral POC determined using Vertical Seismic Profiling (VSP)
  - Vertical POC determined using wellbore logs (e.g., RST)
  - In zone monitoring



Surface Hole/Casing Installation (959 ft) Dual-Wall Reverse Air Circulation

WDC Exploration setting up drilling equipment
(Photo source: K. Delaune, Sandia Technologies)

Running surface Casing to 959 ft
(Photo source: K. Delaune, Sandia Technologies)

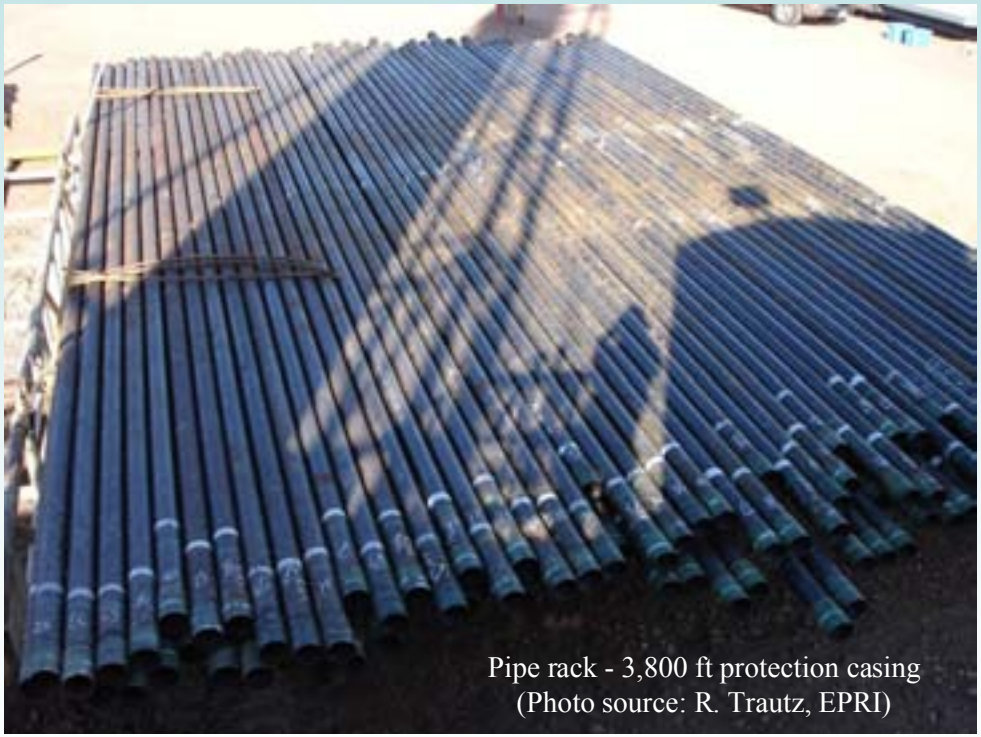
8½ inch Protection Hole (959 - 3,853 ft TD) Conventional Mud Rotary

Clockwise from Top Left:

- Well cellar installation (Photo source: K. Delaune, Sandia Tech.)
- Well cellar completion (Photo source: K. Delaune, Sandia Tech.)
- BearCat #2, 24/7 drilling operations (Photo source: R. Trautz, EPRI)

Protection Casing (TD 2,504 ft)

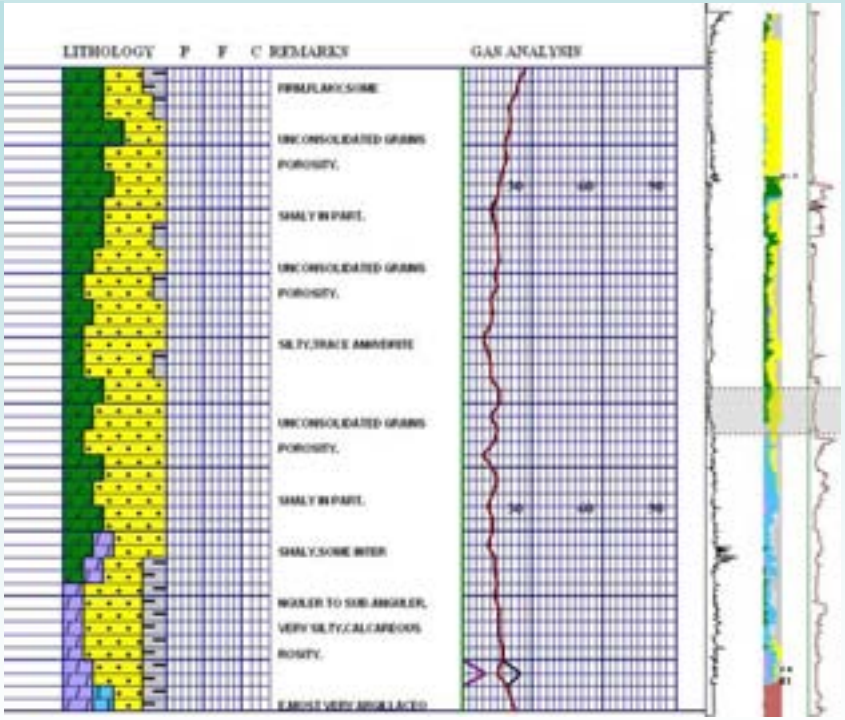
- Balanced cement plug 2,505 – 2,683 ft.
- 5½ inch OD Protection Casing



Pipe rack - 3,800 ft protection casing
(Photo source: R. Trautz, EPRI)

Reservoir Characterization Program

- Mud logs (0 – 3,853 ft)
- Open-hole logs
- Drill-stem tests
  - Martin and Supai Formations
- Rotary side-wall cores (25)
- Fluid samples
  - Base of Coconino Formation > 3,000 EC
  - Supai Formation, 145,000 ppm total chlorides



Partial mud log for the Supai Formation (2,075-2,340 ft)
(Source: Suttles Logging, Inc.)

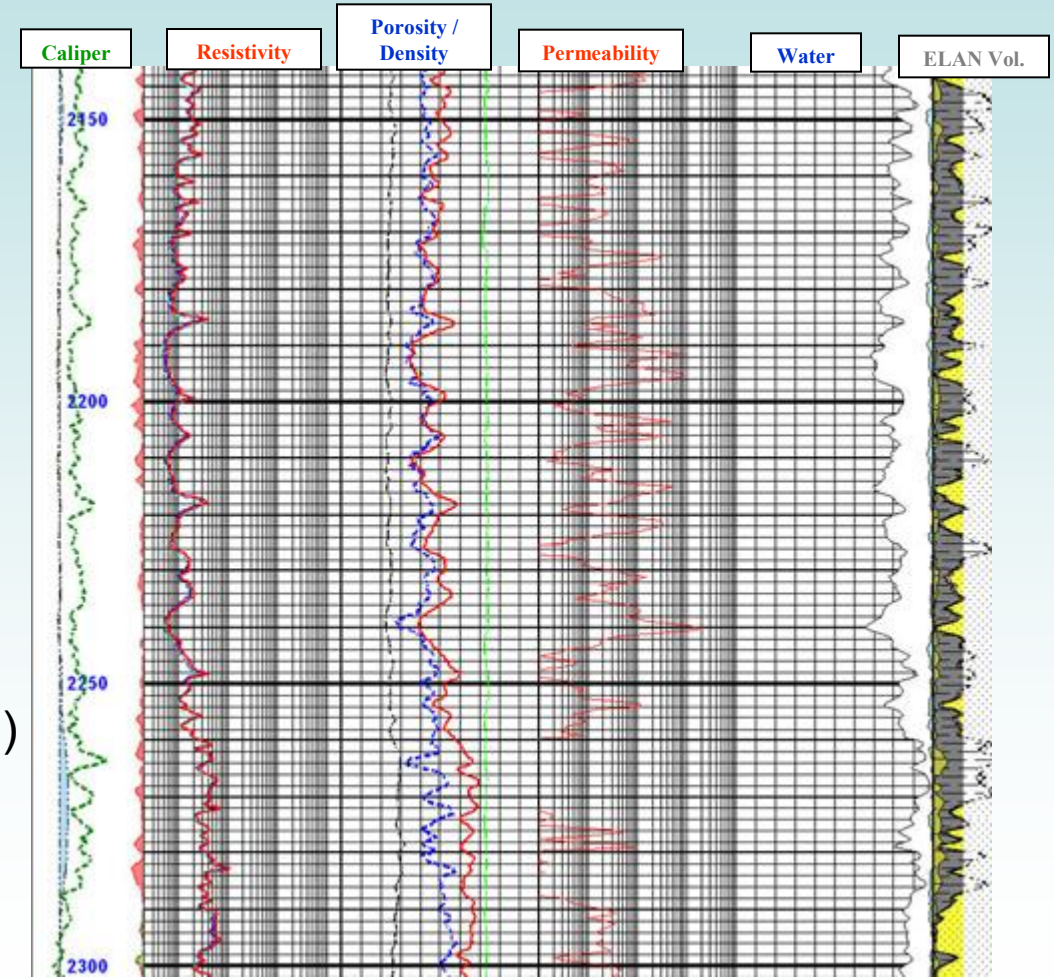
Open-Hole Logs (Schlumberger) – Formation Evaluation

Hoisting downhole geophysical logging tool into well
(Photo source: R. Trautz, EPRI)

Schlumberger wireline processing truck on location
(Photo source: R. Trautz, EPRI)

Open-Hole Logs

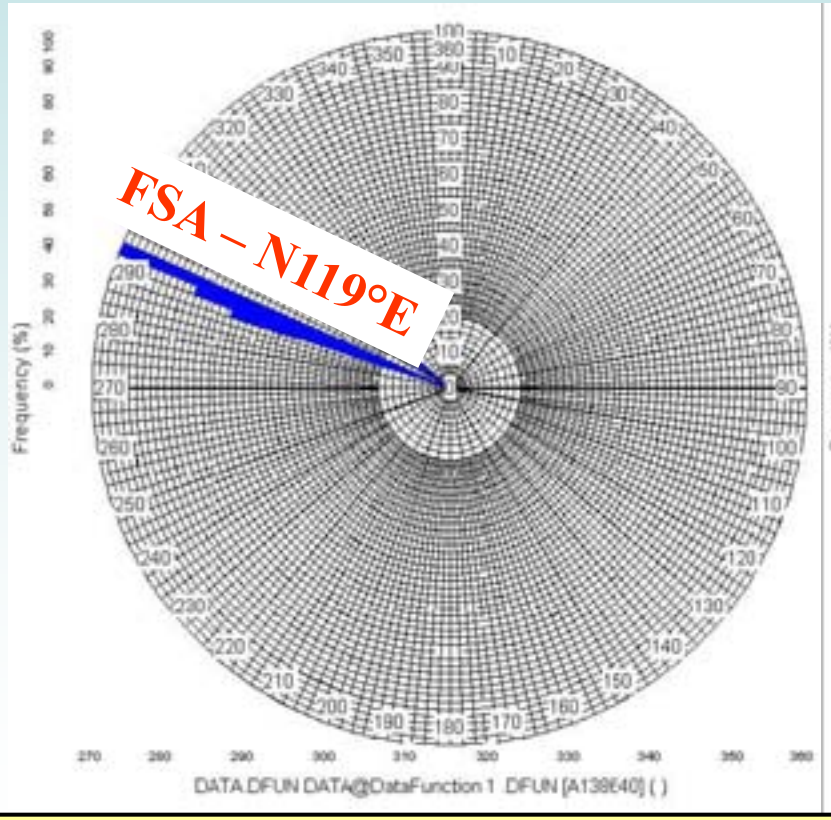
- Platform Express®
  - Spontaneous potential
  - Caliper
  - Gamma Ray
  - Resistivity (20, 30, 60 and 90 inches)
  - Neutron porosity
  - Density
- Combinable Magnetic Resonance (CMR)
- Formation Micro-imager (FMI)
- Dipole sonic scanner
- Elemental Capture Spectroscopy (ECS)



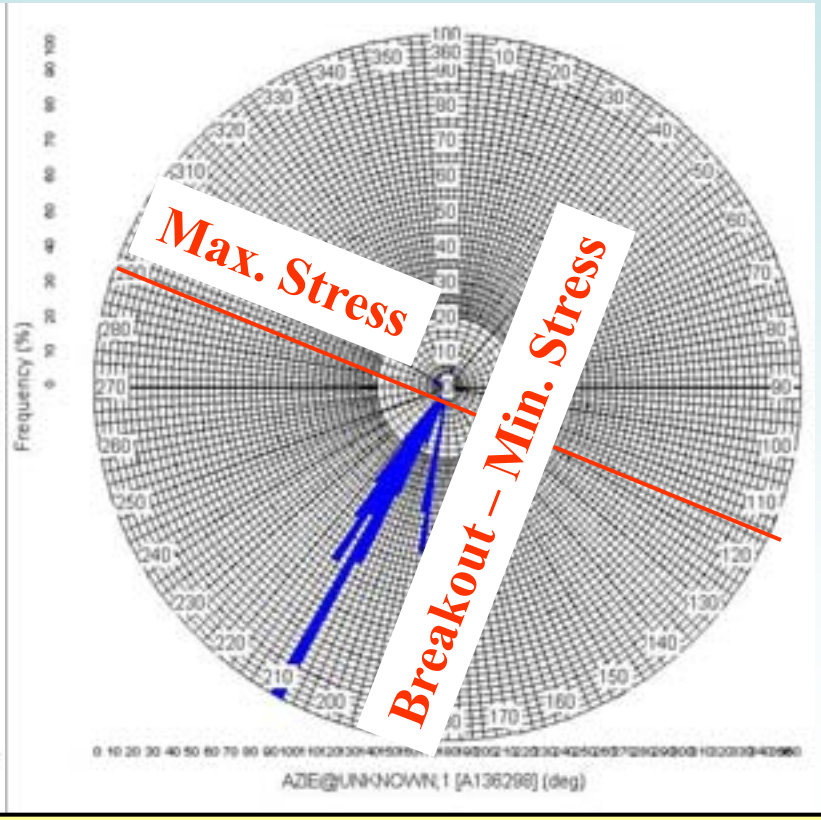
Source: Schlumberger ELAN analysis of formation/fluid properties

Stress Analysis
Comparison of Dipole Sonic, Caliper & FMI

Rose diagram fast-shear azimuth



Rose diagram borehole enlargement



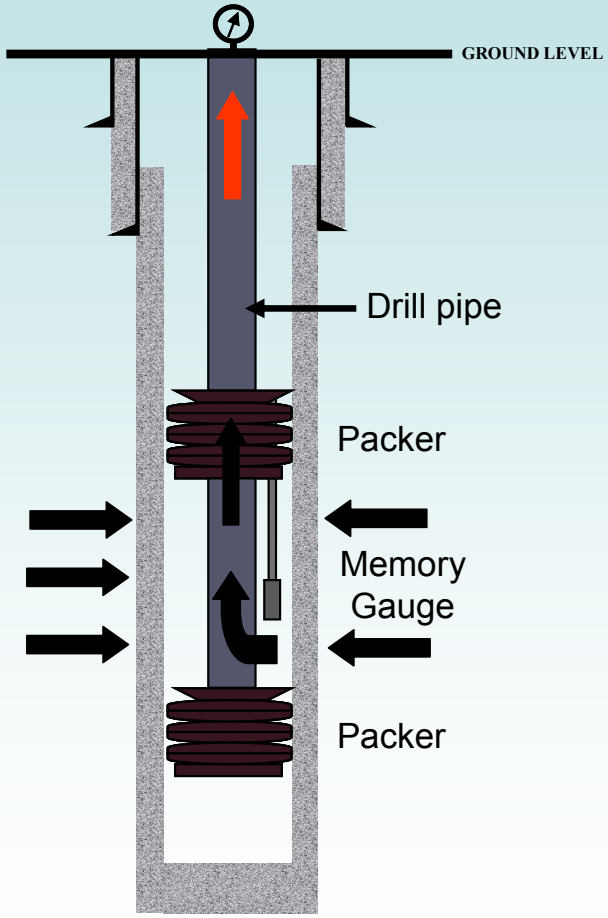
Perpendicular relation suggests borehole enlargement is in the direction of minimum horizontal stress.

Drill Stem Tests (DST) – Formation Evaluation

DST assembly prior to installation

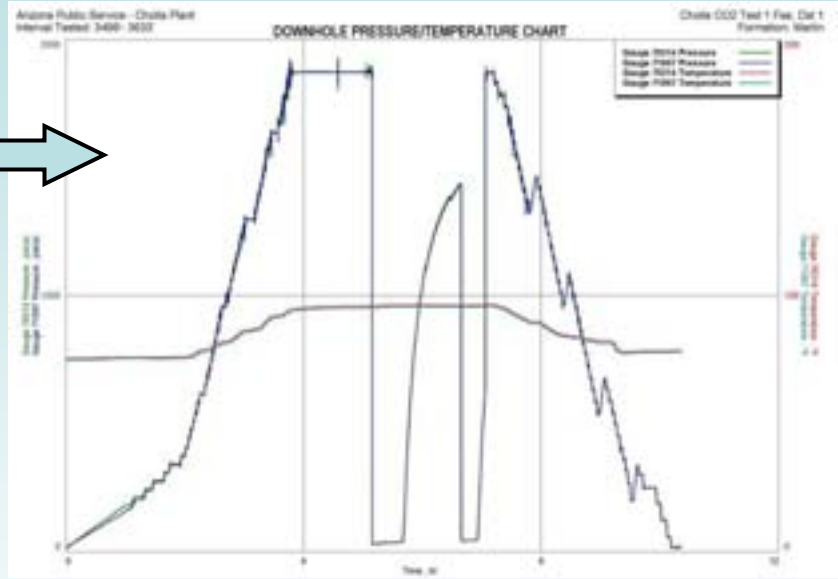
"Blow" at top of well

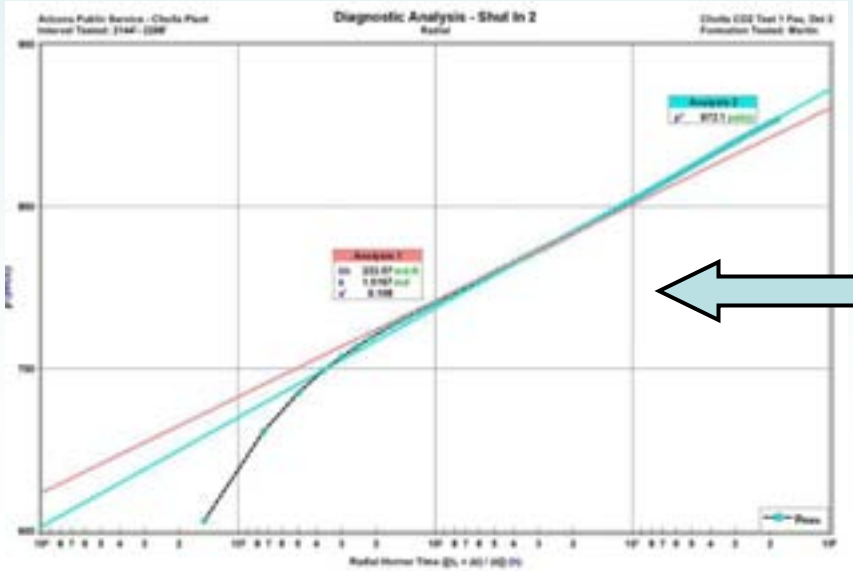
Upper pressure / temperature gauge assembly



Drill-Stem Test Results

- Martin Formation (3,498–3,633 ft)
- Radial flow did not develop
- Permeability too low to measure





- Supai Formation (2,144–2,298 ft)
- Radial flow
- Permeability = 1.5 mD

Rotary Side-Wall Cores (Results)

INVENTORY OF ROTARY CORE ANALYSES SAMPLES

Sandia Technologies
Cholla CO2 Test 1 Fee Well
Cholla Plant Field

Navajo County, AZ
File: H-44837
Date: 09-03-09

Weatherford LABORATORIES

	Sample Number	Sample Depth, feet	Net Confining Stress, psi	Permeability, millidarcys		Porosity, percent		Grain Density, gm/cc	Lithological Descriptions
				to Air	Klinkenberg	Ambient	NCS		
DST	1-1R	1340.00	350	0.068.	0.037.		6.4.	2.80.	Anhydrite halite?
	1-2R	2140.00	600	1.92.	1.51.	16.5.	16.4.	2.68.	Ss vfg-fg reddish scalc
	1-3R	2191.00	600	33.0.	28.0.	22.7.	22.7.	2.67.	Ss vfg-fg reddish scalc
	1-4R	2240.00	600	58.7.	51.0.	24.2.	24.1.	2.66.	Ss vfg-fg reddish scalc
	1-5R	2682.00	700	0.0012.	0.0002.	1.2.	1.2.	2.70.	Ls sandy reddish
	1-6R	3069.00	850	+		8.0.		2.66.	Mudstone calc spyr frac
	1-7R	3191.00	850	0.036.	0.017.	4.4.	4.4.	2.69.	Ls shly frac
	1-8R	3259.00	900	0.152.	0.094.	7.7.	7.7.	2.66.	Ss fg reddish calc
	1-9R	3301.00	900	0.0017.	0.0003.	4.5.	4.4.	2.70.	Ss fg calc
	1-10R	3322.00	900	0.0018.	0.0004.	1.6.	1.6.	2.72.	Ls crsxln
	1-11R	3433.00	950	+		8.6.		2.67.	Claystone scalc frac
	1-12R	3469.00	950	0.0062.	0.0019.	6.6.	6.6.	2.81.	Dol w/sd lam
	1-13R	3492.00	950	0.158.	0.099.	10.2.	10.1.	2.64.	Ss mg-crs calc
	1-14R	3521.00	950	0.018.	0.008.	8.0.	7.9.	2.74.	Ss fg-mg sdol
	1-15R	3526.00	950	0.015.	0.006.	10.3.	10.2.	2.81.	Dol sandy
	1-16R	3538.00	950	0.019.	0.008.	14.3.	14.3.	2.80.	Ss vfg-fg reddish sdol
	1-17R	3546.00	950	0.021.	0.009.	8.3.	8.2.	2.83.	Dol
DST	1-18R	3585.00	950	0.011.	0.004.	11.3.	11.2.	2.82.	Dol sandy
	1-19R	3588.00	950	0.014.	0.005.	11.6.	11.6.	2.81.	Dol sandy
	1-20R	3600.00	950	2.49.	1.93.	9.7.	9.7.	2.64.	Ss fg-mg
	1-21R	3613.00	950	0.045.	0.023.	17.0.	16.9.	2.82.	Dol lmy
	1-22R	3633.00	1000	0.040.	0.019.	13.9.	13.8.	2.82.	Dol reddish streaks
	1-23R	3654.00	1000	+		7.6.	7.5.	2.69.	Ss vfg-fg reddish frac
	1-24R	3678.00	1000	0.106.	0.062.	5.9.	5.8.	2.64.	Cong mic reddish
	1-25R	3740.00	1000	0.0027.	0.0007.	0.4.	0.4.	2.65.	Cong spyr mic reddish wcmt

Source: Sandia Technologies LLC

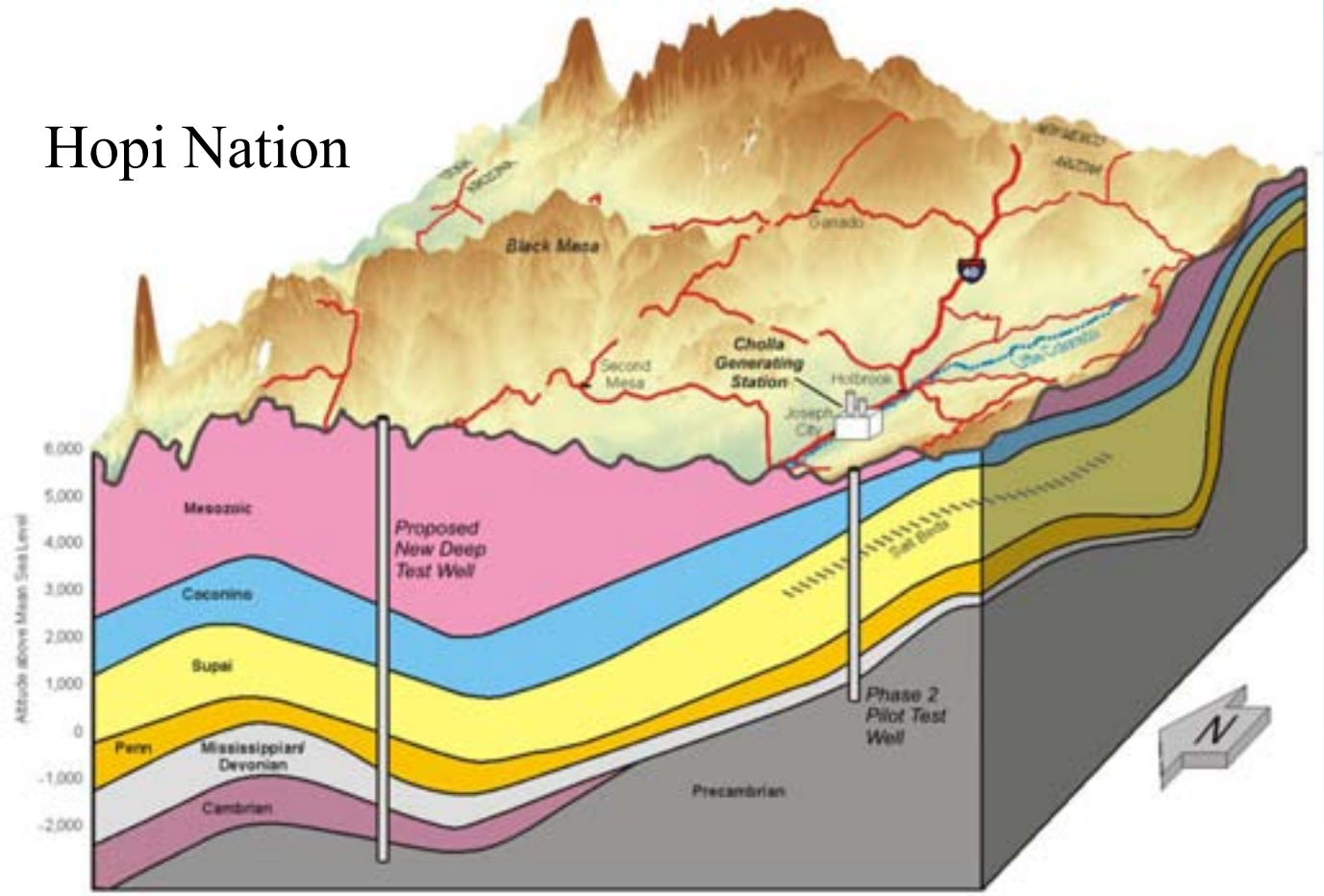
Permeability & Porosity Comparison

Supai Formation	Geometric Mean k (mD)	Average Porosity (%)
- DST	1.5	--
- CMR & Neutron Porosity logs (Elan)	8.2	21.0
- Core (n=3)	12.9	20.8
Martin Formation		
- DST	--	--
- Core (n=11)	0.015	10.5

Site Summary

- Martin and Naco Formation
  - No permeable vuggy zones
  - Minor evidence of fracturing at basement interface
  - No injectivity at the well site
- Supai Formation
  - Reservoir pressure (852 psi) below CO_2 supercritical point
- Permeability too low to support commercial-scale CO_2 injection at the well site
- Local conditions may not be representative of entire region
  - Supai Formation dips to the north
  - Martin sandier to the east toward the Defiance Uplift
- Alternative targets exist (e.g., Tapeats Sandstone)

Future Direction



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- Regulatory agencies
  - USEPA, ADEQ and AZ O&GCC

Photo source: R. Trautz, EPRI