

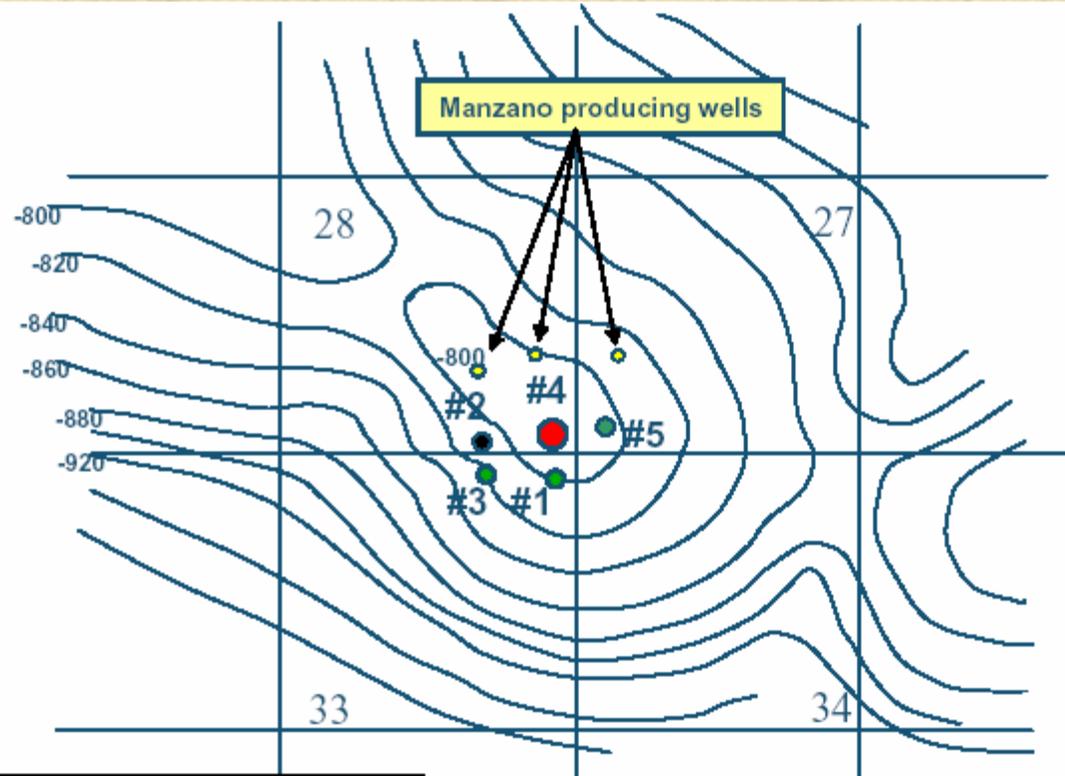
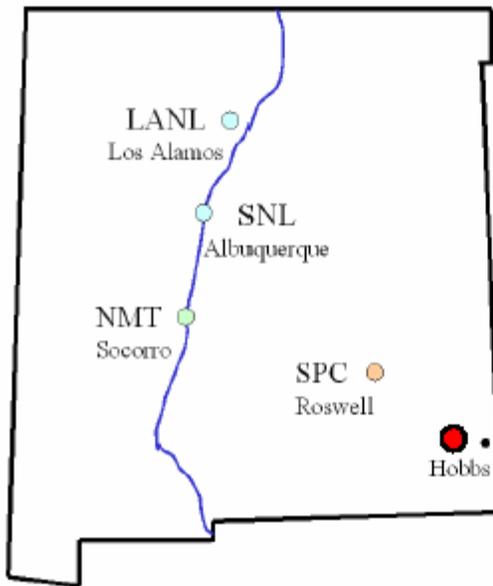
Geologic Considerations for CO Injection at the West Pearl Queen Field

John C. Lorenz and Scott P. Cooper

Sandia National Laboratories,
Albuquerque, NM

funded by the National Energy Technology
Laboratory, Morgantown, WV

Geology and Location

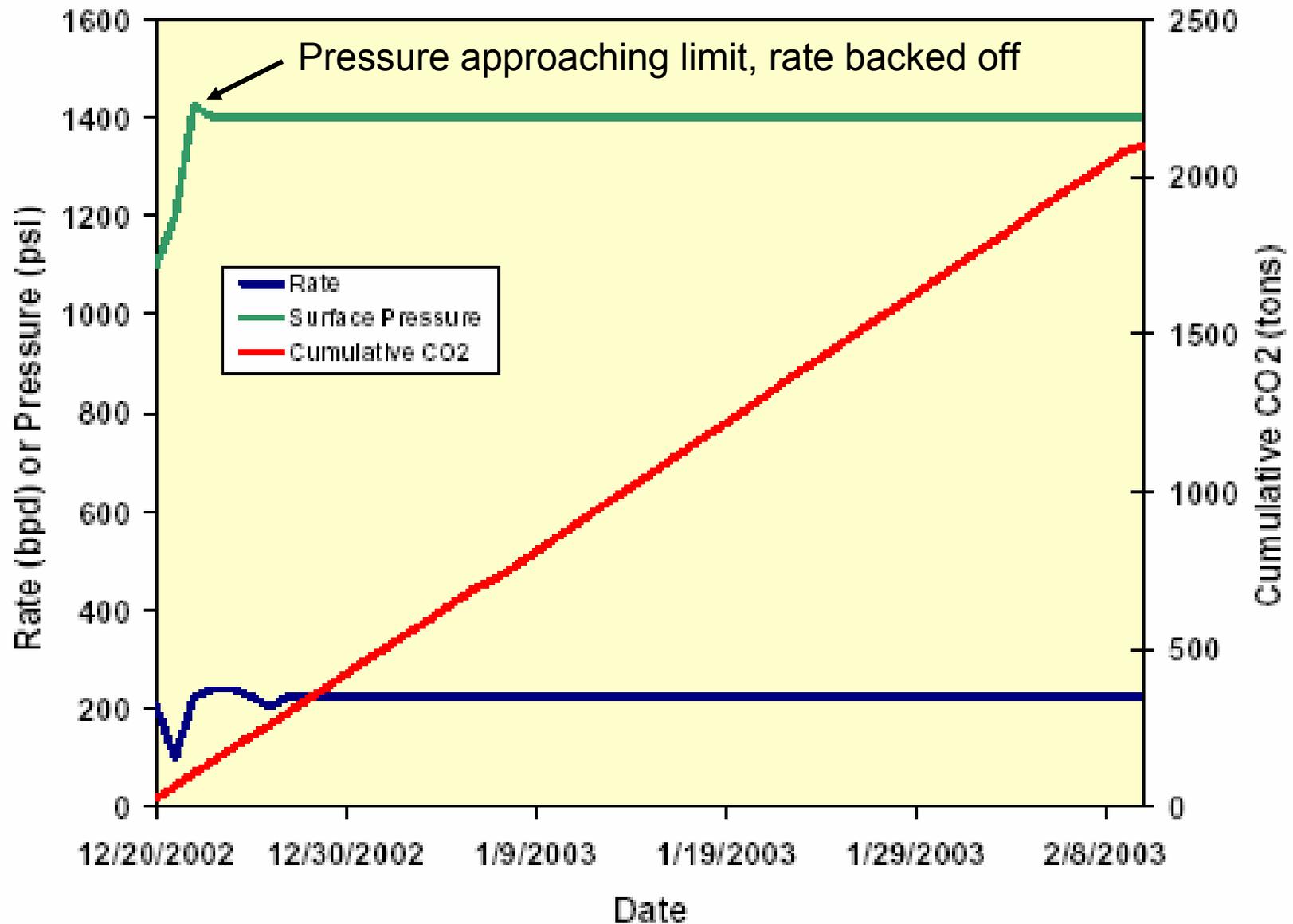


First Production in 1984
Produced about 250000 barrels of oil till 2000
No enhanced oil recovery operations

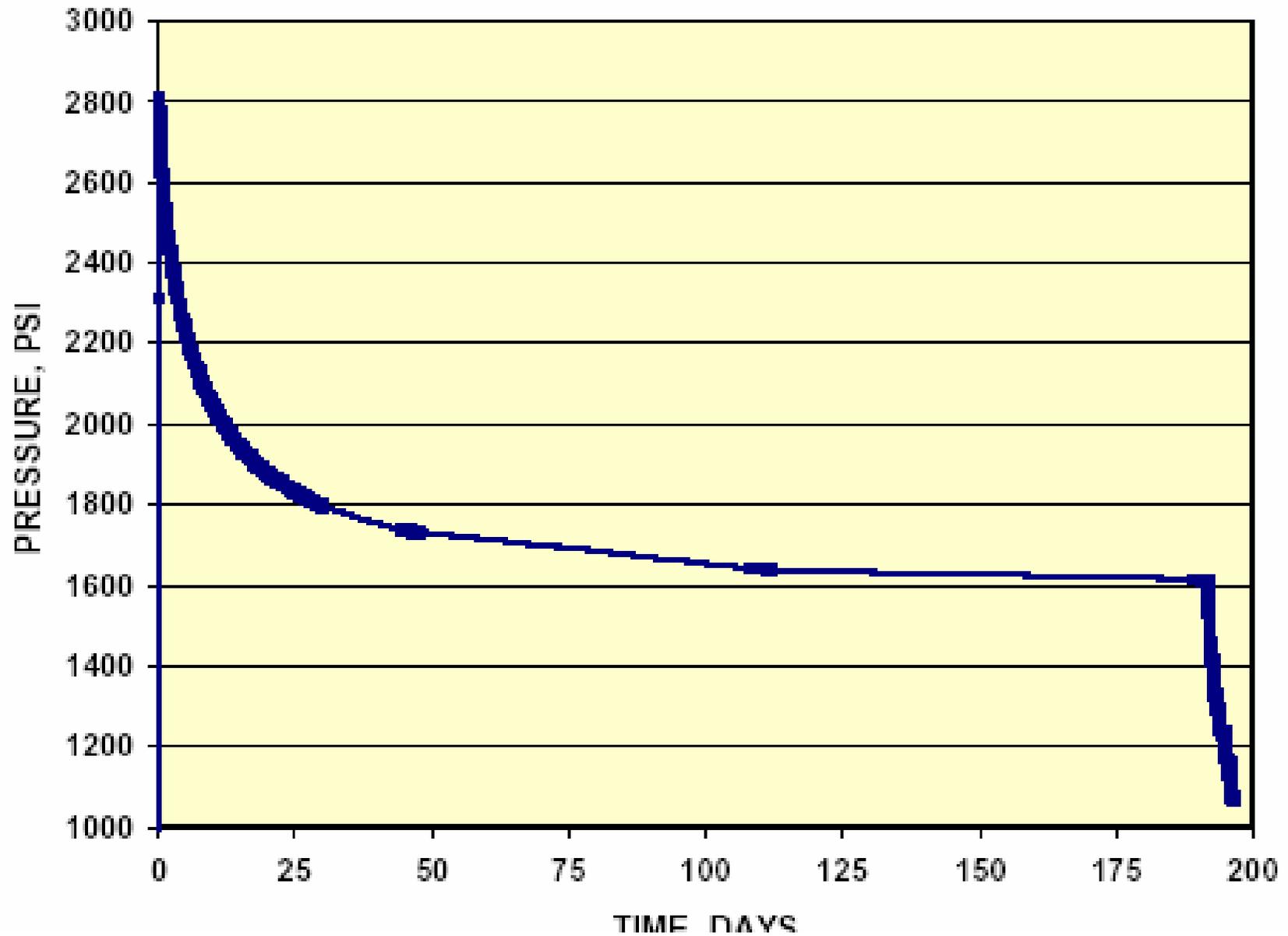
Strata Production Co. Wells

- #4 CO₂ Injection & monitoring well
- #5 Monitoring & producing well
- #1&3 Waste water injector well
- #2 Plugged well

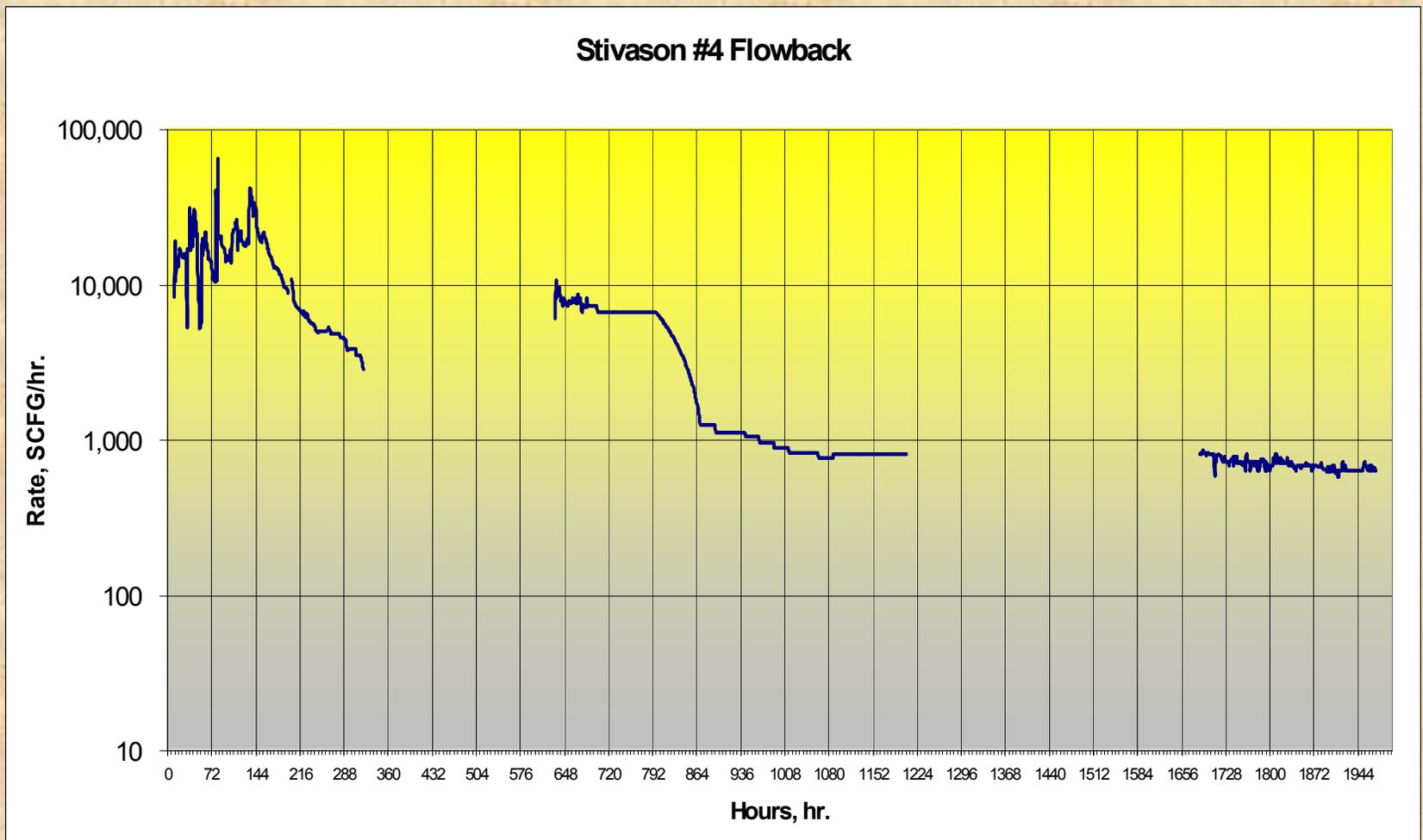
Injection: Anticipated 100 t/d, Actual 40 t/d



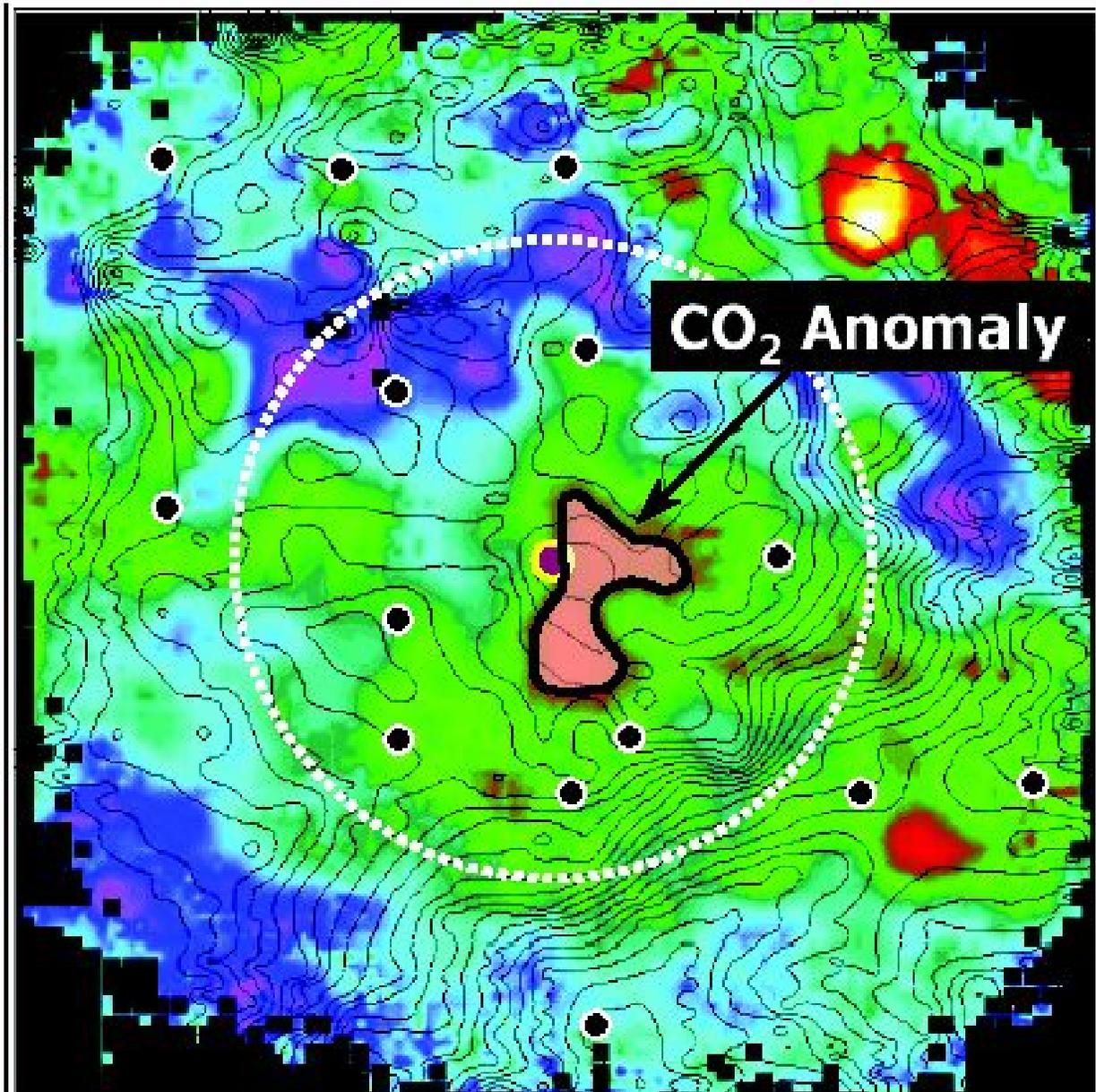
Soak: Rapid Pressure Equilibration



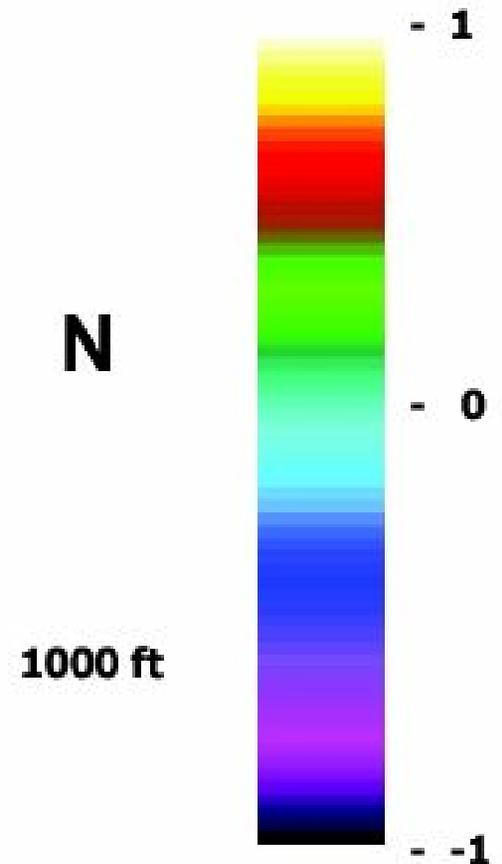
Injected 34 MMCF
Recovered 5.8 MMCF (16.9%)



Queen RMS Amp. Difference



RMS Amp. Difference
Base - Monitor



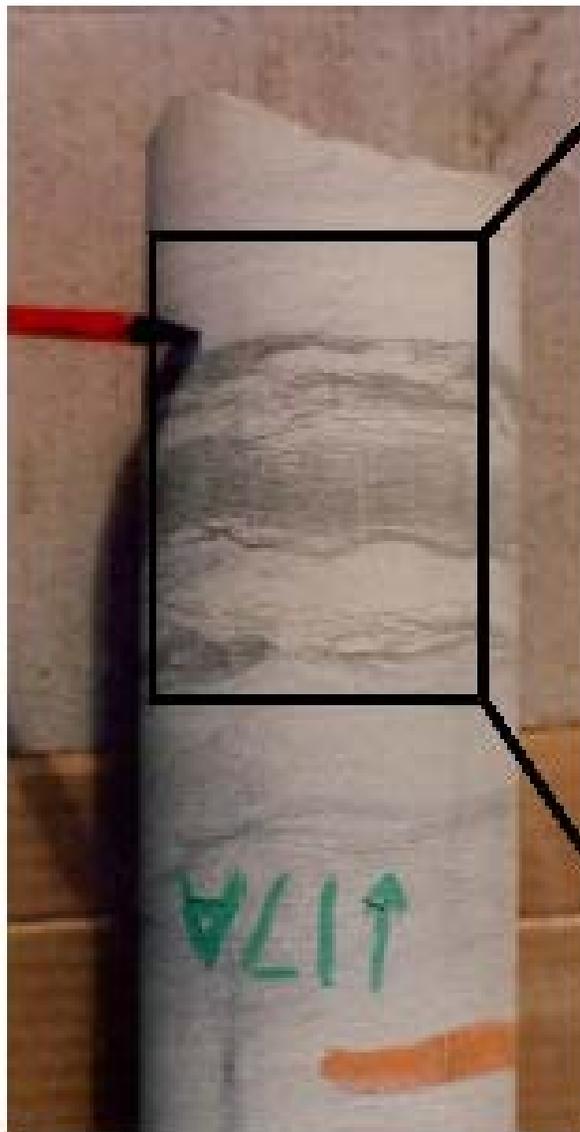
Depth Structure Overlay
Top of Queen
CI = 4 ft

Puzzling Results

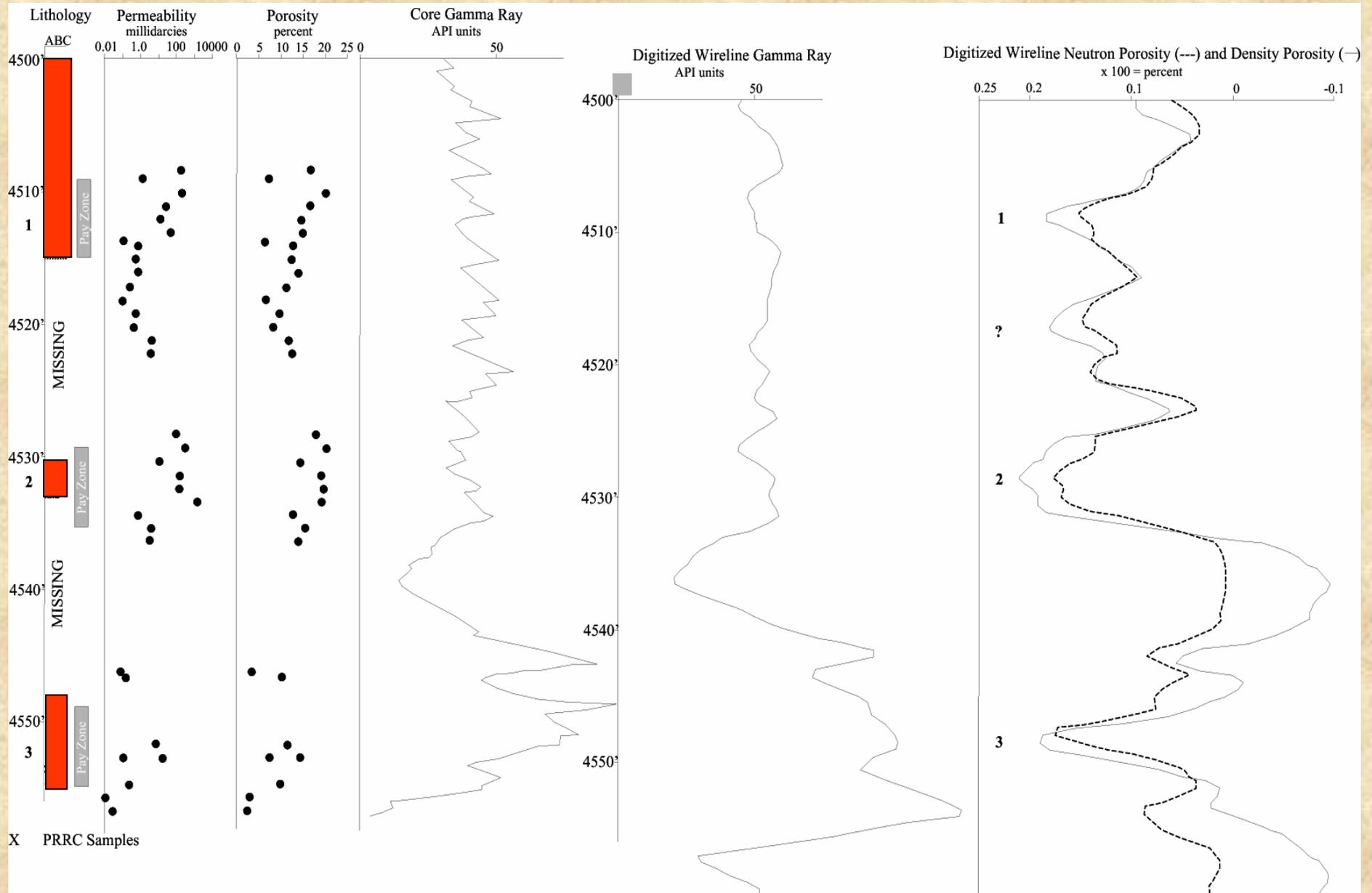
- Excessive injection pressure
- Rapid pressure equilibration
- Minimum volume of post-soak recovery
- Slow CO₂ migration to adjacent wells
- No EOR effects on adjacent wells
- Localized gas plume at the base of the injection well

“Let’s look at the Geology”





Reservoir is a feldspathic sandstone

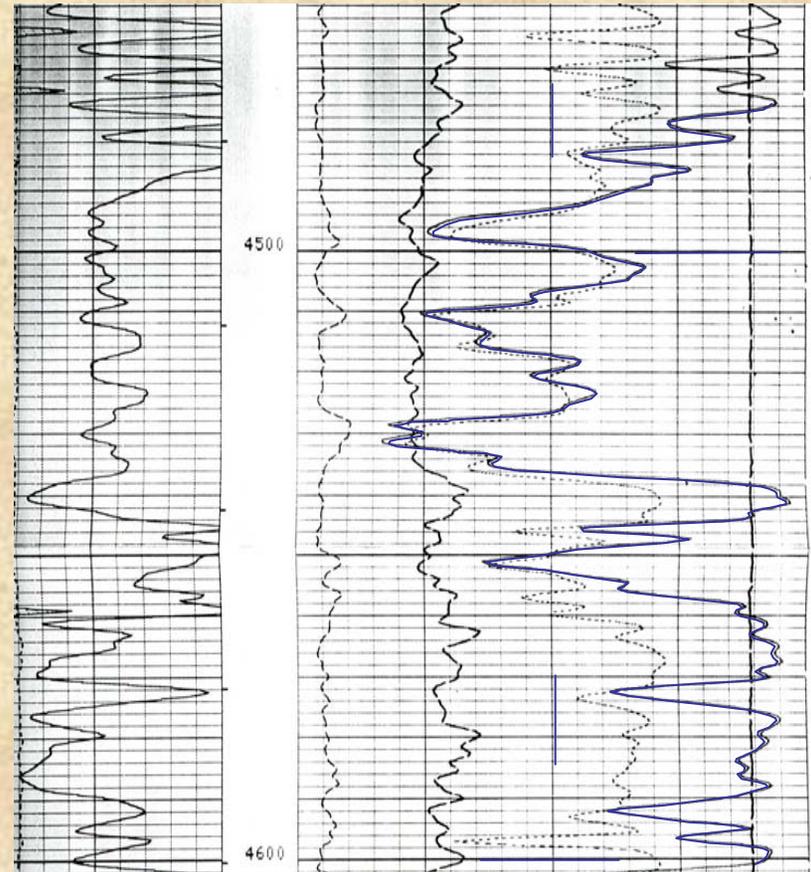
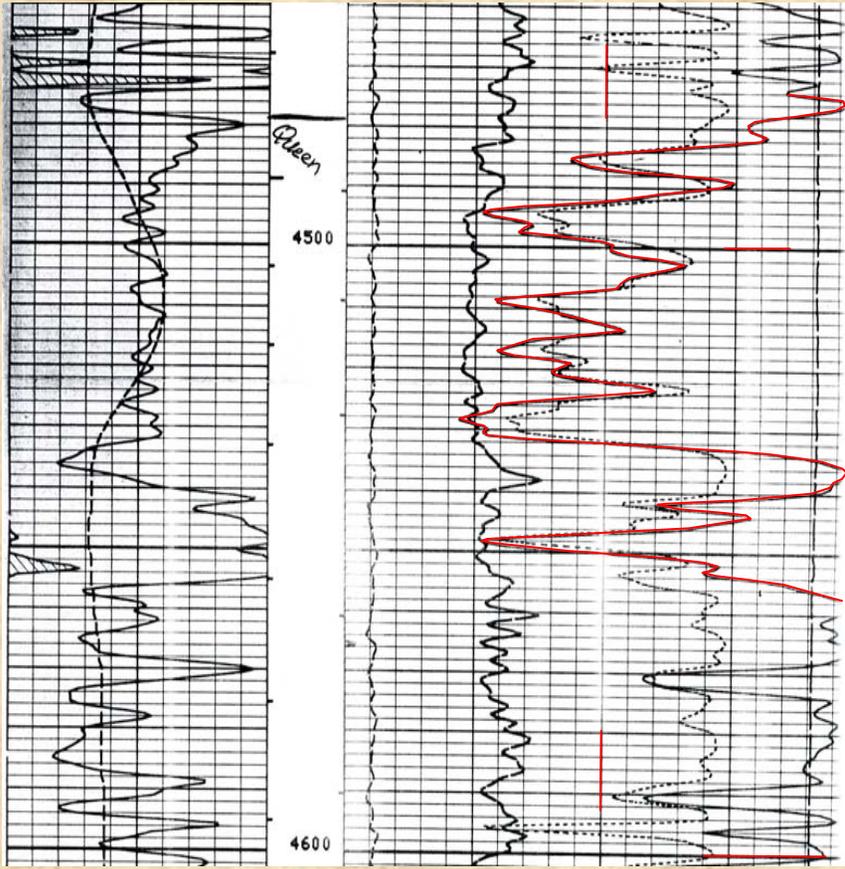


Gamma Ray

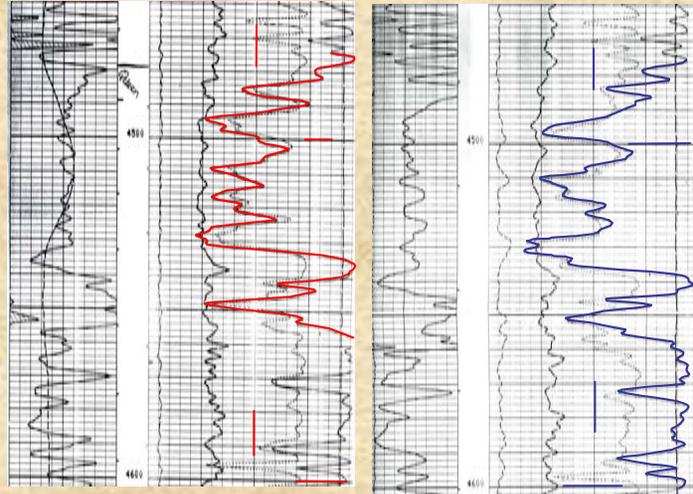
Resistivity

Gamma Ray

Resistivity



----1000 ft/300 m----

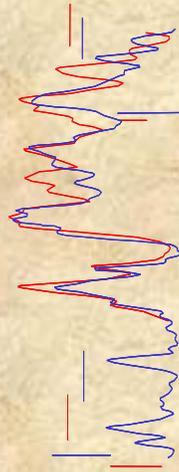
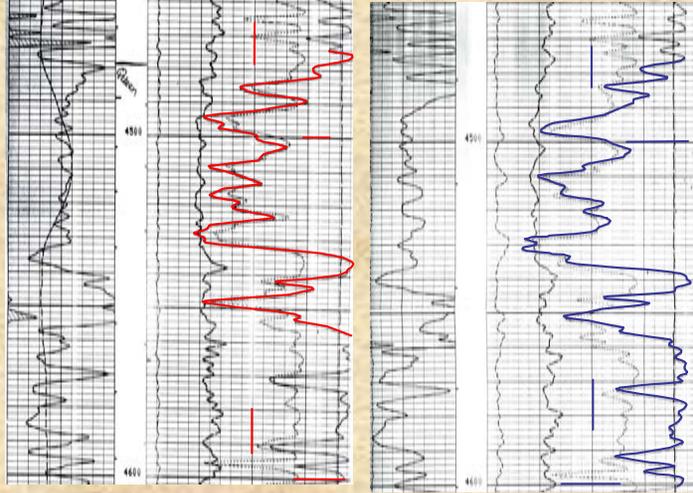


----1000 ft/300 m----

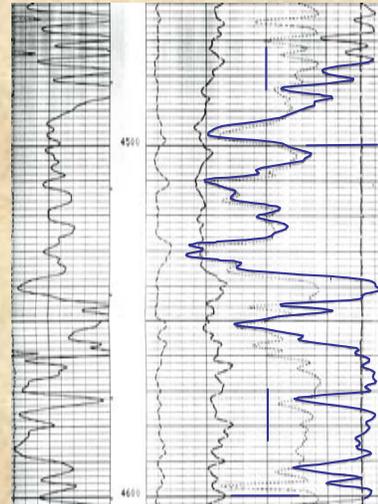
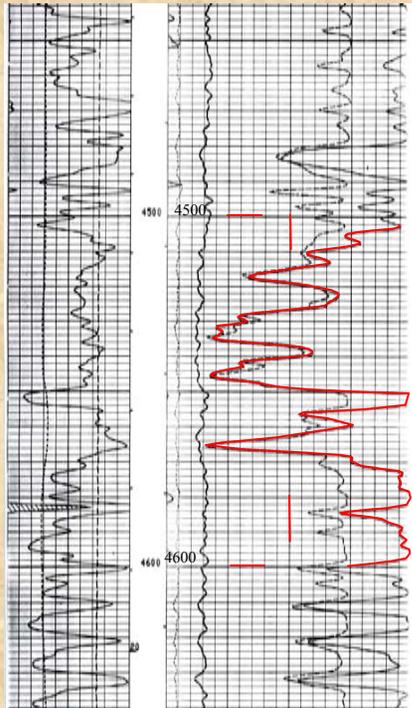


Stivason Fed. #4

Stivason Fed. #1



Different
development
of component
beds

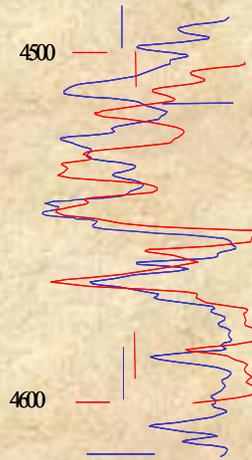
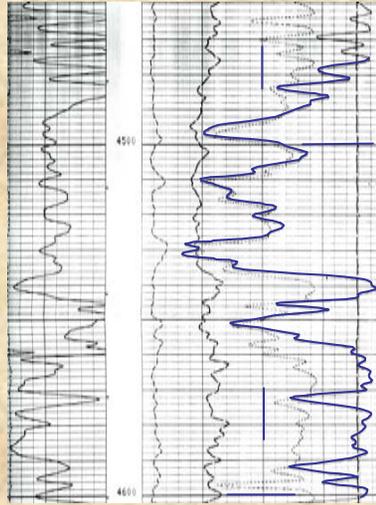
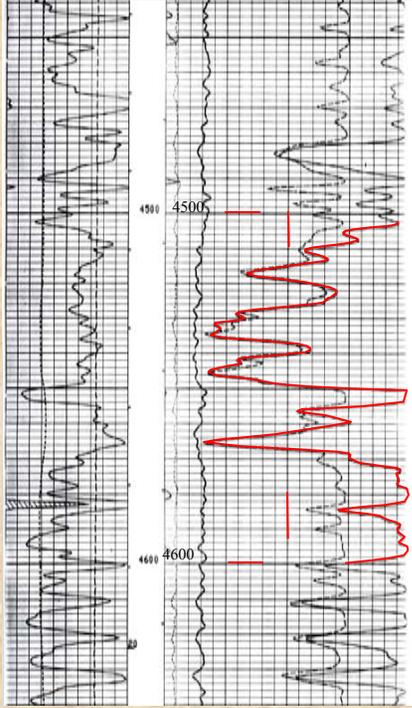


---3000 ft/1000 m---



Stivason Fed. #1

Sun Pearl Federal #3



Total package thins to the north

Component beds come and go





















North

South

4500

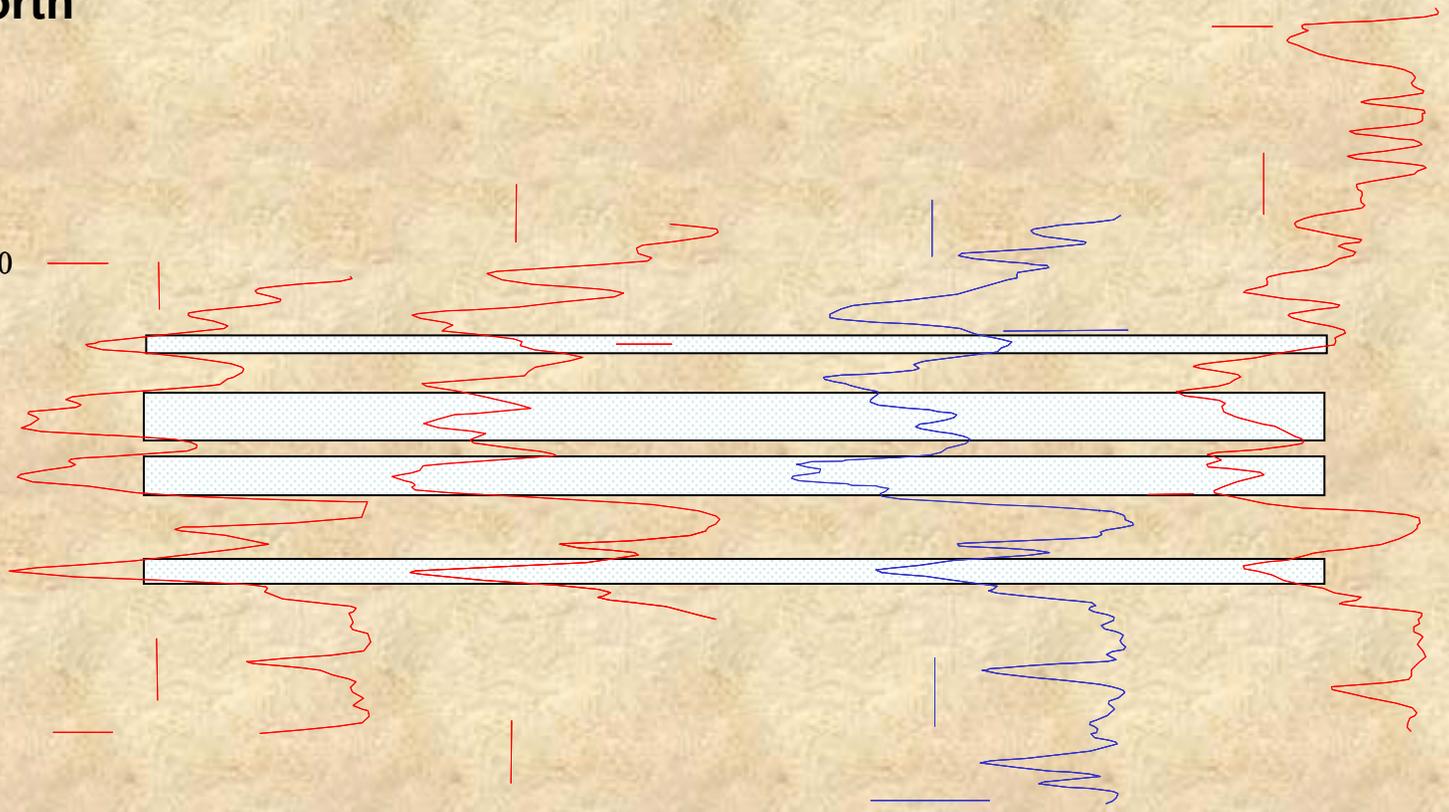
4600

Sun Pearl
Federal #3

Stivason
Fed. #4

Stivason
Fed. #1

Mallon 33
Fed. #4

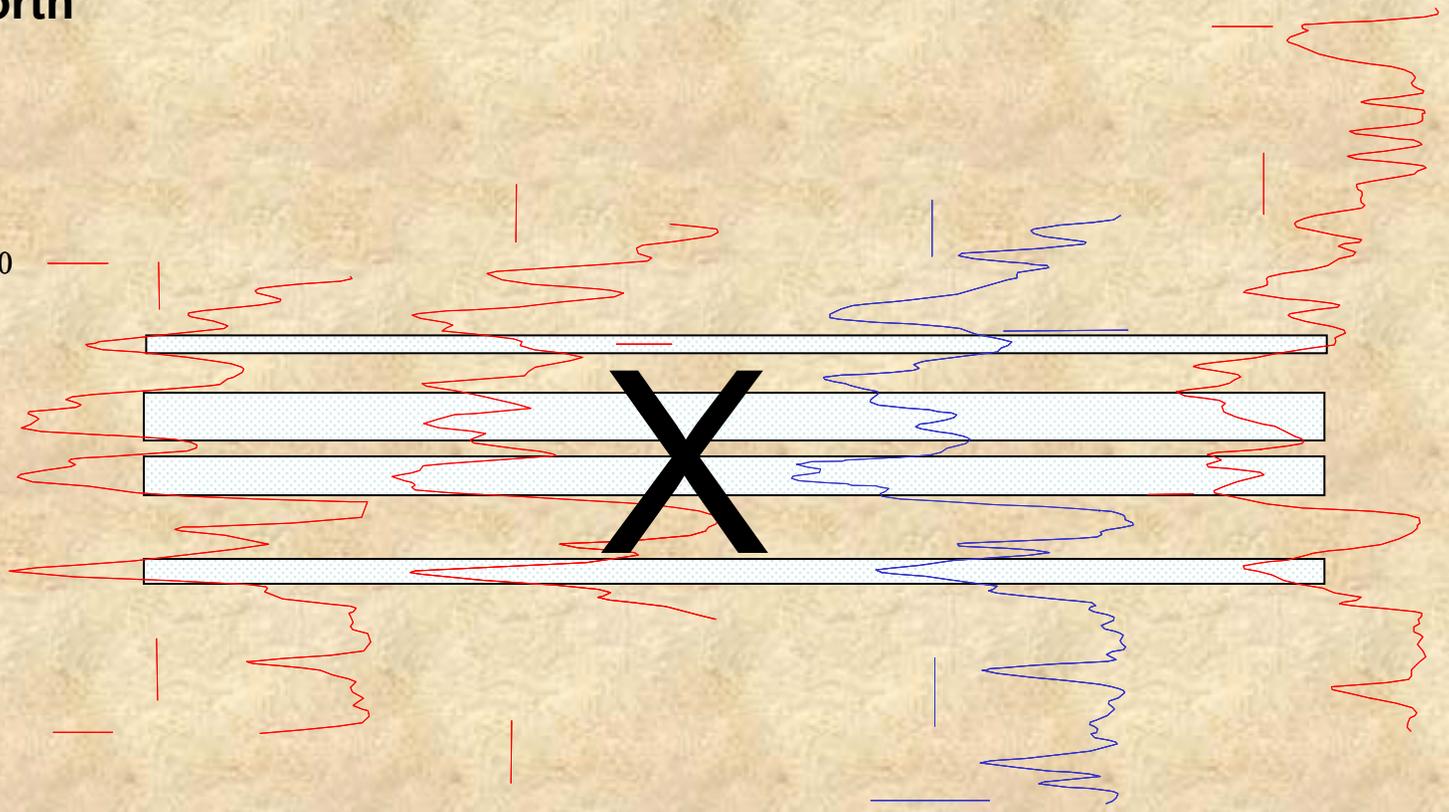


North

South

4500

4600



Sun Pearl
Federal #3

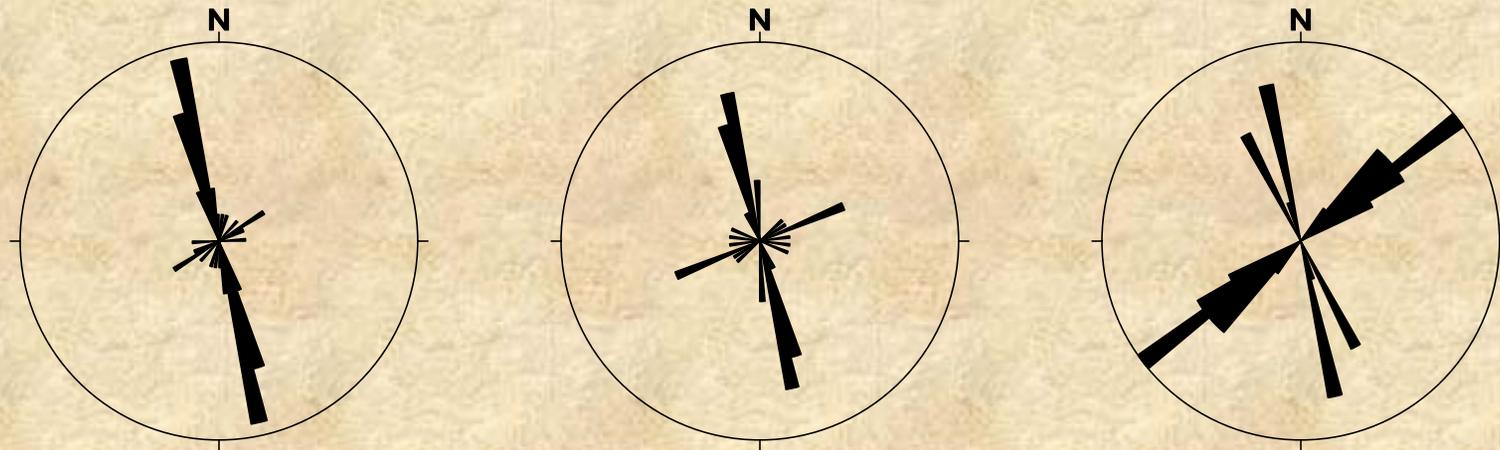
Stivason
Fed. #4

Stivason
Fed. #1

Mallon 33
Fed. #4

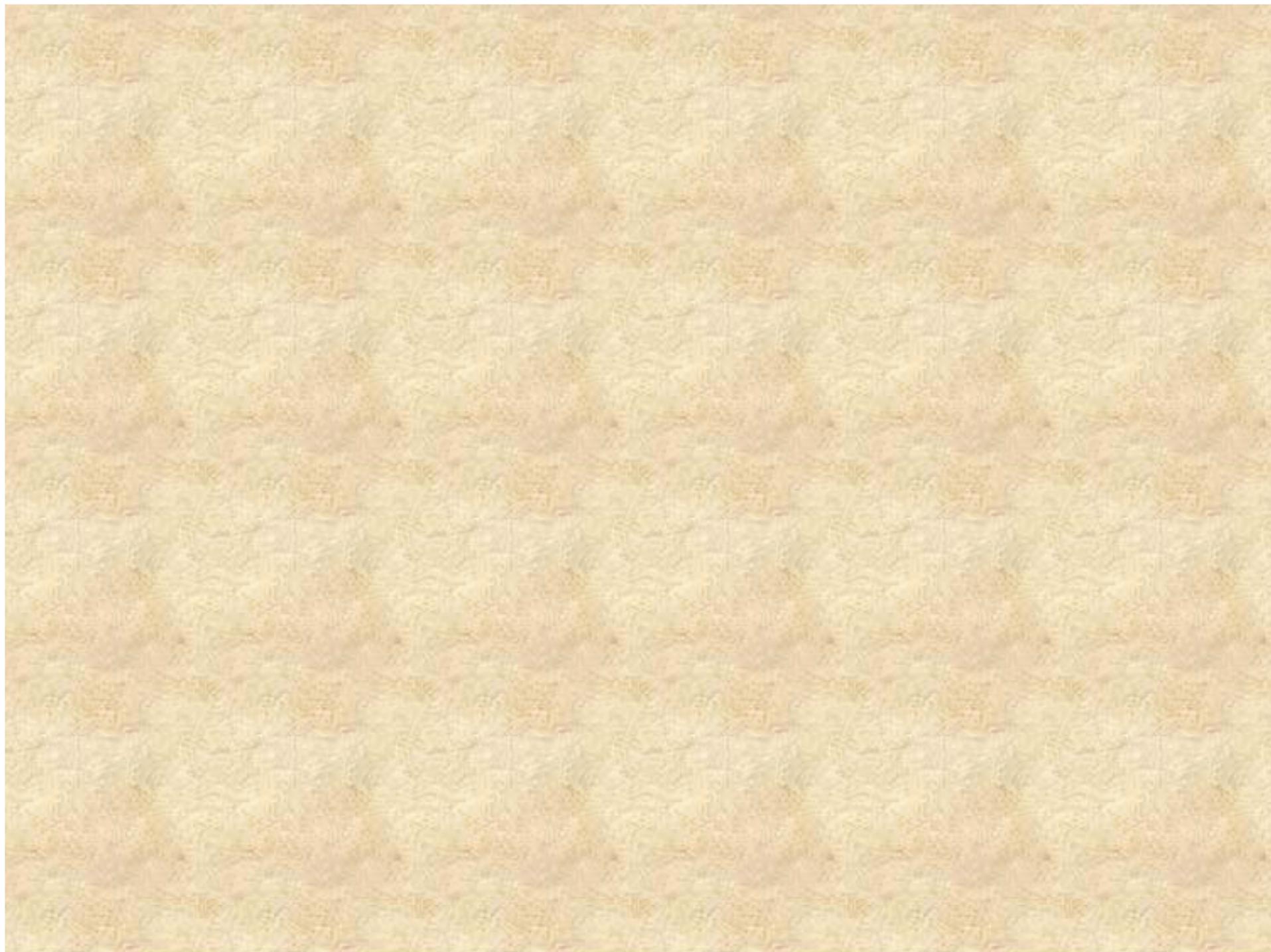


Fracture Strikes in Outcrop



Conclusions: Reasons for High P, Localization of CO₂

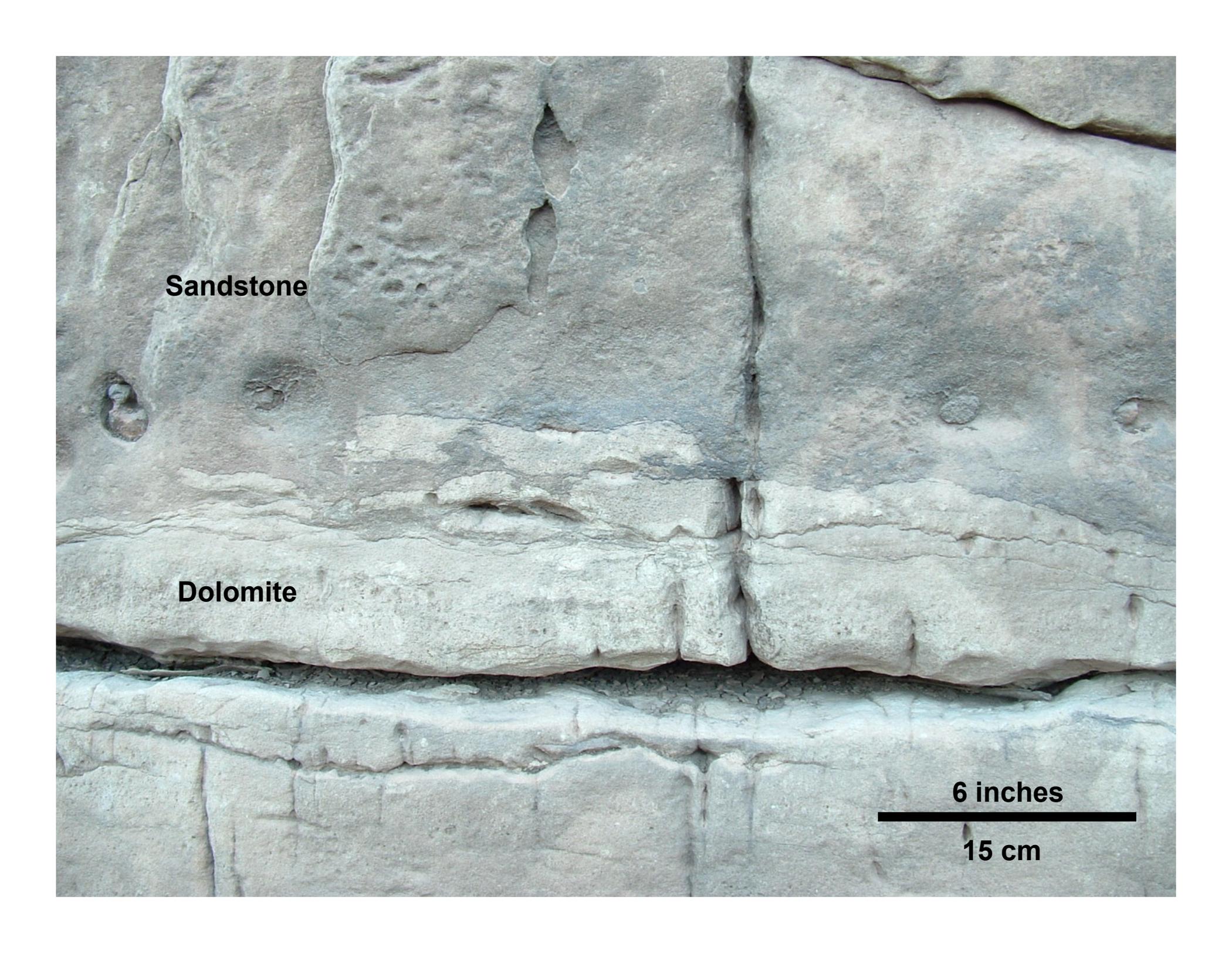
- Bedding is discontinuous at the scale of hundreds of feet
 - Channels
 - Dune edges
 - Thickened lenses
 - Tempestites
- Fractures are likely











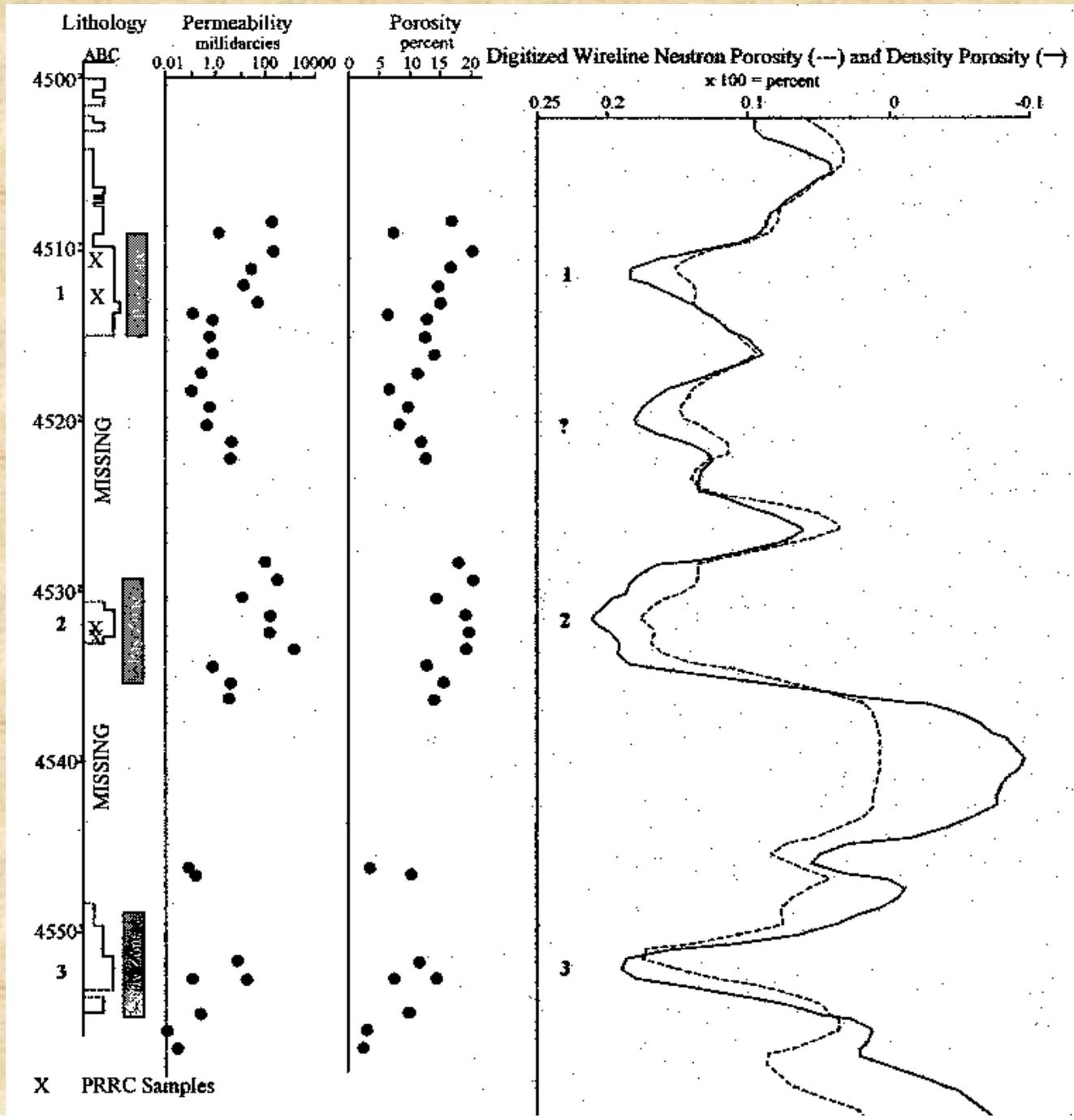
Sandstone

Dolomite

6 inches

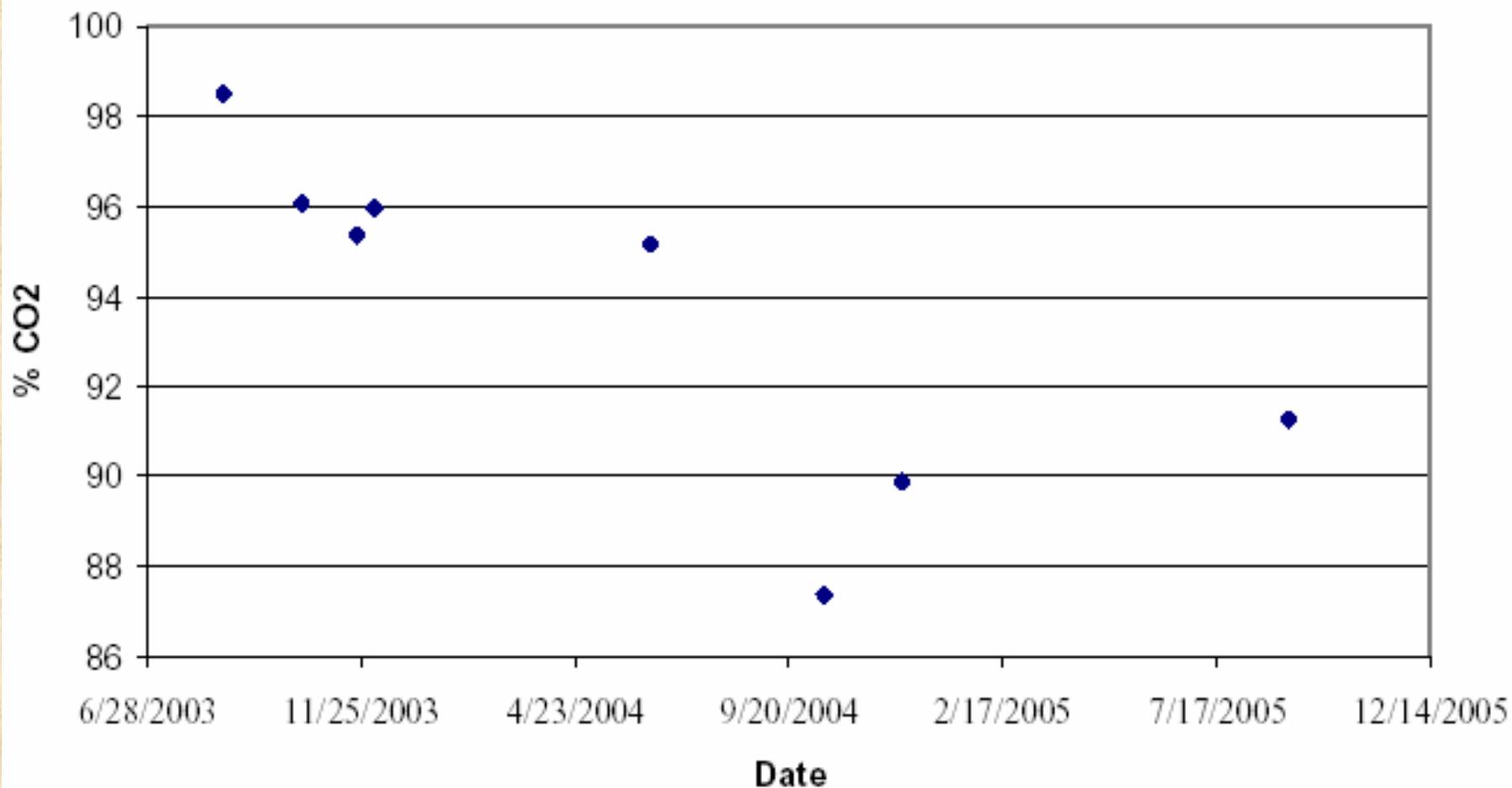
15 cm



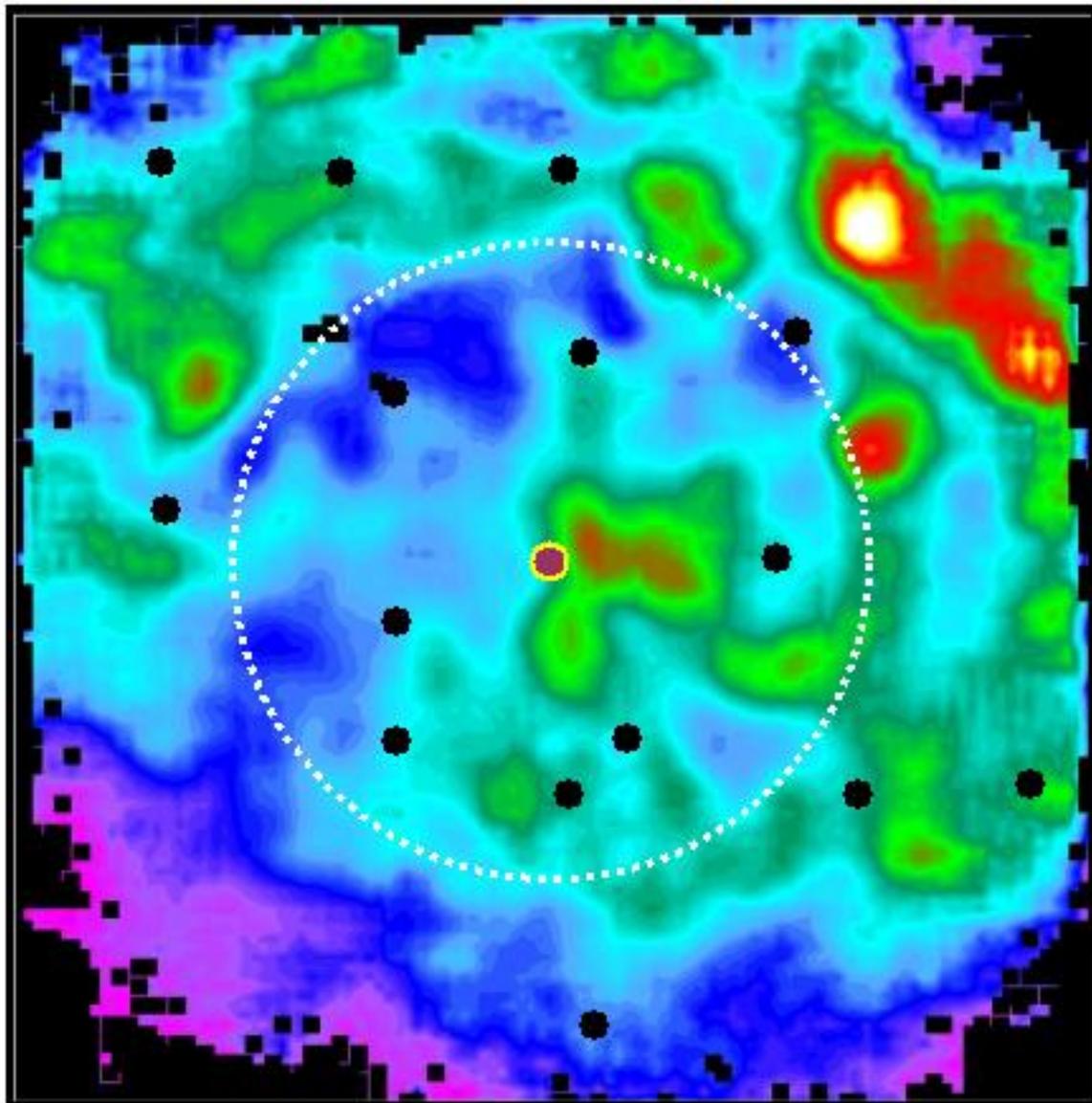


Several porosity zones in the sandstone reservoir

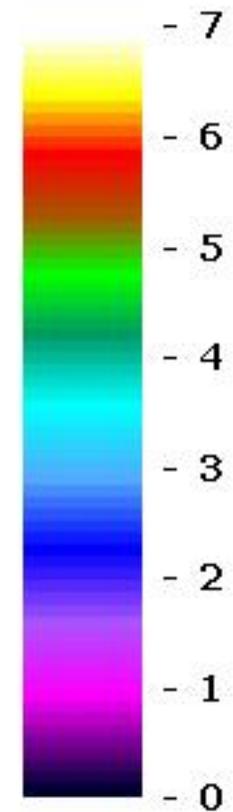
Produced Gas Composition: Stivason Federal #4



Queen RMS Amp. - Baseline

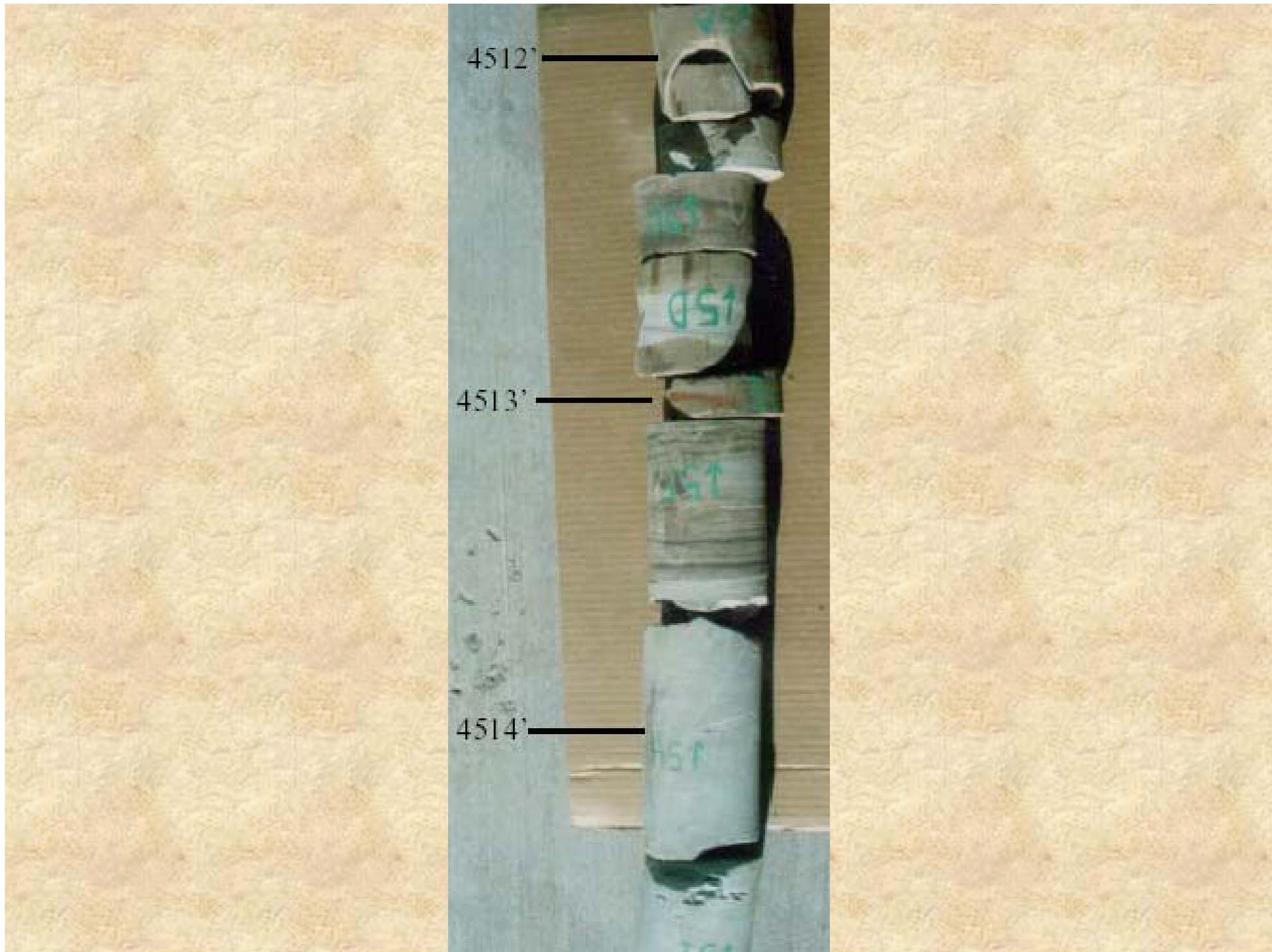


RMS Amplitude

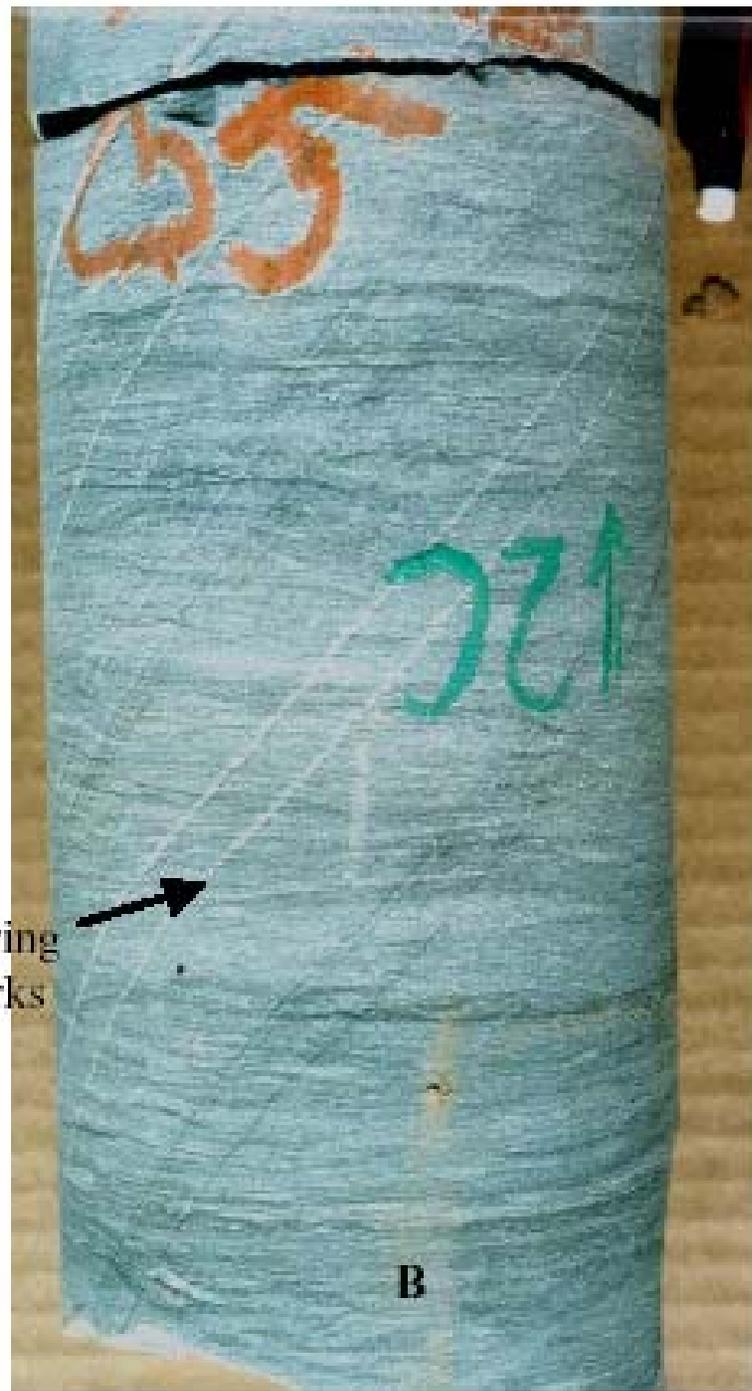


1000 ft









← Coring marks →

A

B

Stivason Federal #4 Flowback

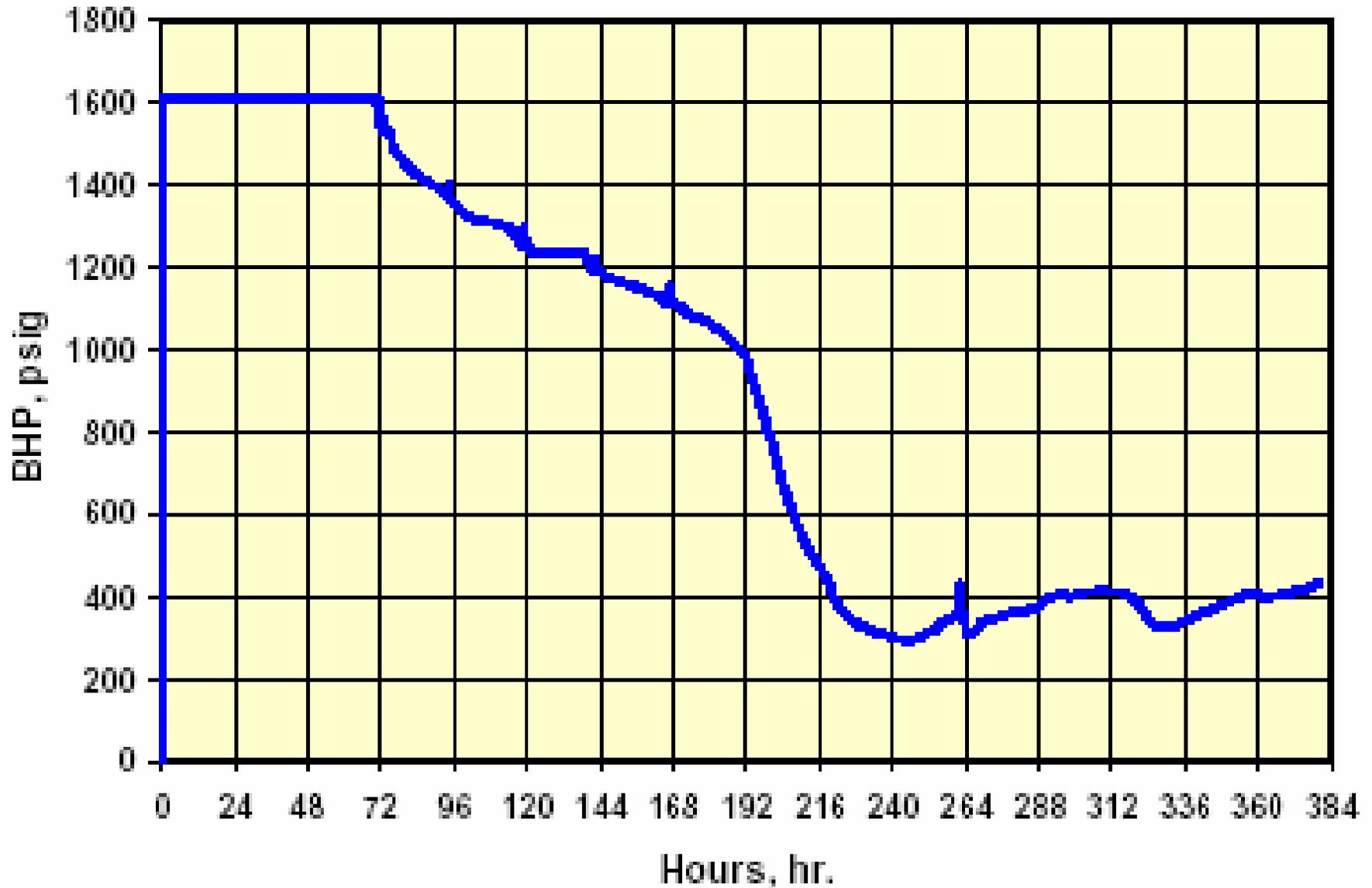
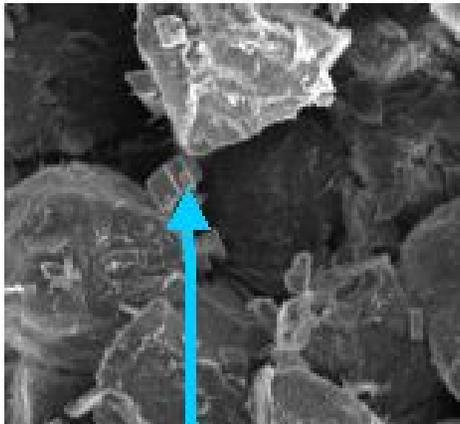


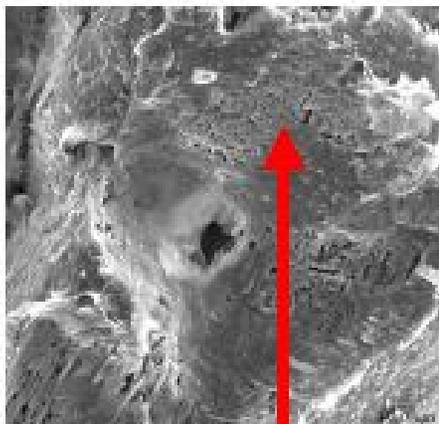
Figure 6.3. Bottom-hole pressure drop during initial part of blow down.

Static Laboratory Experiments

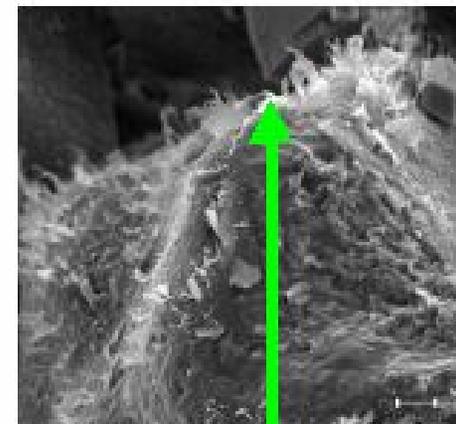
Reacted Sample (17 Months)



K-feldspar remains stable



Na-Ca-feldspar (Albite) Dissolves



Significant Clay Growth Occurs

Brine Chemistry (17 Months)

	Al (ppm)	Si (ppm)	Na (ppt)	K (ppt)	Mg (ppt)	Ca (ppt)	Cl (ppt)	SO ₄ (ppt)	HCO ₃ (ppt)
Pre-Test	0.05	12.3	52	1.6	3.1	3.1	109	1.8	0.12
19 months	0.33	3.6	54	1.6	4.2	3.8	104	1.8	-----

- Changes in Al and Si are consistent with growth of clays.
- Increased Mg and Ca are consistent with carbonate dissolution.
- Constant SO₄⁻ shows that increased Ca failed to initiate gypsum or anhydrite ppt.
- K-feldspar apparently did not dissolve to any significant degree

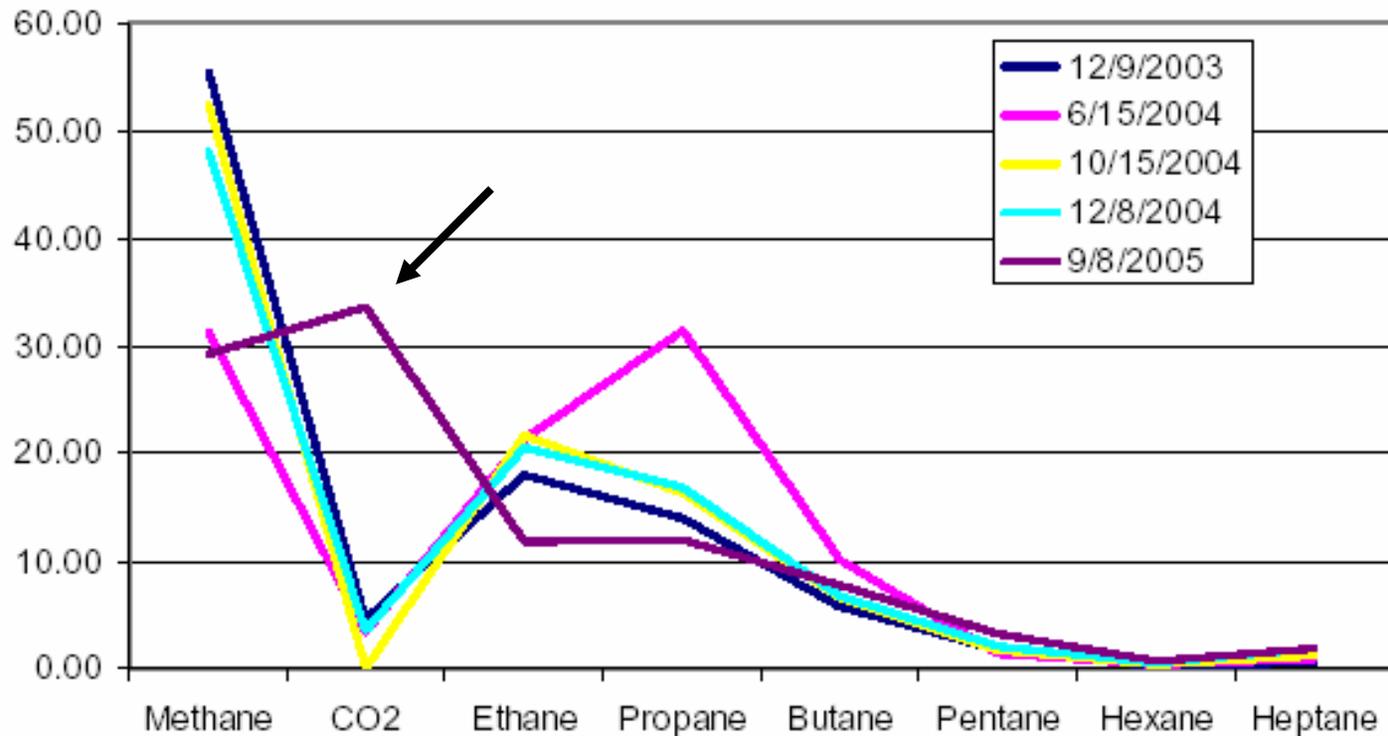
Field Experiment Observations

- **Low injection rates**
 - Tighter reservoir
- **Lower production rates during venting**
 - Possible impact of CO₂ on reservoir rock behavior or plume dissipation away from injection well
- **Produced about 40% of injected CO₂ over 2 years of production.**
- **No production response on offset wells**
 - Migration of CO₂ towards offset well limited
- **CO₂-reservoir fluid interactions**
 - Produced oil composition indicate oil/CO₂ interactions
 - Produced brine composition non-conclusive
- **P-wave time-lapse seismic anomalies able to discern subtle changes in reflection amplitudes due to CO₂ plume**
 - No indication of upward migration



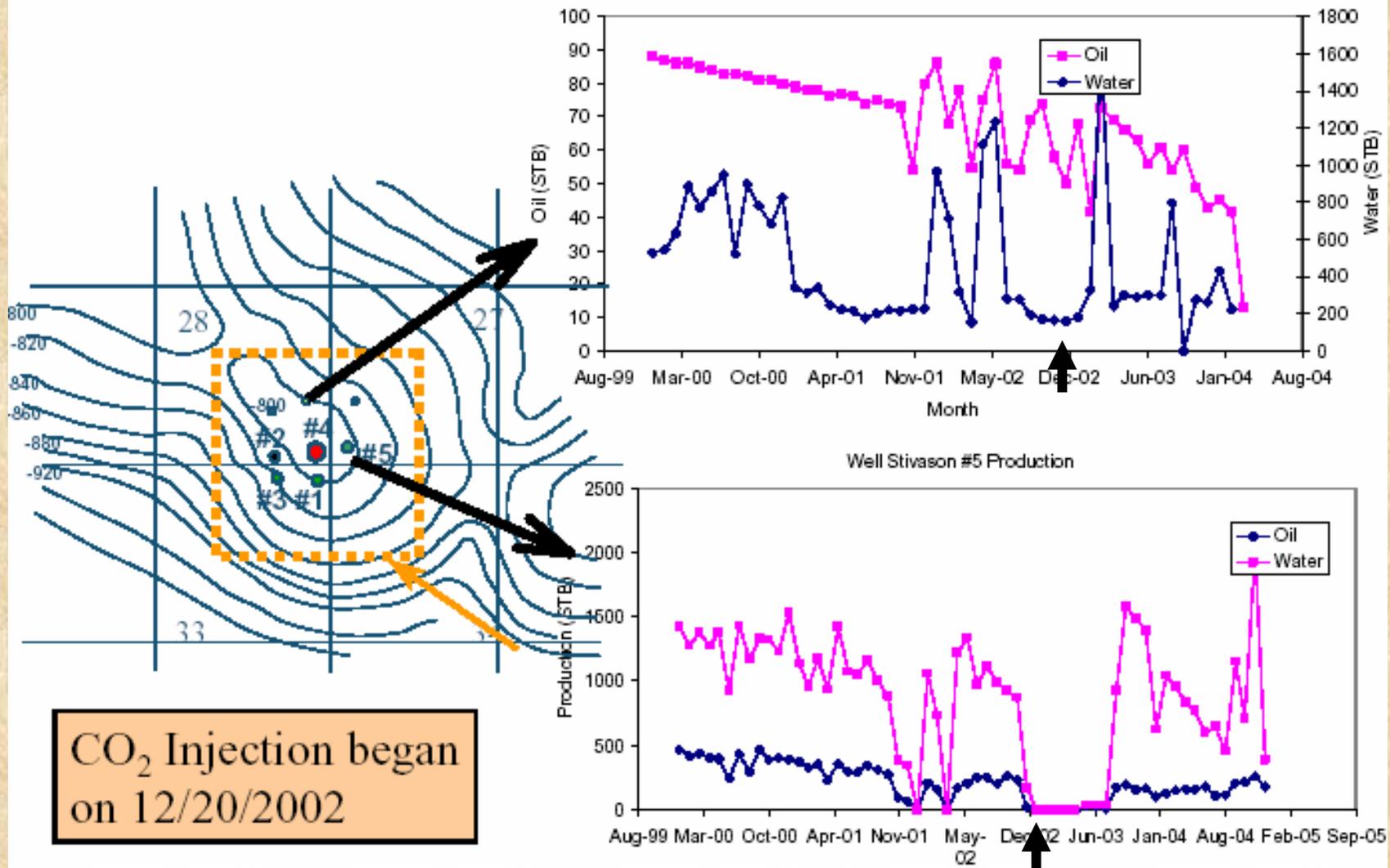
CO₂ breakthrough *three years* after start of injection

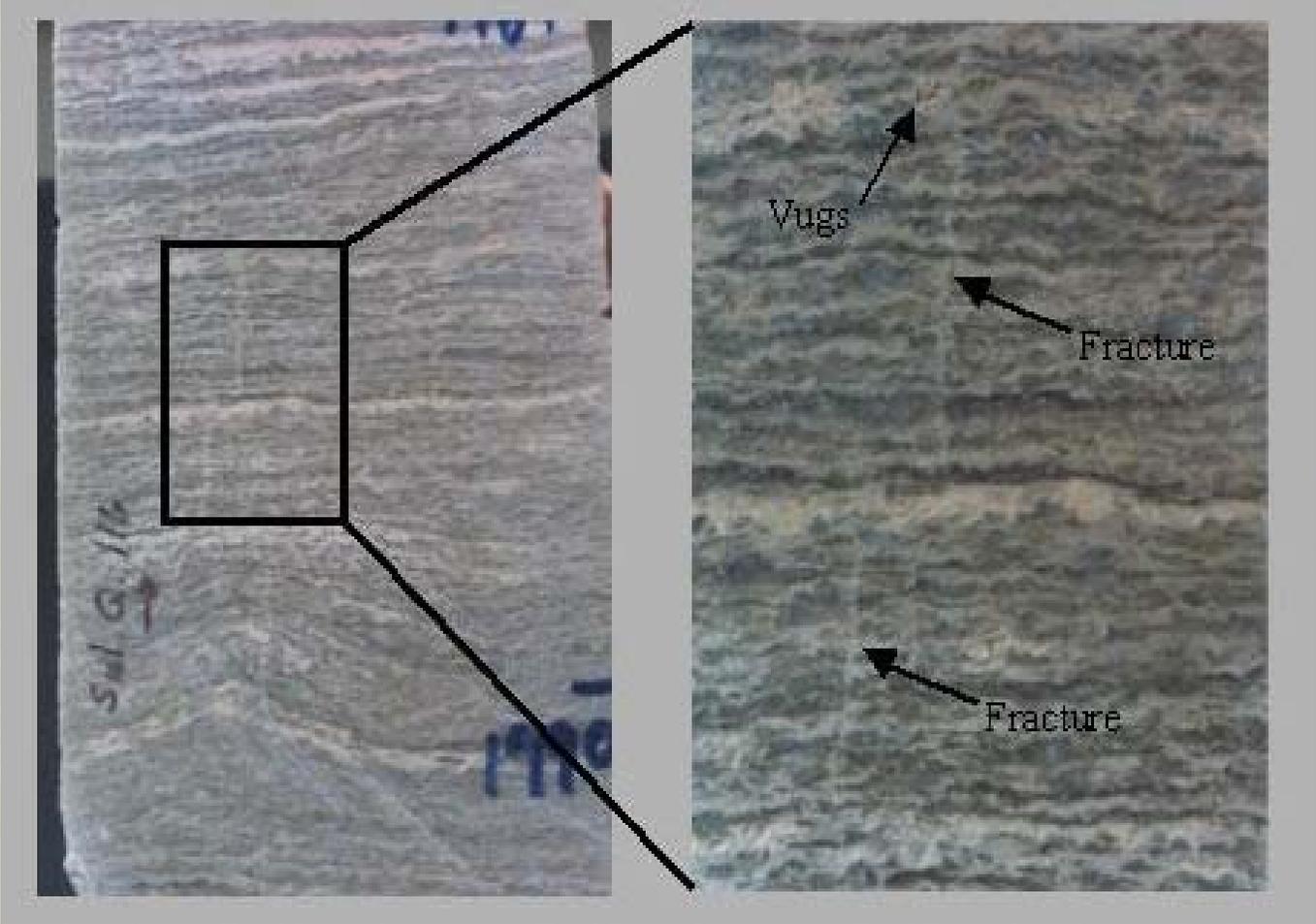
Produced Gas Composition: Stivason Federal #5



No enhanced oil production

Offset Well Production





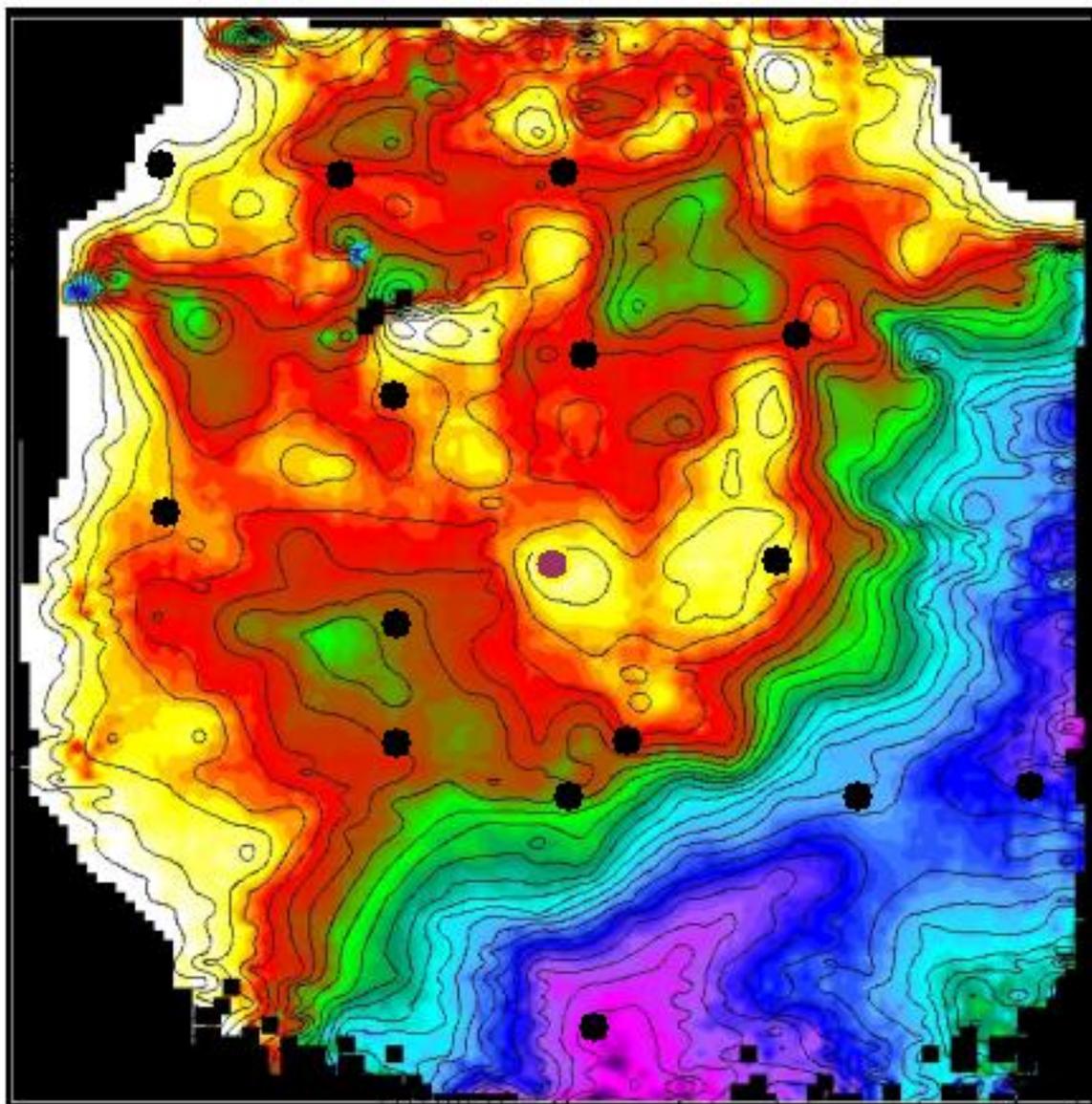
West Pearl Queen Geology

- Irregularly bedded sandstone, siltstones and sandy siltstones
 - 65 % quartz, 25 % feldspar, dolomite and calcite cement
- The reservoir is layered, with three high-porosity zones separated by shaley units
 - Net thickness: 25 feet, gross thickness: 40 feet
- Best matrix permeabilities are on the order of 100 md, porosities about 15-20%
- No known faults
- Natural fractures are probable, most likely to trend NE-SW
 - Fractures do not appear to contribute to flow
- Predicted stress anisotropy, maximum NE-SW

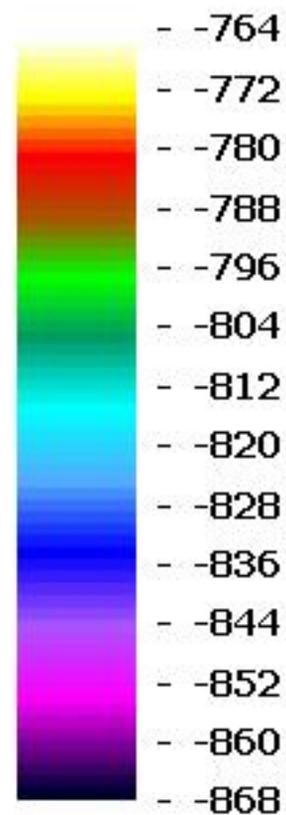




Queen - Depth Structure Map



Sub-Sea Depth (feet)



CI = 4 ft

1000 ft







Generalized Stratigraphic Column

Period	Epoch	Formation		
Permian	Ochoan	Dewey Lake		
		Rustler		
		Salado		
	Guadalupian	Artesia Group*	Tansill	
			Yates	
			Seven Rivers	
			Queen	
			Grayburg	
			San Andres	
			Glorieta	
	Leonardian	Yeso Group	Paddock	
			Blinebry	
			Tubb	
			Drinkard	
		Abo		
	Wolf-campian	Wolfcamp		

Back-reef depositional environment

23 ft Net Thickness
~40 ft Gross Thickness

Shattuck Sandstone Member

Irregularly bedded sandstones, siltstones, and sandy siltstones, containing irregular anhydrite beds and nodules. The sandstones are a heterogeneous mix of oxidized detrital sands and siltstones, with detrital and authigenic cements of dolomite, gypsum, anhydrite, and halite.

Modified from Talley, 1997

* Bell Canyon & Cherry Canyon Fms. In Delaware Basin fore-reef facies





Stivason Federal Well #1 Core

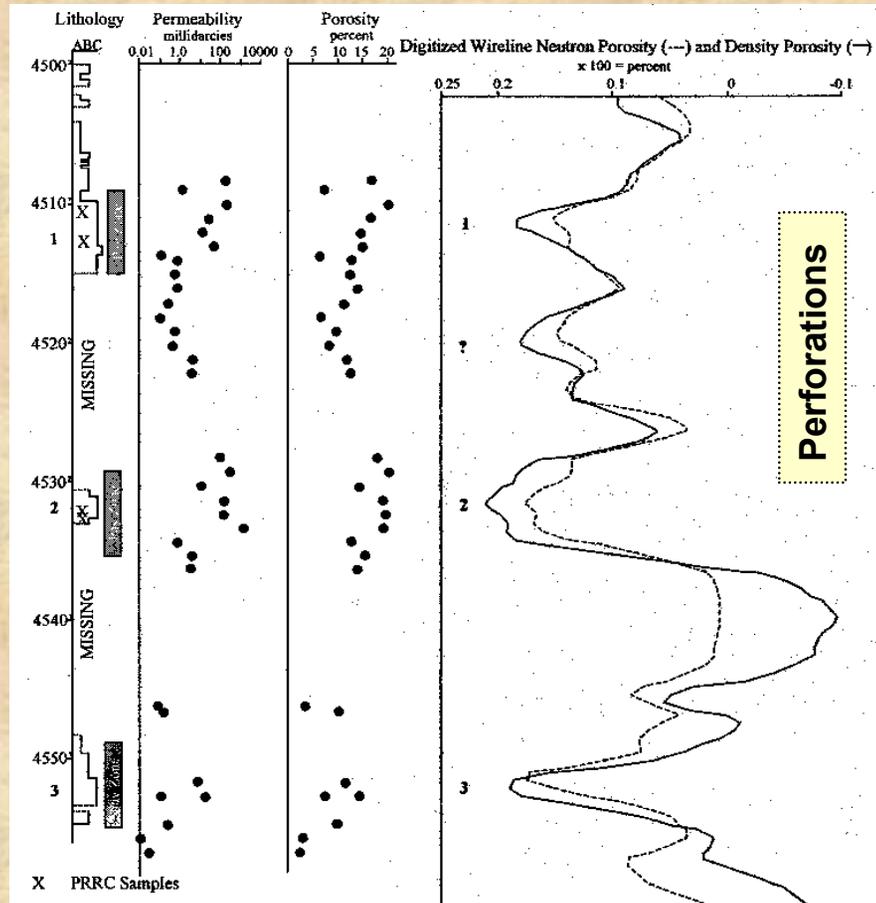


Top
4500'

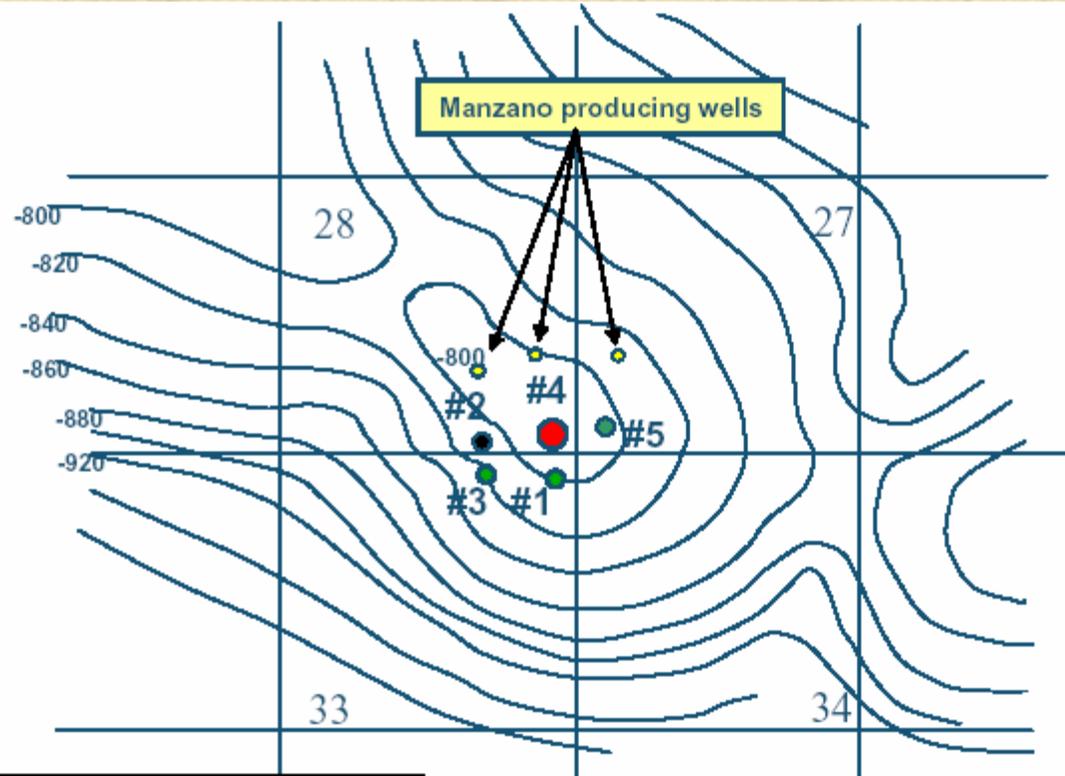
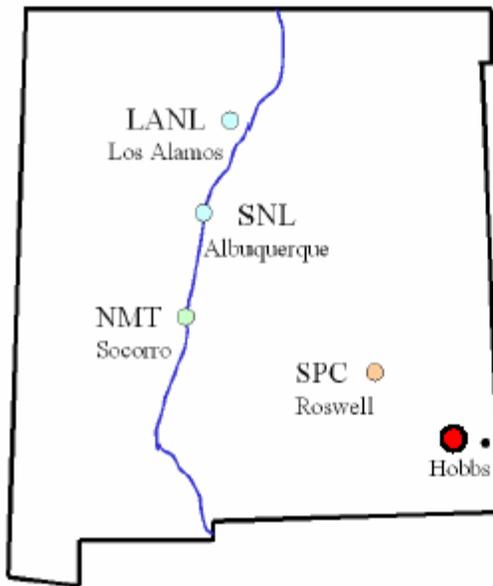
Bottom
4555'

Core Analysis & Testing

Wireline neutron & density porosity



Geology and Location



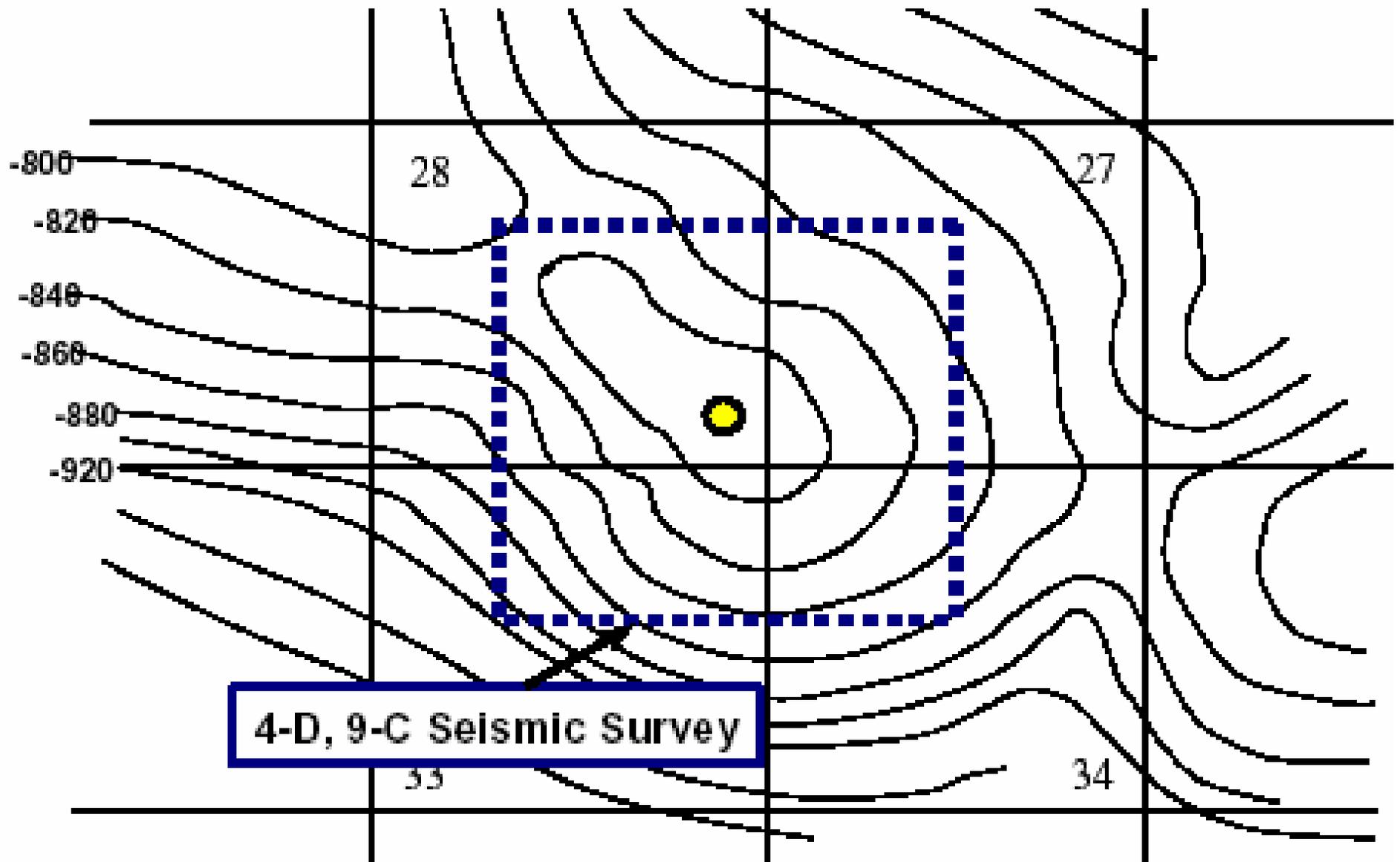
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No enhanced oil recovery operations

Strata Production Co. Wells

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- #1&3 Waste water injector well
- #2 Plugged well

Top of Queen Sand

(Section 28-T19 S- R34E.; 20' contour interval; Datum S.L.)







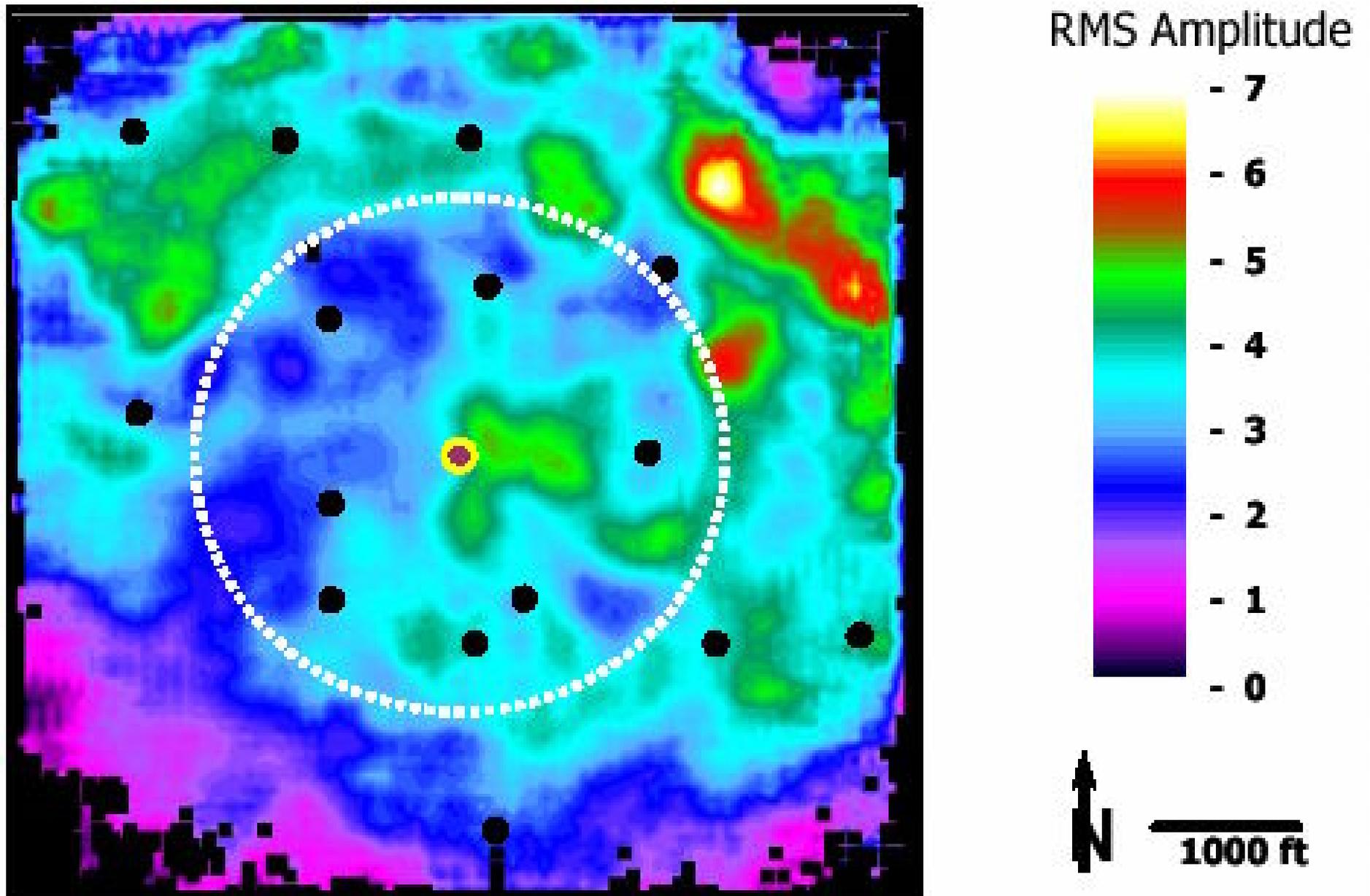
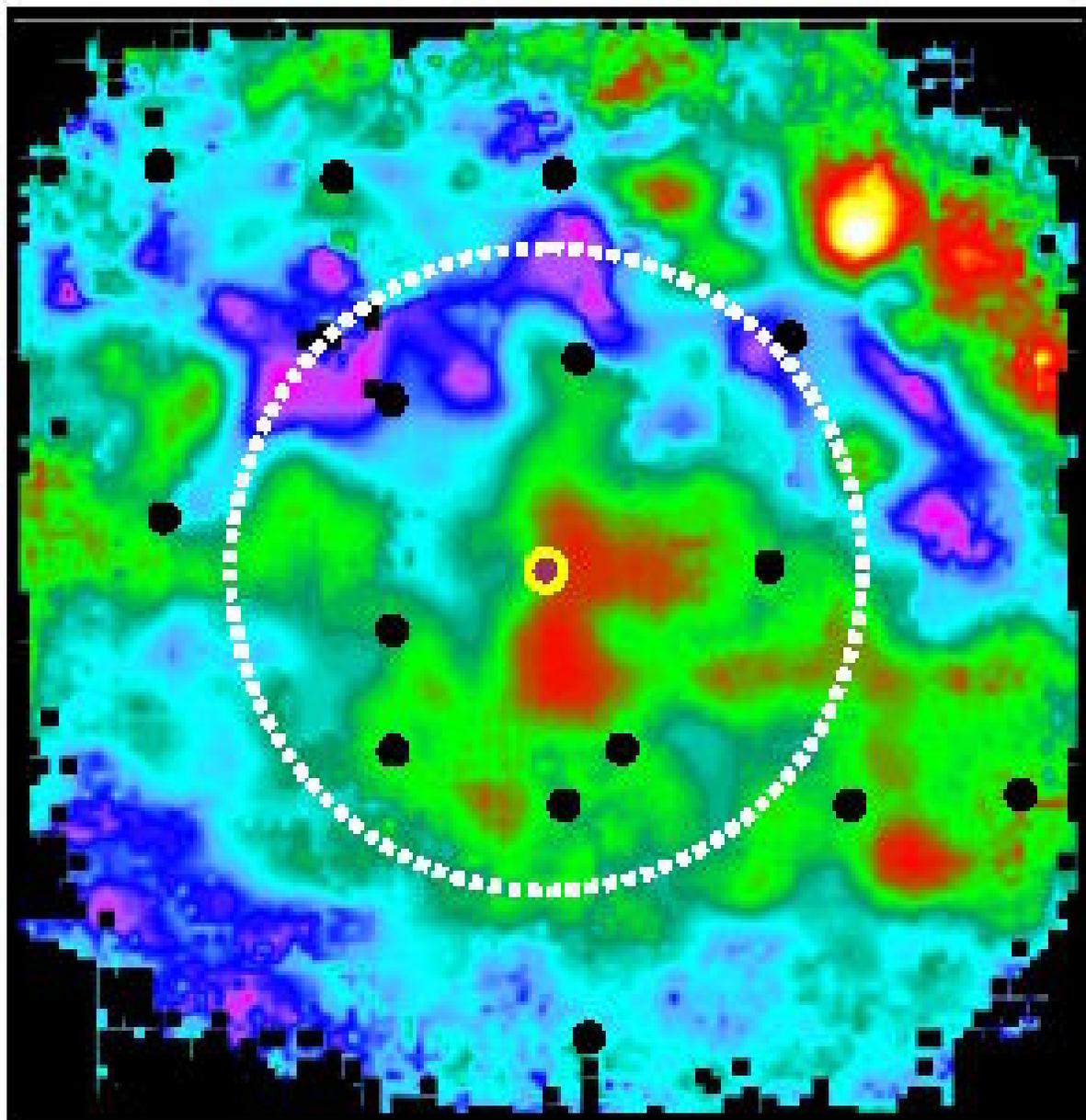


Figure 7.15. RMS reflection amplitude for monitor survey – P wave.



RMS Amp. Difference
Base - Monitor



- 0

- -1



1000 ft

Figure 7.16. RMS reflection amplitude differences – P wave.