1.4 Overview of the CO_2 Pilot in the Spraberry Trend Area

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Abstract

The overall goal of this project is to assess the economic feasibility of CO_2 flooding the naturally fractured Spraberry Trend Area in West Texas. This objective is being accomplished by conducting research in four areas and implementation of a field demonstration pilot. Research areas are as follows: 1) extensive characterization of the reservoirs, 2) experimental studies of crude oil/brine/rock (COBR) interaction in the reservoirs, 3) analytical and numerical simulation of Spraberry reservoirs, and, 4) experimental investigations on CO_2 gravity drainage in Spraberry whole cores. This report provides initial results of the project for each of the four areas and outlines the field demonstration pilot progress.

In the first area, reservoir characterization has been established based on petrophysical and geological analysis combined with core-log integration. A shaly sand rock model for describing the Spraberry Trend Area Reservoir has been established, and as a result, a better log interpretation algorithm for identifying Spraberry pay zones has been developed.

In the second area, COBR interaction in the Spraberry matrix has been analyzed based on results of laboratory experiments. Initial water saturation and historical water saturation in the Spraberry sands has been determined to be between 0.20 and 0.40 depending on permeability of the sand. Macroscopic displacement efficiency during water imbibition has been estimated to be about 50%. Wettability of the Spraberry sands has been determined. The Amott wettability index to water was estimated to be about 0.55 indicating that the Spraberry sands are weakly water wet. Water-oil capillary pressure has been established. The experimental capillary pressure curve confirms the rock wettability determined based imbibition test. Interfacial tension (IFT) between Spraberry oil and brine has been measured to be 32 mN/m. Experimental results have been used in analytical and numerical reservoir simulations.

In the third area, performance of the Spraberry reservoirs has been explored based on reservoir characterization and laboratory investigations. Scaling of imbibition oil recovery results to reservoir geometry indicates that higher oil recovery should have been achieved during water flooding, although the Spraberry sands are weakly water wet.

Reasons for the poor performance of water flood were analyzed. Inflow performance of Spraberry Trend wells has been analyzed using a new mathematical model developed for wells intersecting long fractures. Computer simulation of a Spraberry waterflood pilot has been conducted using laboratory measured parameters to understand Spraberry waterflood performance.

In the fourth area, efficiency of CO_2 gravity drainage has been investigated based on laboratory experiments. Minimum Miscibility Pressure (MMP) was measured to be 1,550 psig. IFT of the CO_2/Spraberry oil under reservoir conditions was determined. The IFT at the MMP is about 1.5 mN/m. Investigation of vaporization of oil fractions into CO_2 was initiated. Preliminary results show insignificance of the mechanism. CO_2 gravity drainage experiments were carried out using Spraberry oil and whole cores. 51% of original oil in place was recovered from a 0.01 md Spraberry whole core within 200 days during CO_2 gravity drainage. Experimental data were matched by a mathematical model.

The field demonstration pilot is underway to test the results of the laboratory and modeling applications. This pilot consists of 6 WIW's, 3 producers, and 4 GIW's and the associated production/injection facilities. The GIW's will be drilled during the end of 1999 and the CO_2 injection is slated to begin during the 1st quarter of 2000. Extensive field testing is ongoing to further characterize the reservoir. These tests include pressure buildups and falloffs, step-rate injection tests, injection profile logs, and the interference test currently in progress.

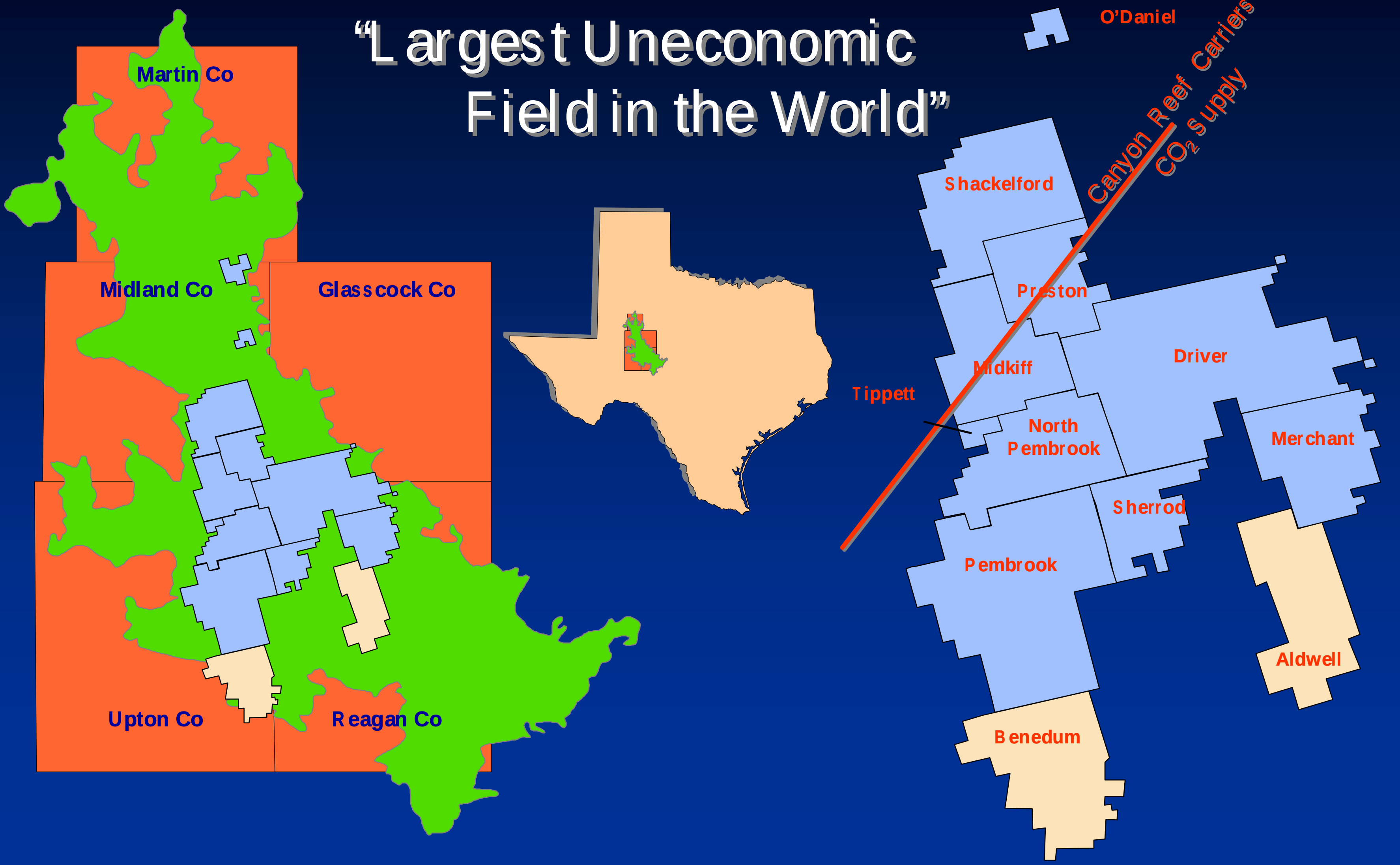
"Overview of DOE/NPTO Class III Field Demonstration: CO_2 Pilot in the Naturally Fractured Spraberry Trend Area"

David S. Schechter

Petroleum Recovery Research Center
New Mexico Institute of Mining and Technology

Spraberry Trend Area

"Largest Uneconomic Field in the World"

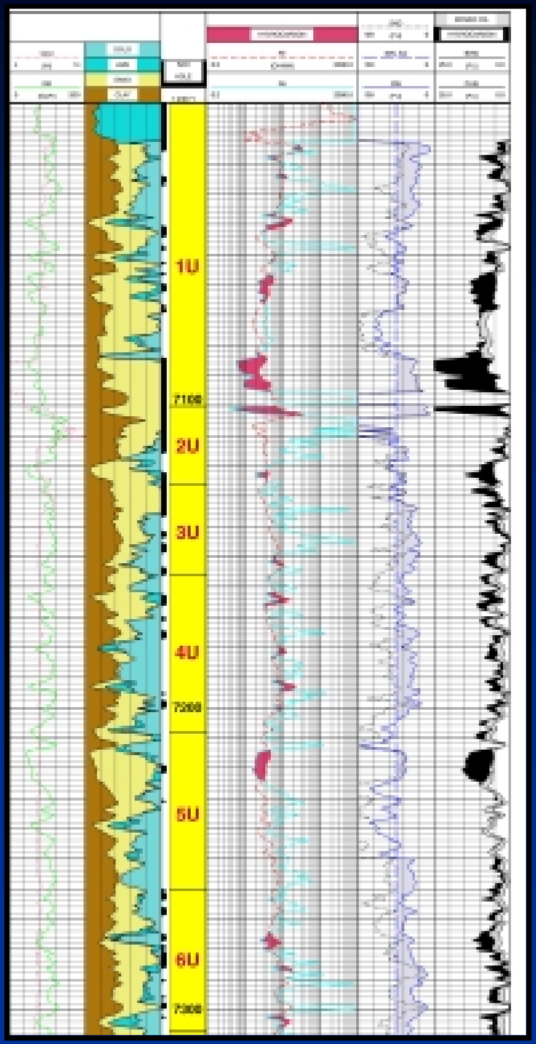


Key Elements in Designing Water and Gas Injection in Naturally Fractured Reservoirs

I. Extent and location of matrix porosity
II. Wettability of oil saturated matrix
III. Connectivity of fracture system
- Vertical communication
- Areal communication

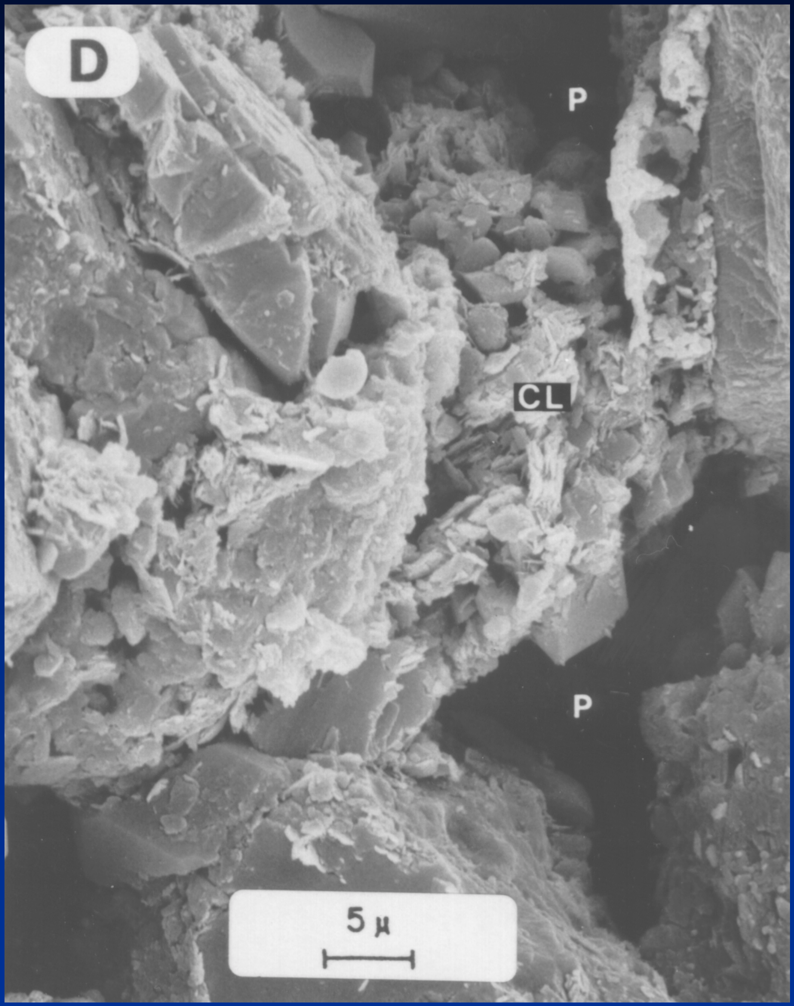
IV. Time scale for transfer mechanisms
- Capillary imbibition
- Diffusion
- Gravity drainage

Upper Spraberry Type Log



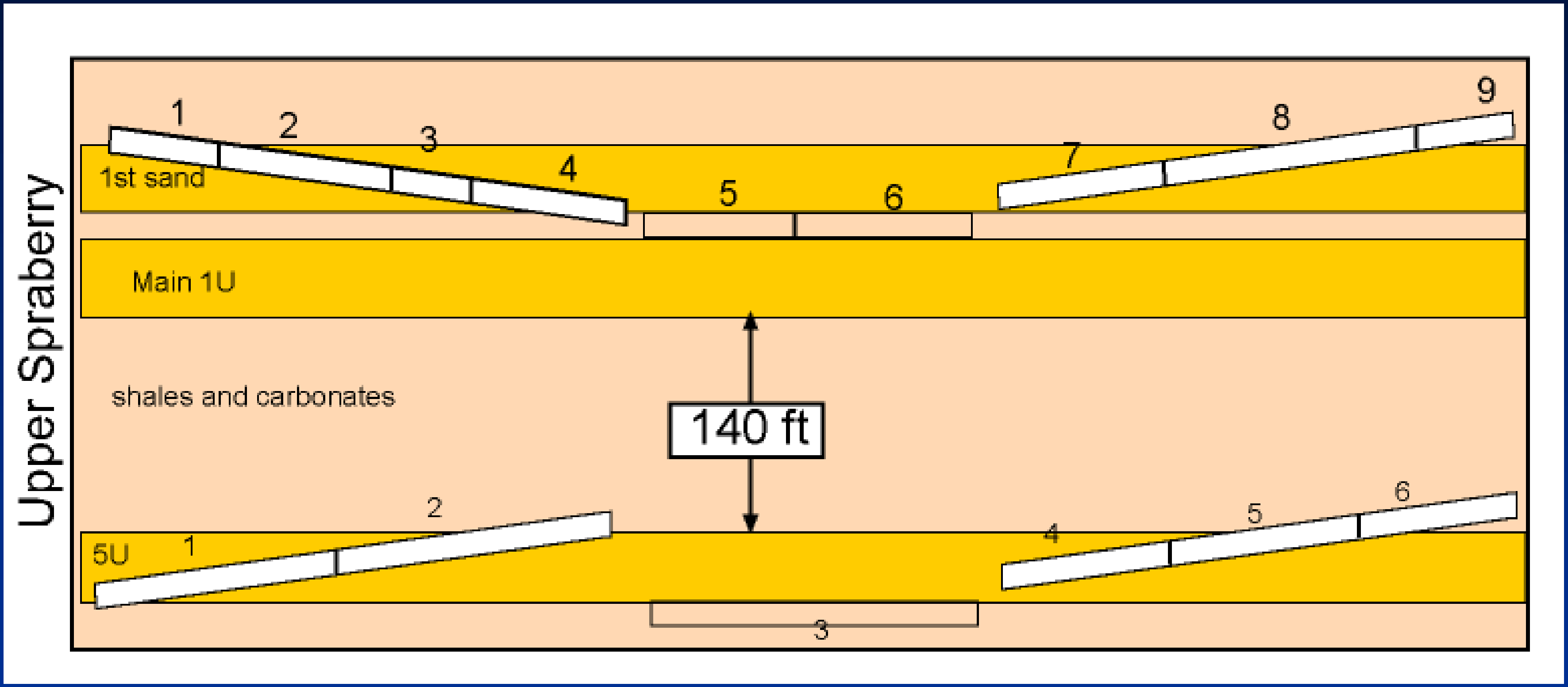
Rock Type A: Main Pay

- Ø > 7%
- k > 0.1 md
- Clay < 7%
- Intergranular Pores
- Swi: 35 - 50 %

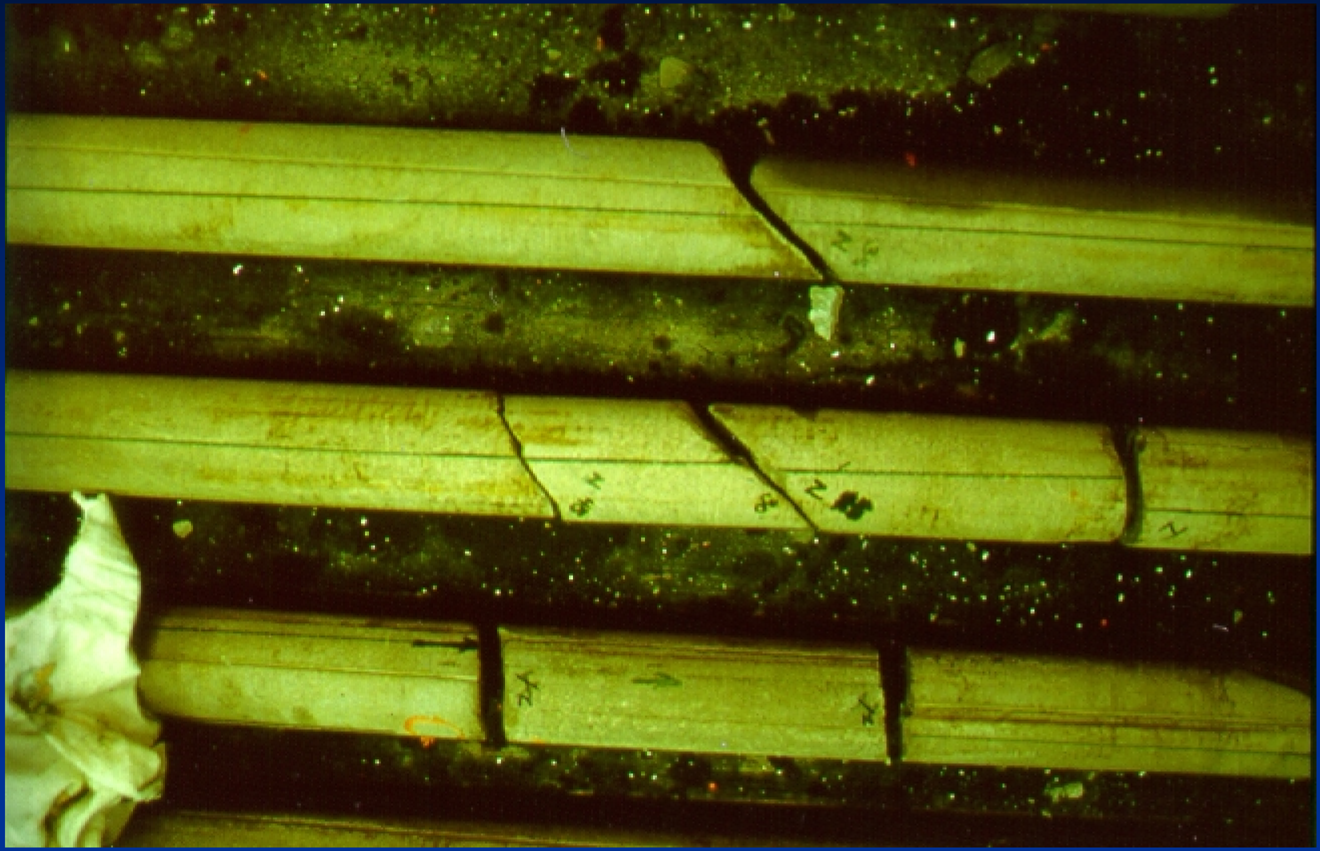


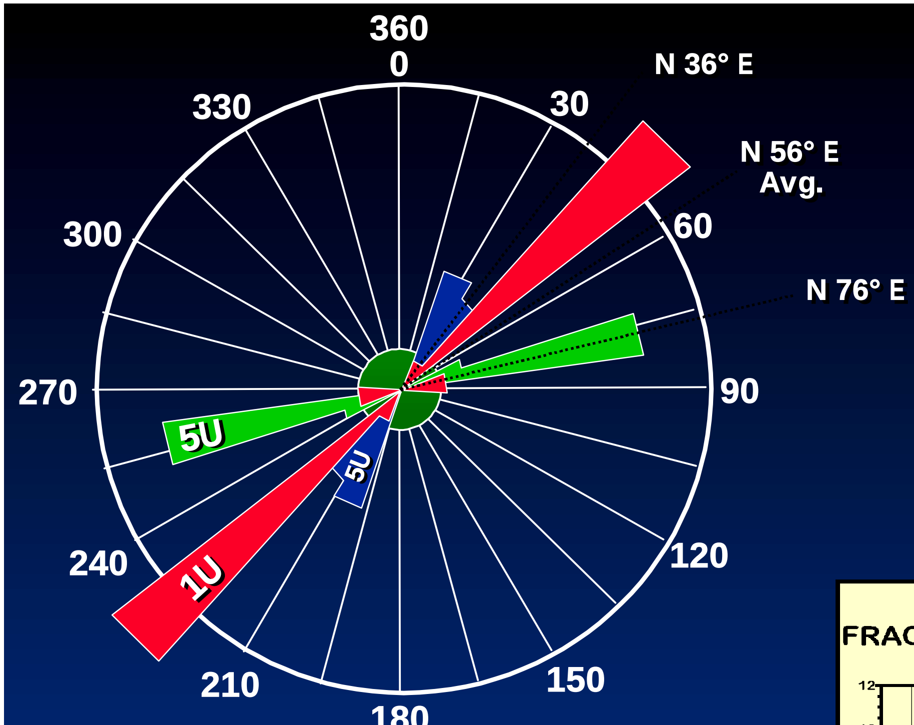
Vertical, Mineralized Fracture: 1U Payzone Shackelford 1-38A

Horizontal Core Well - O'Daniel #28

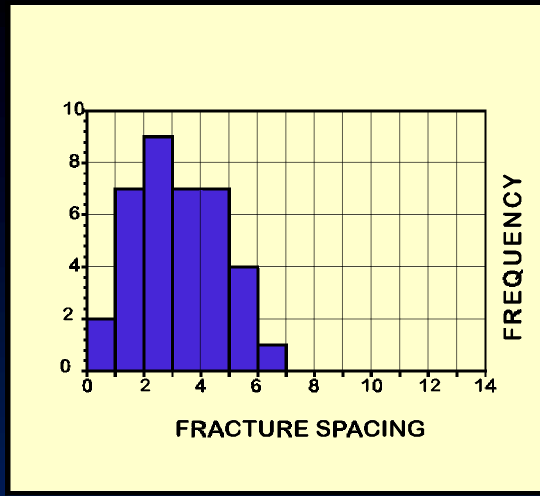


5U ENE & NNE Fractures

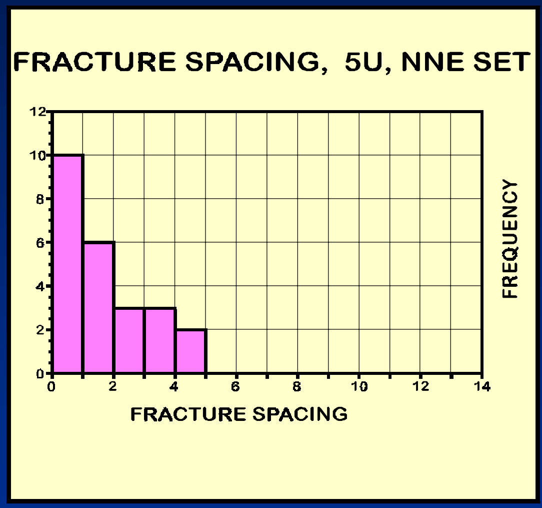




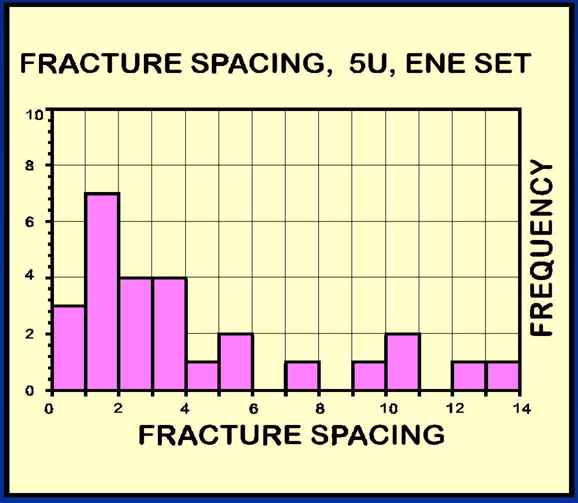
Overlay of 1U and 5U Fractures



•N42E orientation.
•Average spacing of 3.2 ft
• Smooth mineralized surfaces.



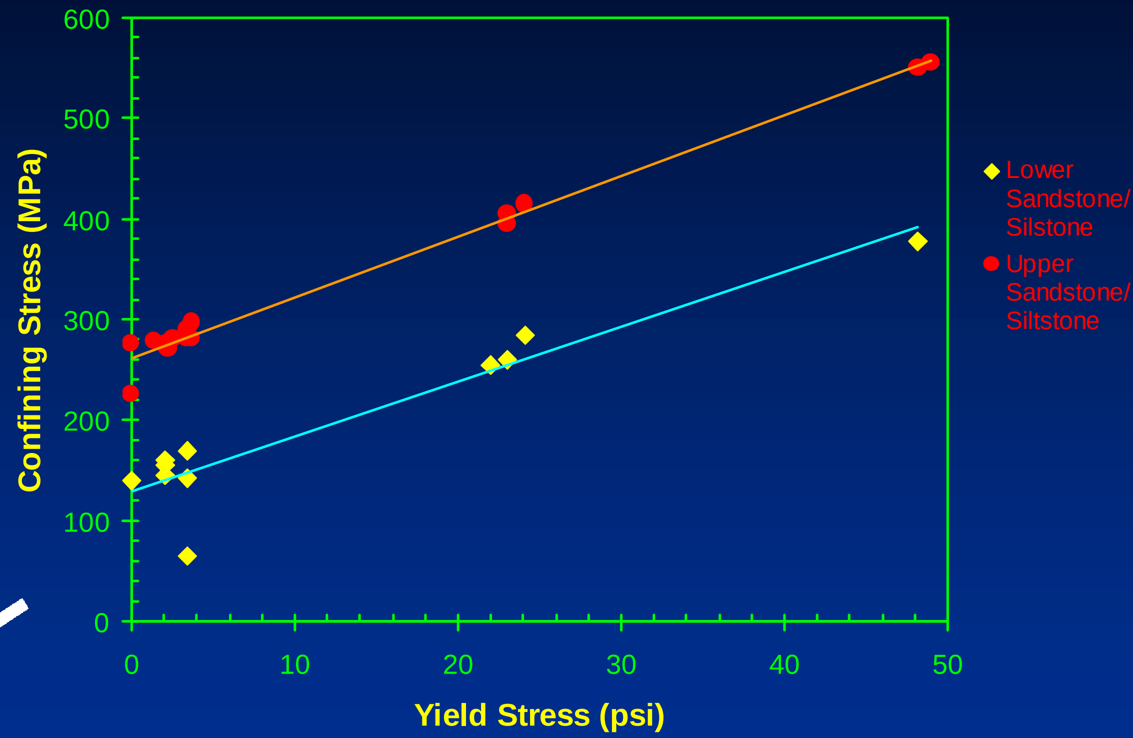
- N32E orientation.
- Average spacing of 1.62 ft.
- Fractures have stepped surfaces.
- No mineralization



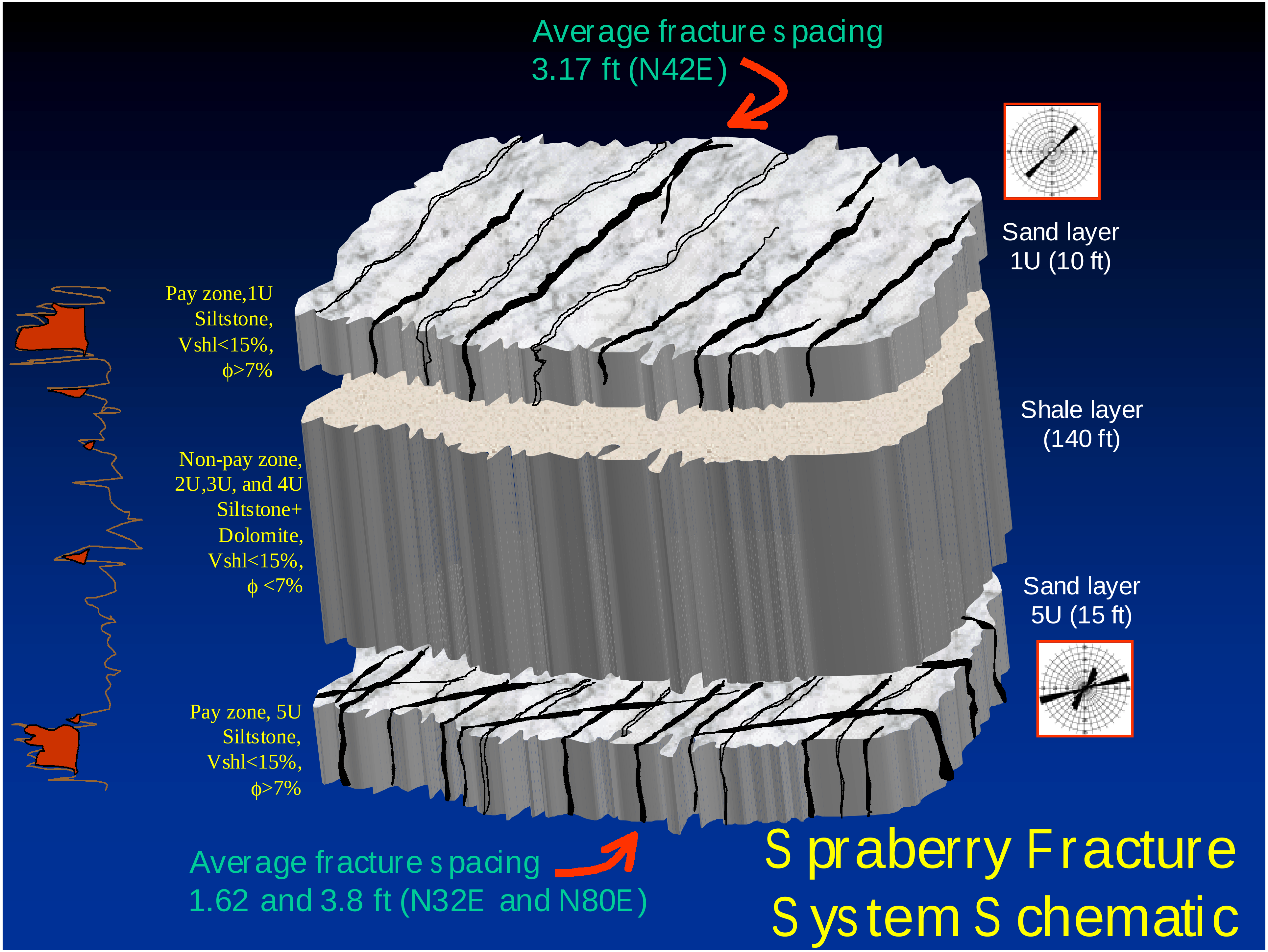
- N70E orientation.
- Spacing skewed normal distribution with an average of 3.79 ft.
- Fractures have smooth surfaces
- No obvious mineralization.

Geomechanical Properties of Upper (1U) and Lower (5U) Sand Intervals

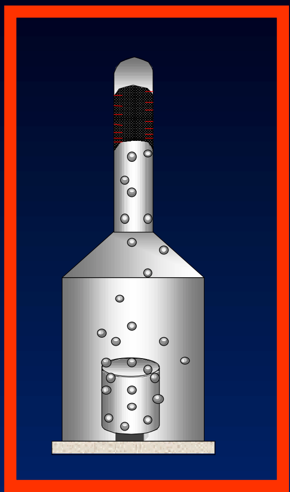
- Low average Poisson's ratio (0.11)
- Elastic moduli of these units are nearly equal (about 2.4 x 10^4 MPa).
- Yield stress (mechanical yield strength) of the upper unit is nearly twice that of the lower unit.



Fracture variability between 1U and 5U due to differences in the clay and quartz content, 1U low clay, high cementation - stronger rock than 5U

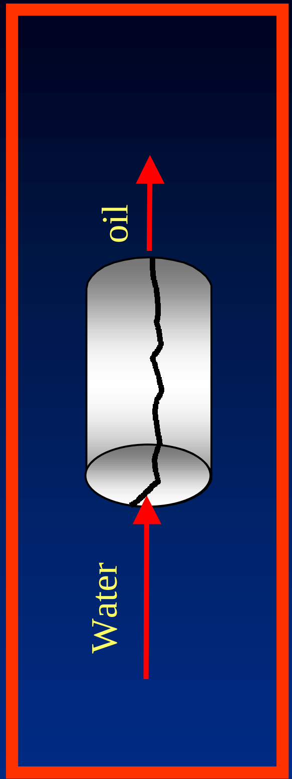

Average fracture spacing
3.17 ft (N42E)
Sand layer
1U (10 ft)
Pay zone,1U
Siltstone,
Vshl<15%,
ϕ>7%
Shale layer
(140 ft)
Non-pay zone,
2U,3U, and 4U
Siltstone+
Dolomite,
Vshl<15%,
ϕ <7%
Sand layer
5U (15 ft)
Pay zone, 5U
Siltstone,
Vshl<15%,
ϕ>7%
Average fracture spacing
1.62 and 3.8 ft (N32E and N80E)
Spraberry Fracture
System Schematic

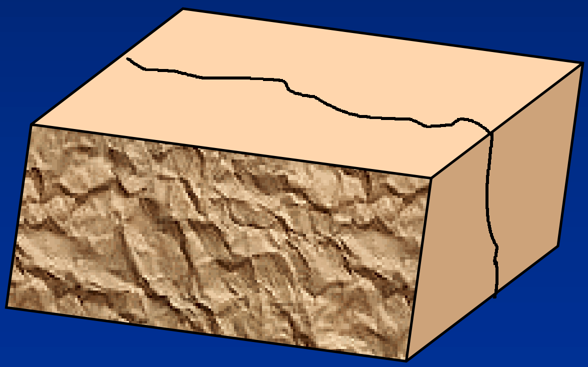
Overview of Imbibition Study



- Wettability Index
- Aging effect on oil recovery
- Effect of P and T on oil recovery
- Upscaling the data
- Capillary pressure curve

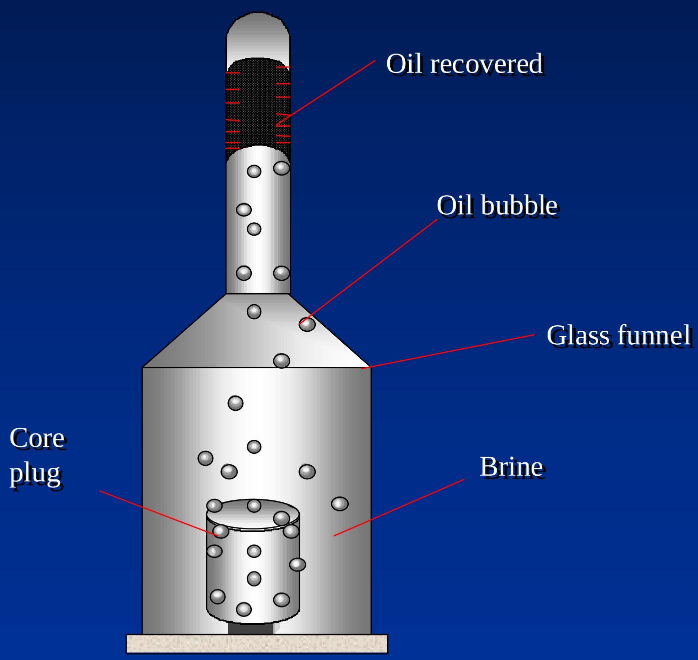
- Oil recovery profile
- modeling the experiments
- Capillary pressure curve
- Key variables in dual porosity simulation
- Determine critical injection rate

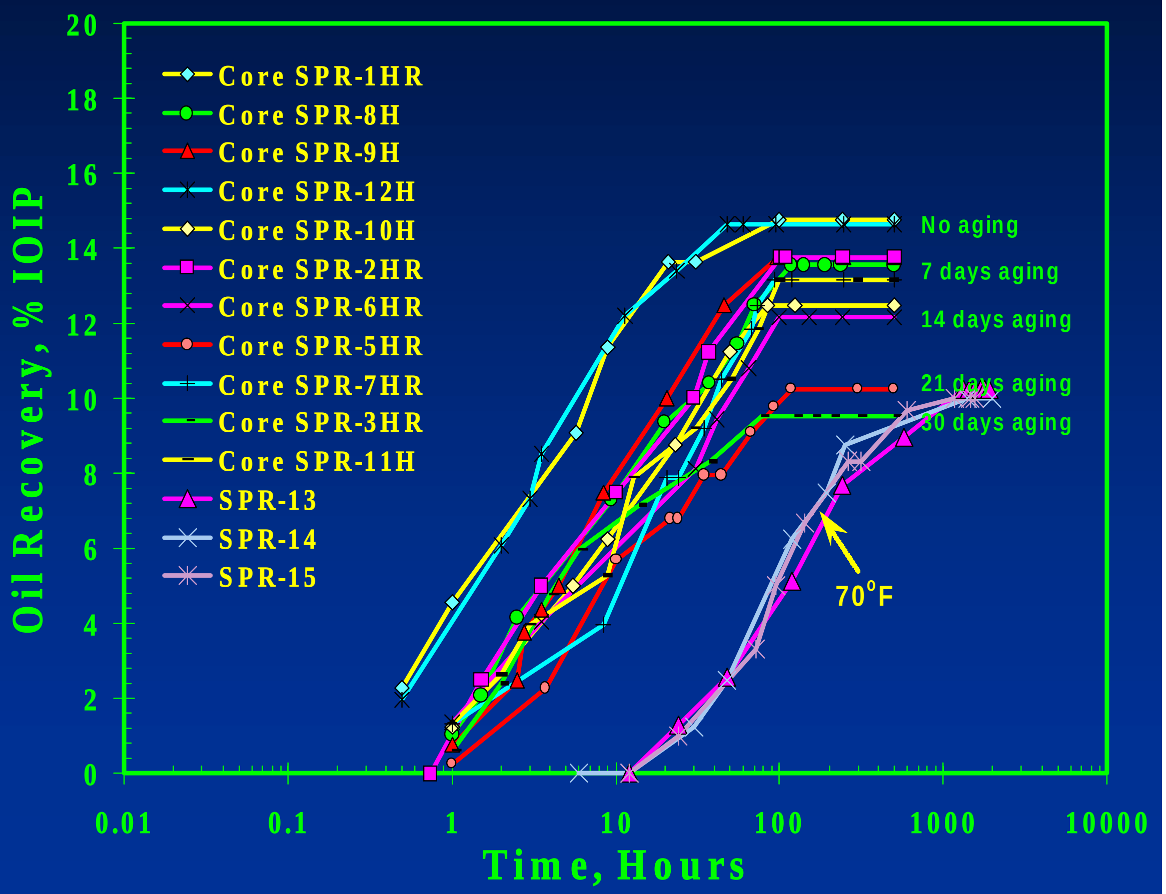


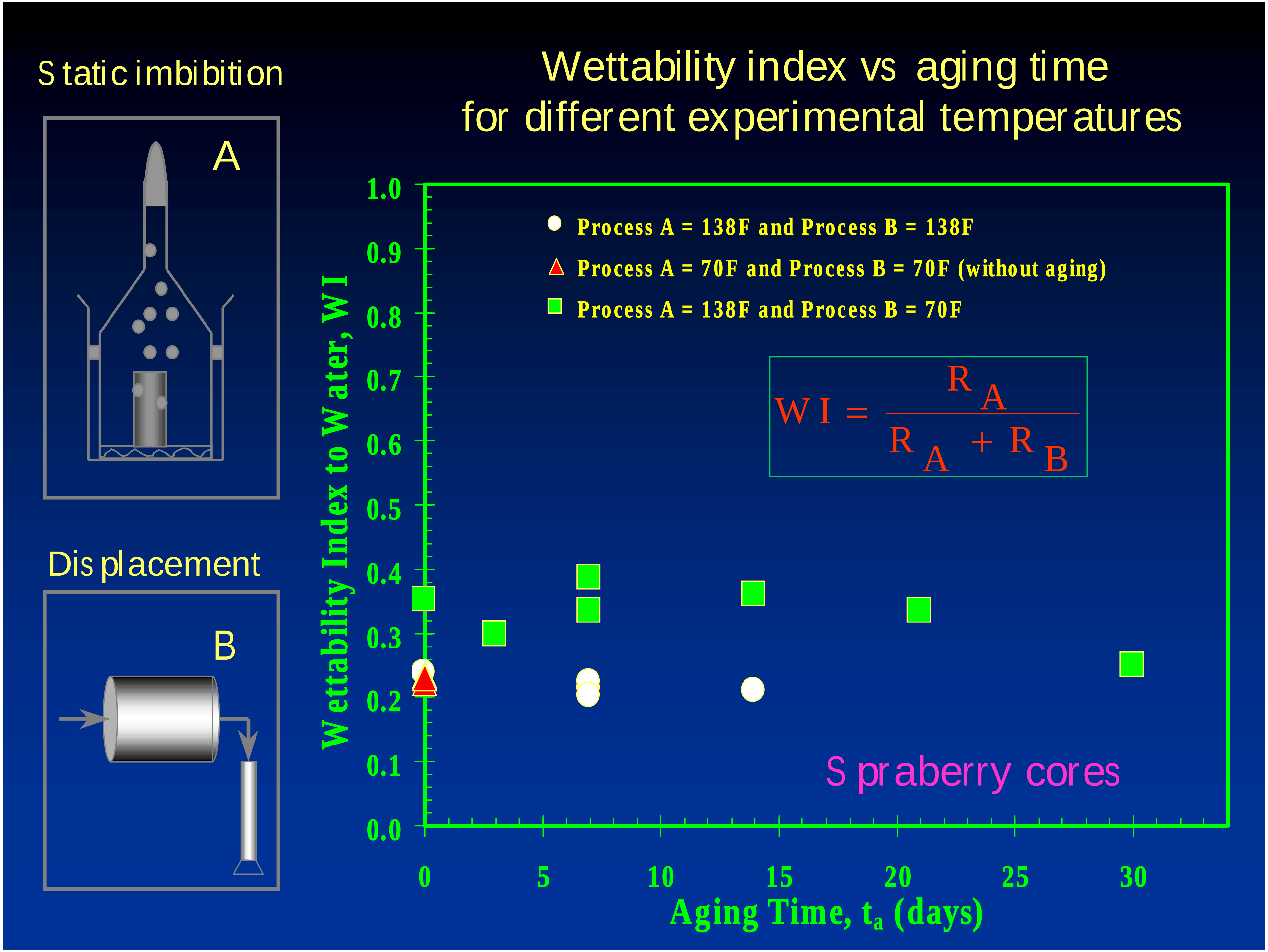


Field dimension

Experimental Set-up for Static Imbibition Tests at Ambient Conditions



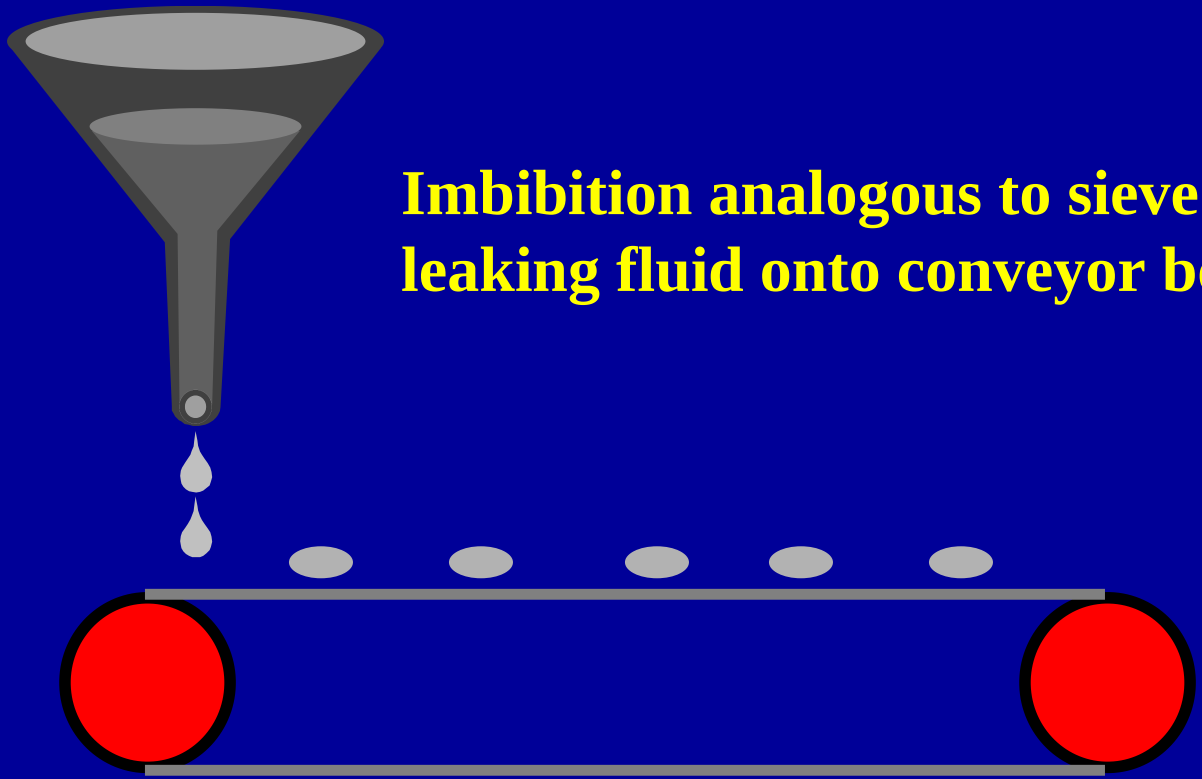



Wettability index vs aging time
for different experimental temperatures
Static imbibition
A
Displacement
B
Process A = 138F and Process B = 138F
Process A = 70F and Process B = 70F (without aging)
Process A = 138F and Process B = 70F
$WI = \frac{R_A}{R_A + R_B}$
Spraberry cores
Wettability Index to Water, WI
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
Aging Time, t_a (days)

Evidence of Weakly Water-Wet Behavior in Spraberry

- Spontaneous imbibition of oil into water saturated Spraberry core
- Spontaneous imbibition of oil into water saturated core during static Eq. P_c meas.
- Low P_c during drainage and imbibition
- Low Amott wettability indices I_w~ 0.2 - 0.3
- Scaled mercury contact angle of 50^o
- Reservoir condition contact angle measurements of 50^o (within 10^o)

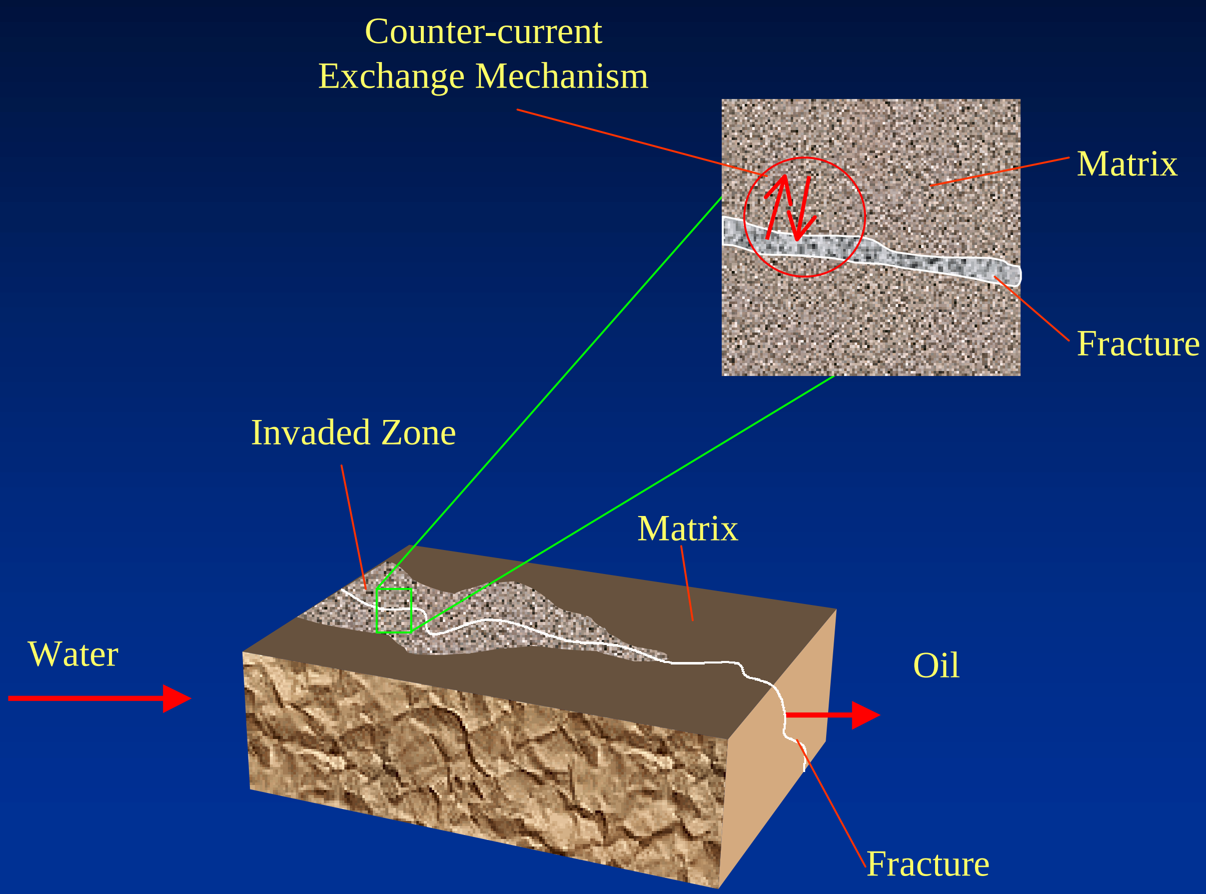
Slow Imbibition is the Rate-Limiting Step



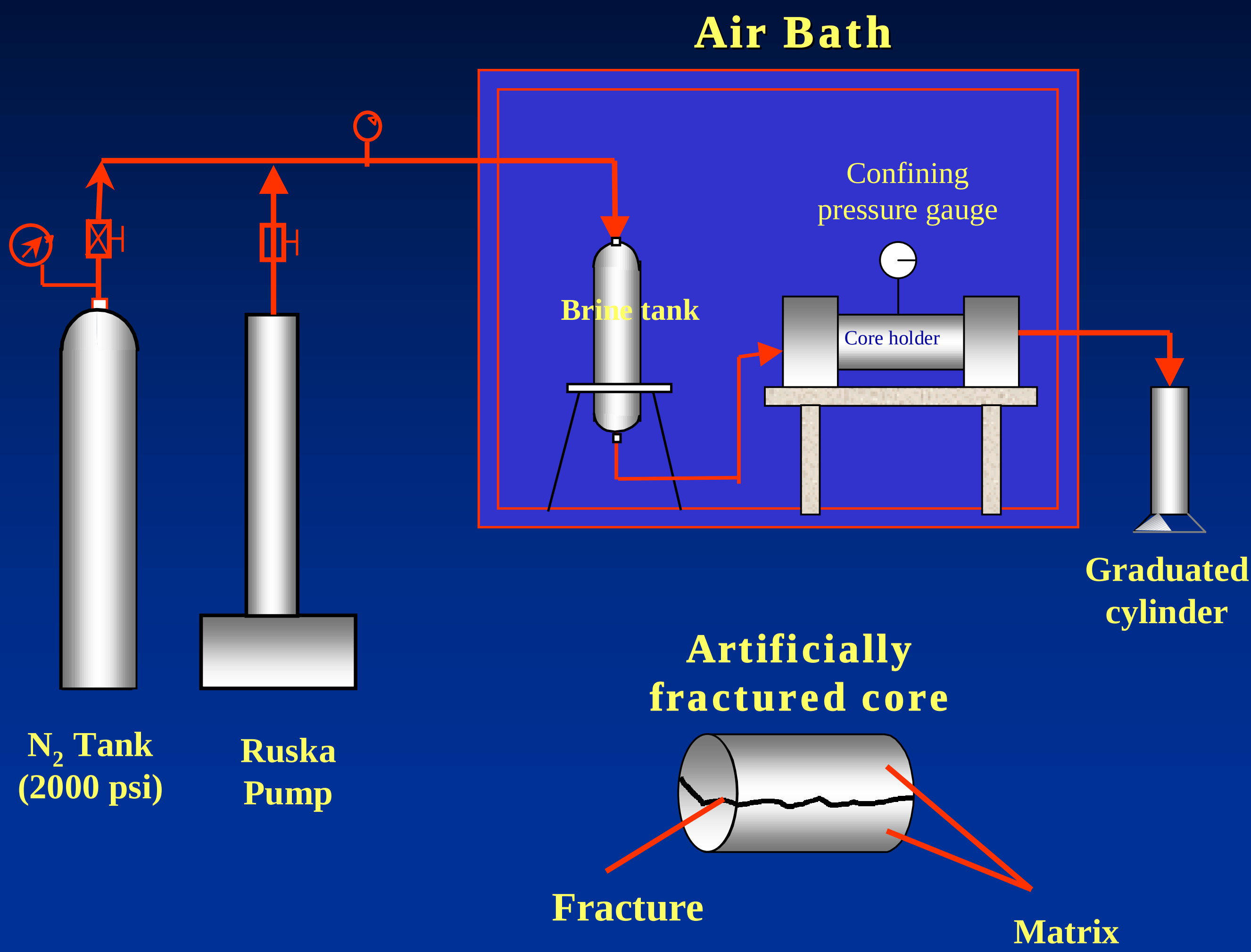
Imbibition analogous to sieve slowly leaking fluid onto conveyor belt

Conveyor belt analogous to water injection into fractures

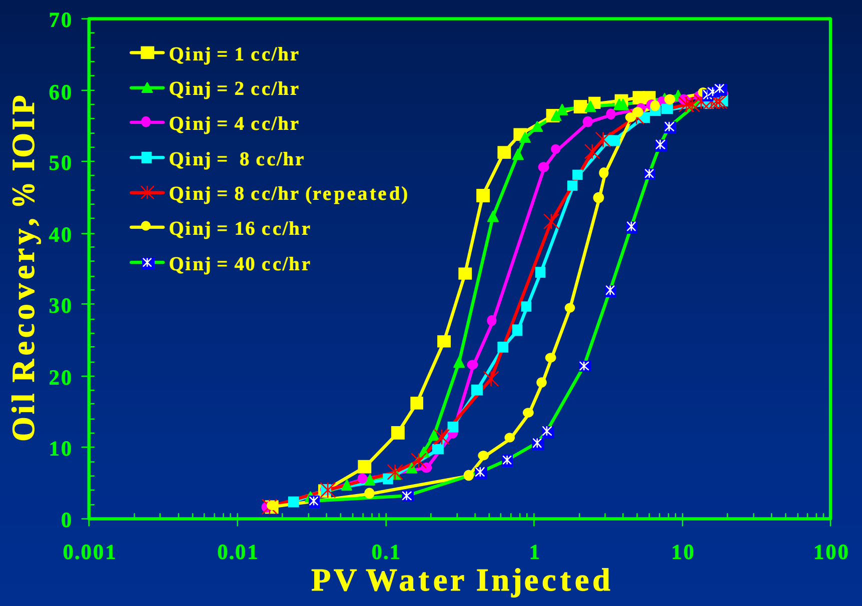
Concept of Dynamic Imbibition Process



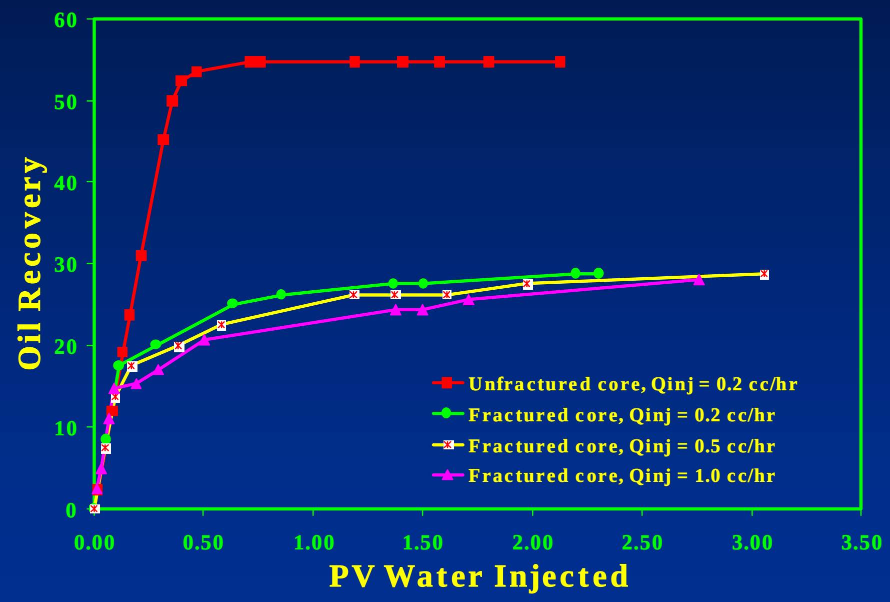
Experimental Set-up for Dynamic Imbibition Tests at Reservoir Temperature



Oil Recovery from Fractured Berea and Spraberry Cores using Different Injection Rates



Berea Cores



Spraberry Cores

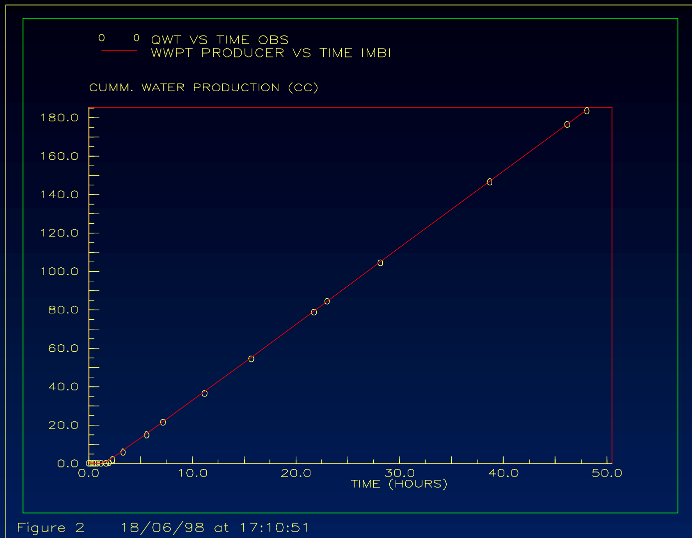
Dynamic Imbibition Modeling

- Single porosity, 2 phase and 3-D
- Rectangular grid block with grid size : 10 x 10 x 3 (Berea) ; z = 9 layers for Spraberry
- Fracture layer between the matrix layers
- Inject into the fracture layer
- Alter matrix capillary pressure only to match the experimental data
  - ☆ zero P_c for fracture
  - ☆ straight line for k_{rw} and k_{ro} fracture
  - ☆ use k_{rw} and k_{ro} matrix from the following equations (Berea core):

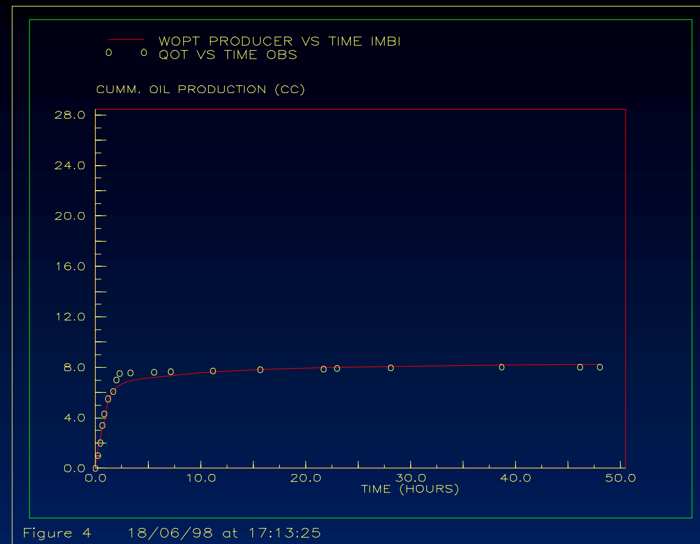
$$k_{rw} = S_w^3 \qquad k_{ro} = (S_o - S_{or})^3$$

Berea Core

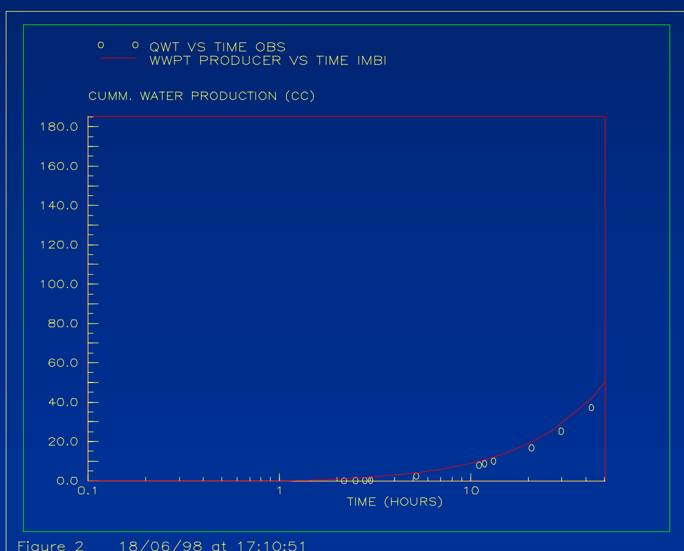
Match Between Experimental Data and Numerical Solution



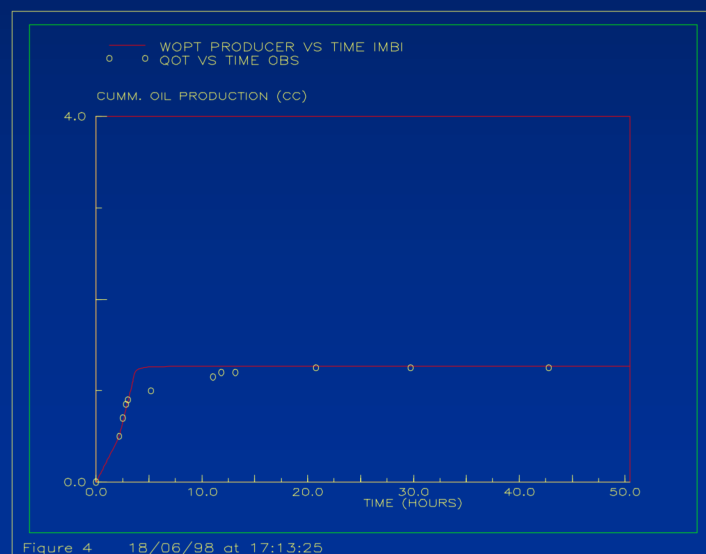
Cumulative water production vs. time



Cumulative oil production vs. time



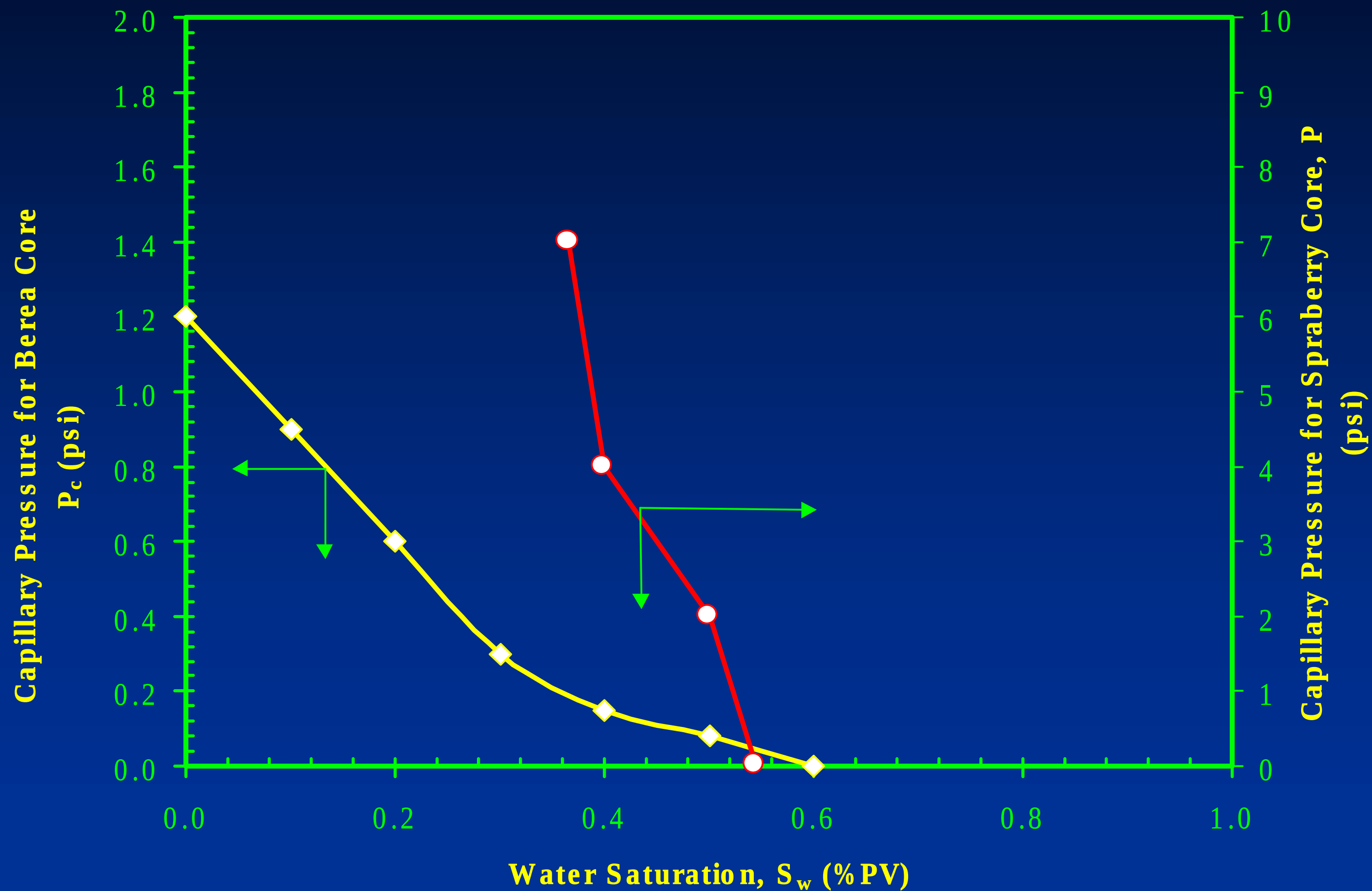
Cumulative water production vs. time



Cumulative oil production vs. time

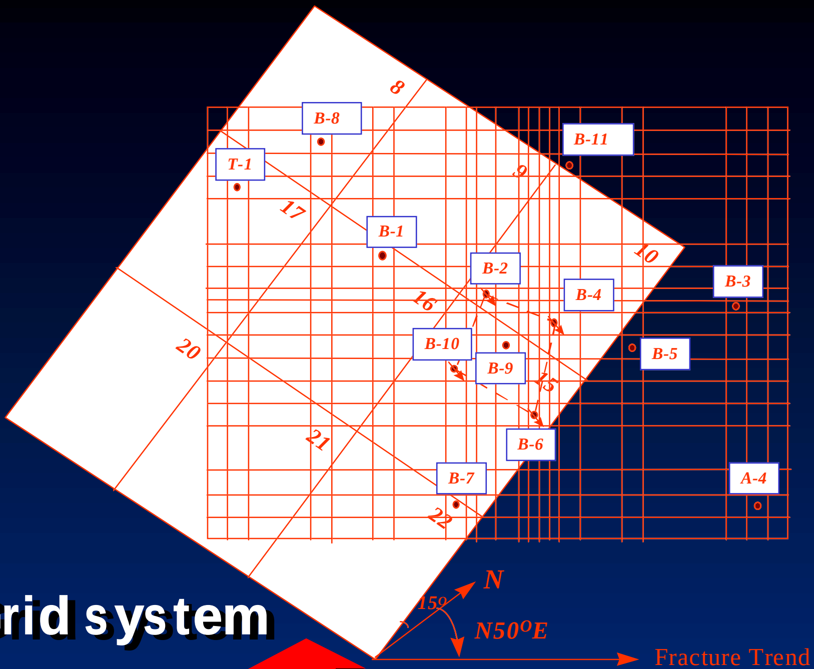
Spraberry Core

Capillary Pressure Curves Obtained by Matching Experimental Data (Berea and Spraberry Cores)

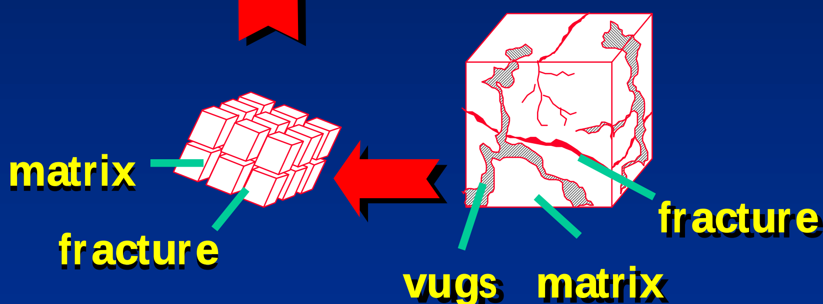


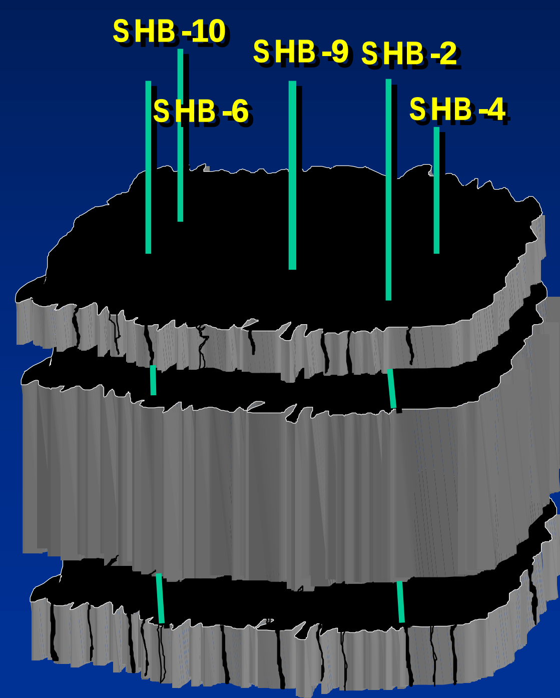
Reservoir Model

Humble Pilot Model



Grid system





80 ACRES

NO COMMUNICATION
BETWEEN LAYER

GRID DIMENSION IS 22X18X3

Reservoir Properties

Net pay zone thickness	20 ft.	**log and core**
Matrix permeability	0.03 md	**well test**
Matrix porosity	0.12	**core**
Gas saturation	0	**assumed**
Overall contact angle	50 degrees	**measured**
Effective fluid viscosity	0.9 cp	**measured**
Oil-water IFT	36 mN/m	**measured**
Oil FVF	1.35 rb/STB	**known**
Imbibition efficiency	13%	**measured**
Capillary pressure		**history match**
Fracture spacing	2.86 ft.	**horizontal core**
Initial water saturation S_{Wi}	0.38	**measured**
Residual oil saturation	0.30	**measured ?**

History Matching

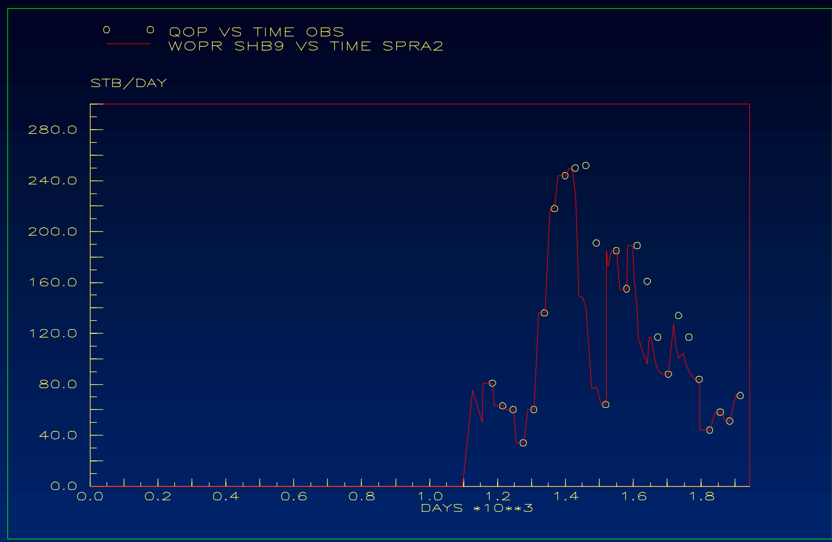


Figure 1 10/09/97 at 11:11:28

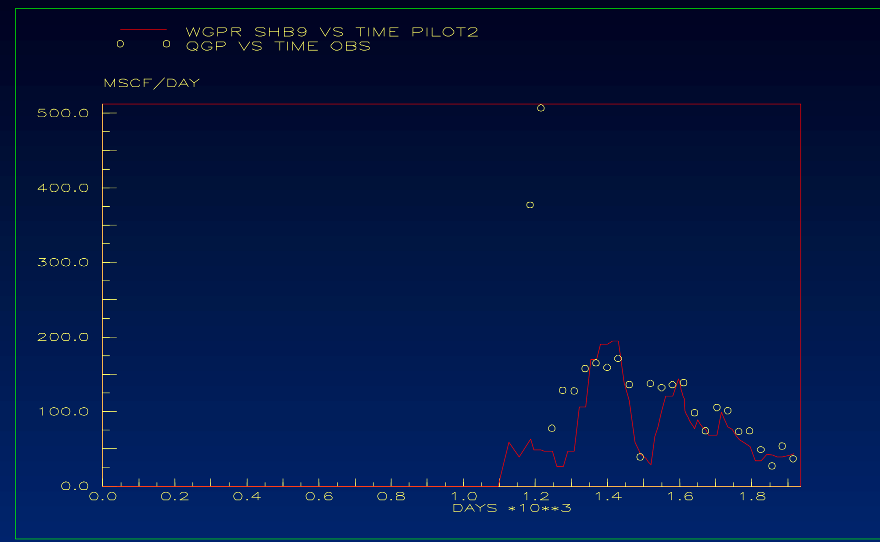


Figure 2 15/09/97 at 13:01:35

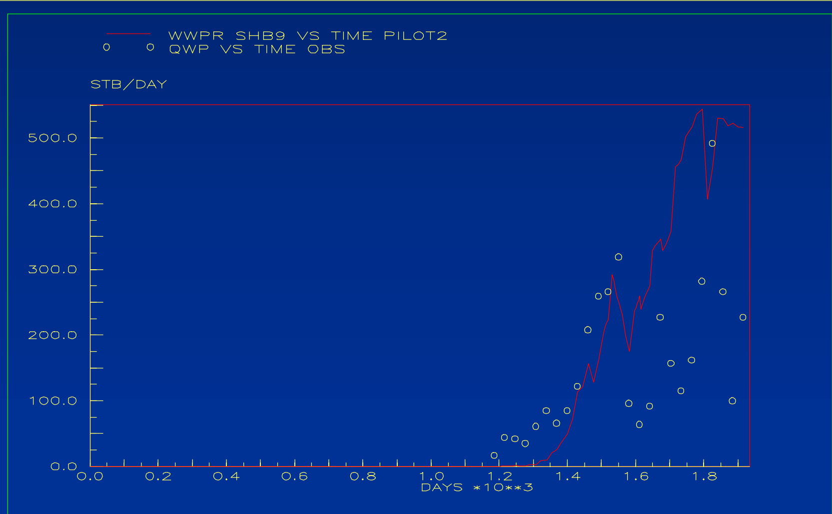


Figure 3 15/09/97 at 13:02:11

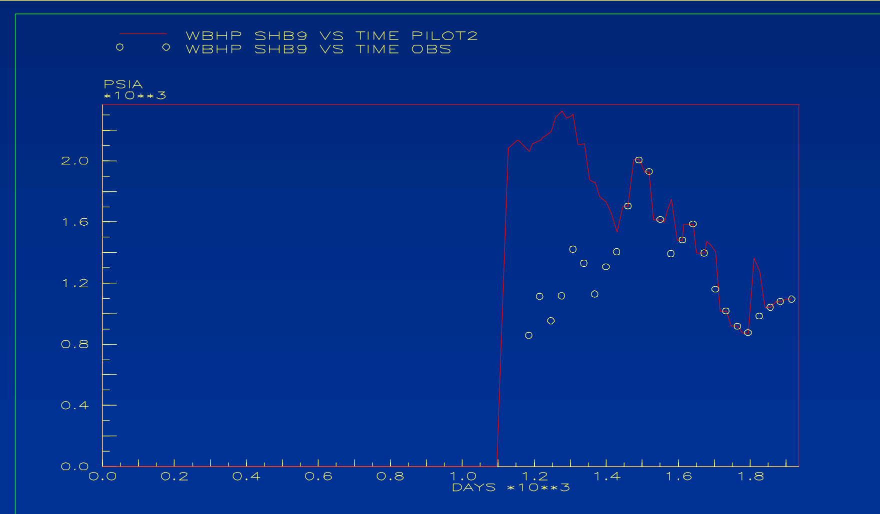
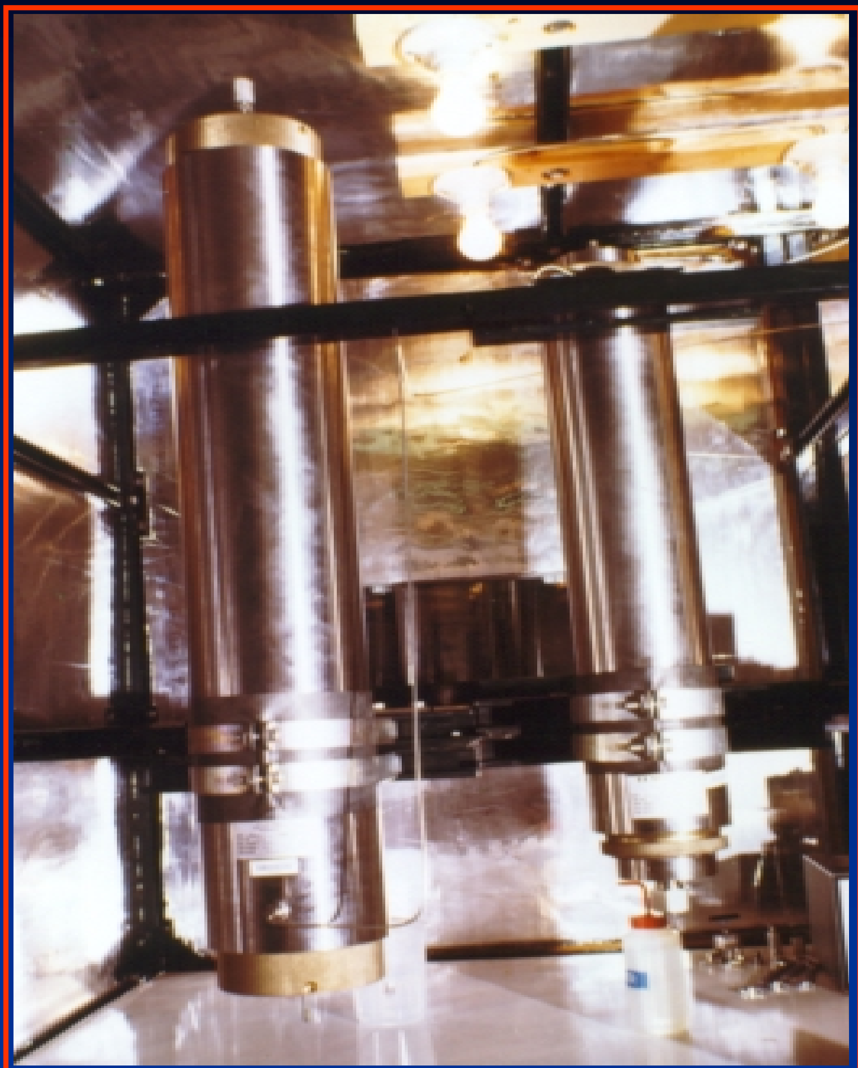
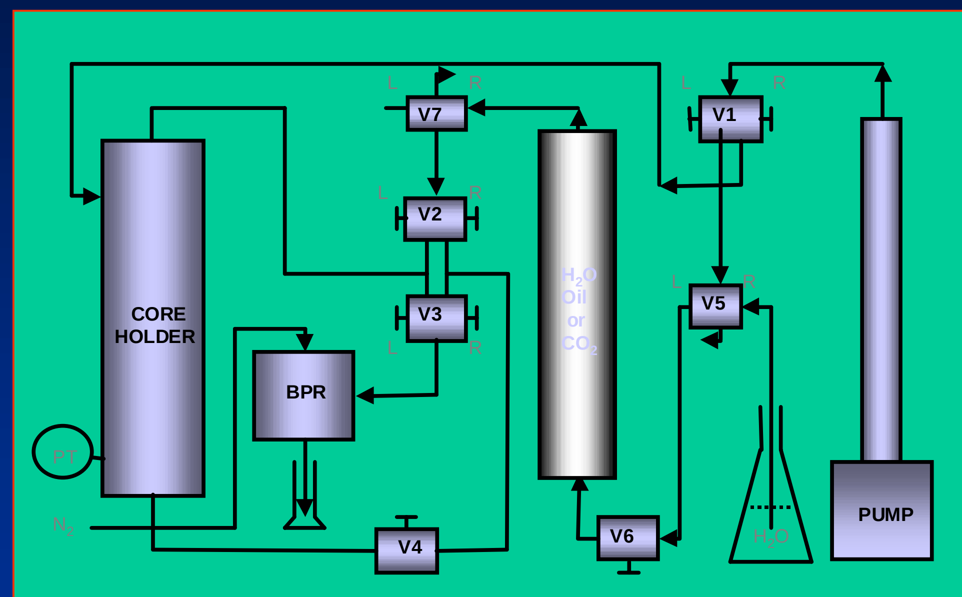


Figure 4 15/09/97 at 13:03:03

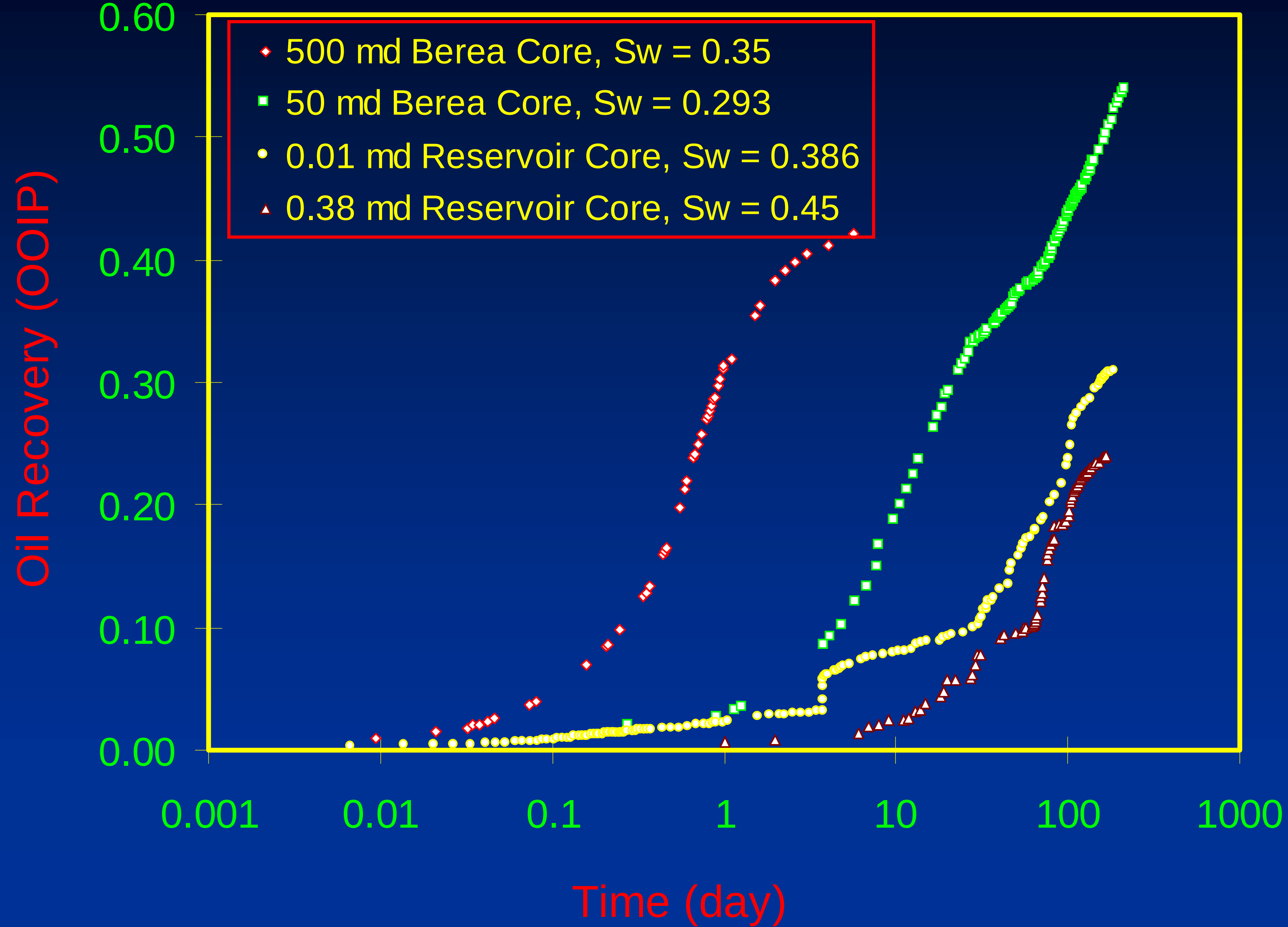
Gravity Drainage Experiment



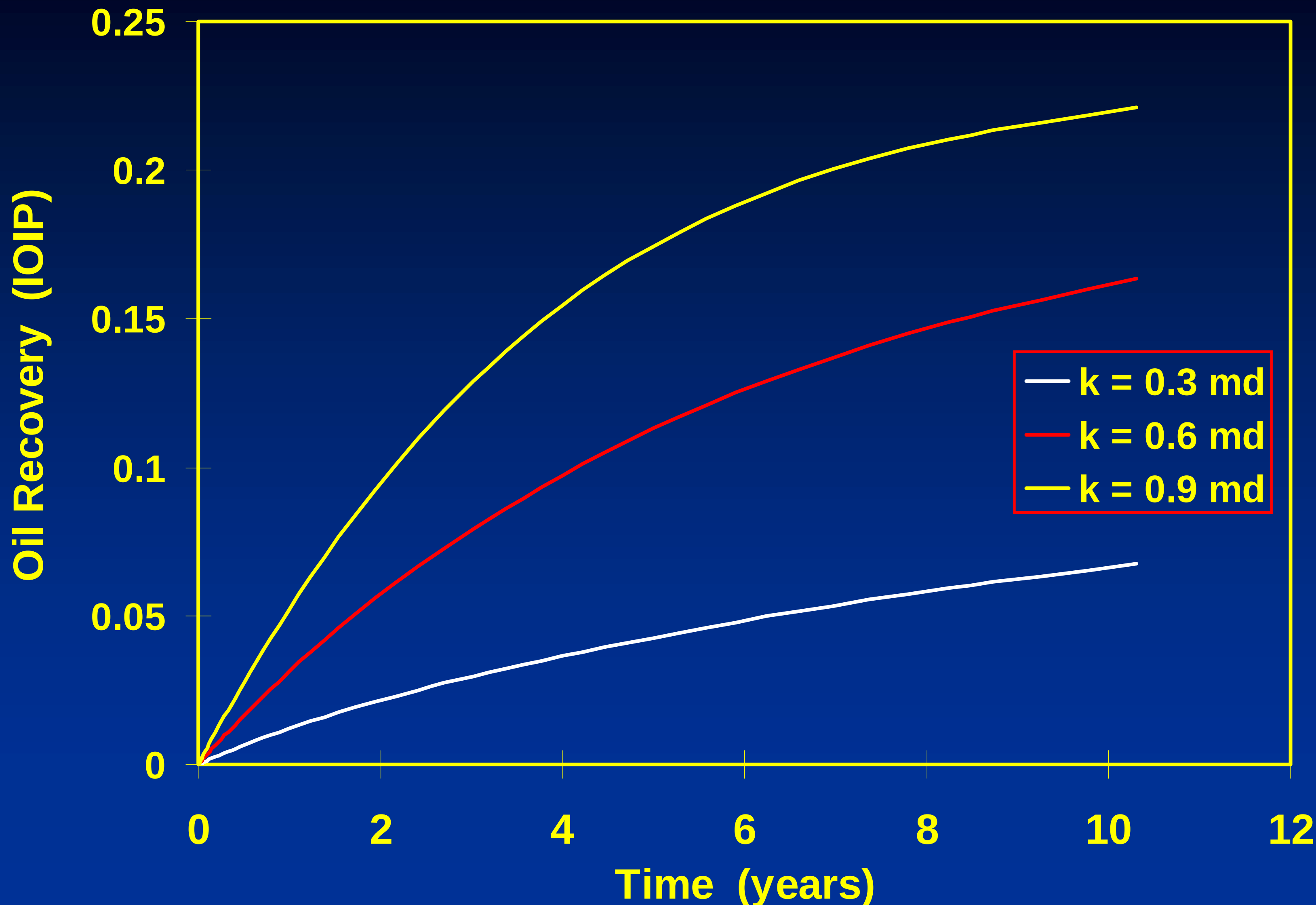


A Schematic Diagram of Experimental Setup

Oil Recovery from CO_2 Gravity Drainage Experiments



Projection of Oil Recovery for the CO_2 Pilot, Fracture Spacing 3.2 ft, Sw = 0.38



Conclusions

- Volume of shale vs. effective porosity crossplots better describe the location of Spraberry pay zones.
- Horizontal cores demonstrate that even a flat lying structure like Spraberry is subject to complicated, multiple fracture sets.

Conclusions…cont'd

- Wettability determined from capillary pressure, spontaneous oil/brine imbibition and contact angle experiments indicate Spraberry sands are weakly water-wet.
- Scaling imbibition results to the Humble waterflood pilot resulted in good history match.

Conclusions…cont'd

- Experimental results of CO_2 gravity drainage in reservoir whole core at reservoir conditions indicate that CO_2 will recover additional oil in Spraberry reservoirs.
- CO_2 injection will commence in the next year to test the economic feasibility of CO_2 injection in the naturally fractured Spraberry Trend Area.

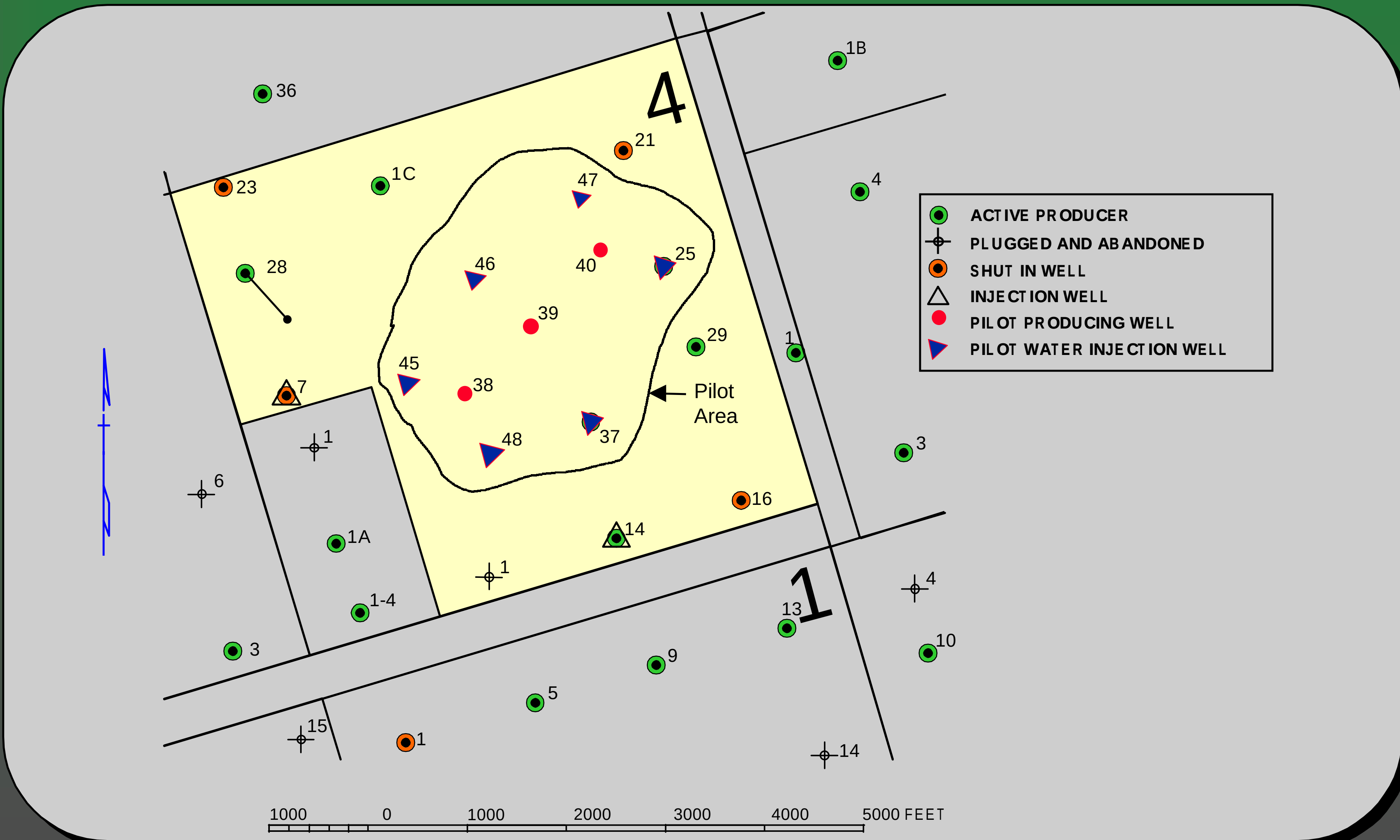
DOE Contract DE-FC22-95BC14292
Industrial Sponsors

- Arch Petroleum Co.
- Chevron
- Marathon
- Mobil
- Pioneer Nat. Res.
- Petroglyph Op. Co.
- Texaco
- The Wiser Oil Co.
- Union Pacific

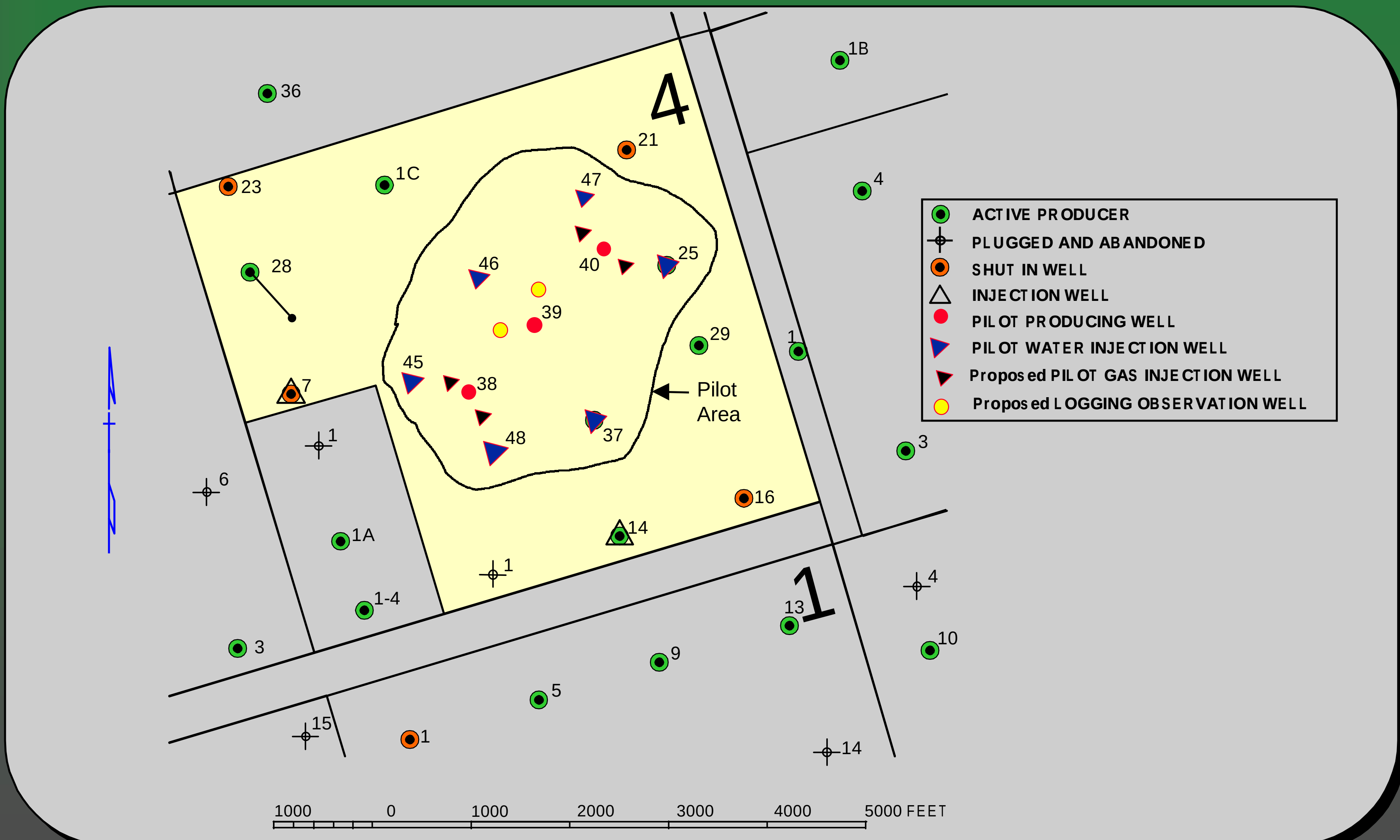
<u>Software Donations</u>

- Geoquest (ECLIPSE)
- Geografix (QLA2)

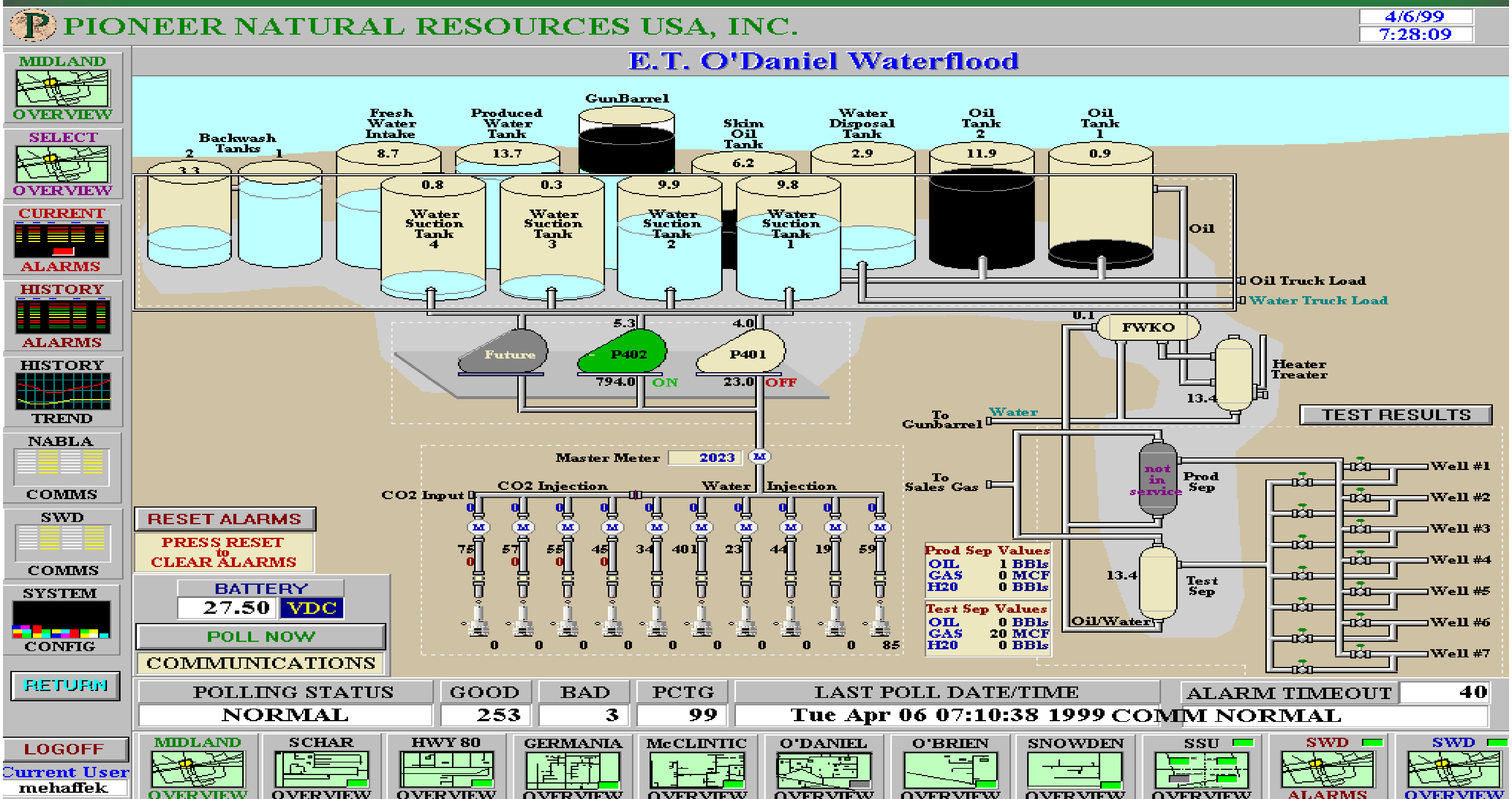
Pilot Design 1998 Drilling



Pilot Design 2000 Drilling



Facility Design



Facility Construction

Facility Construction

Facility Construction

Facility Construction

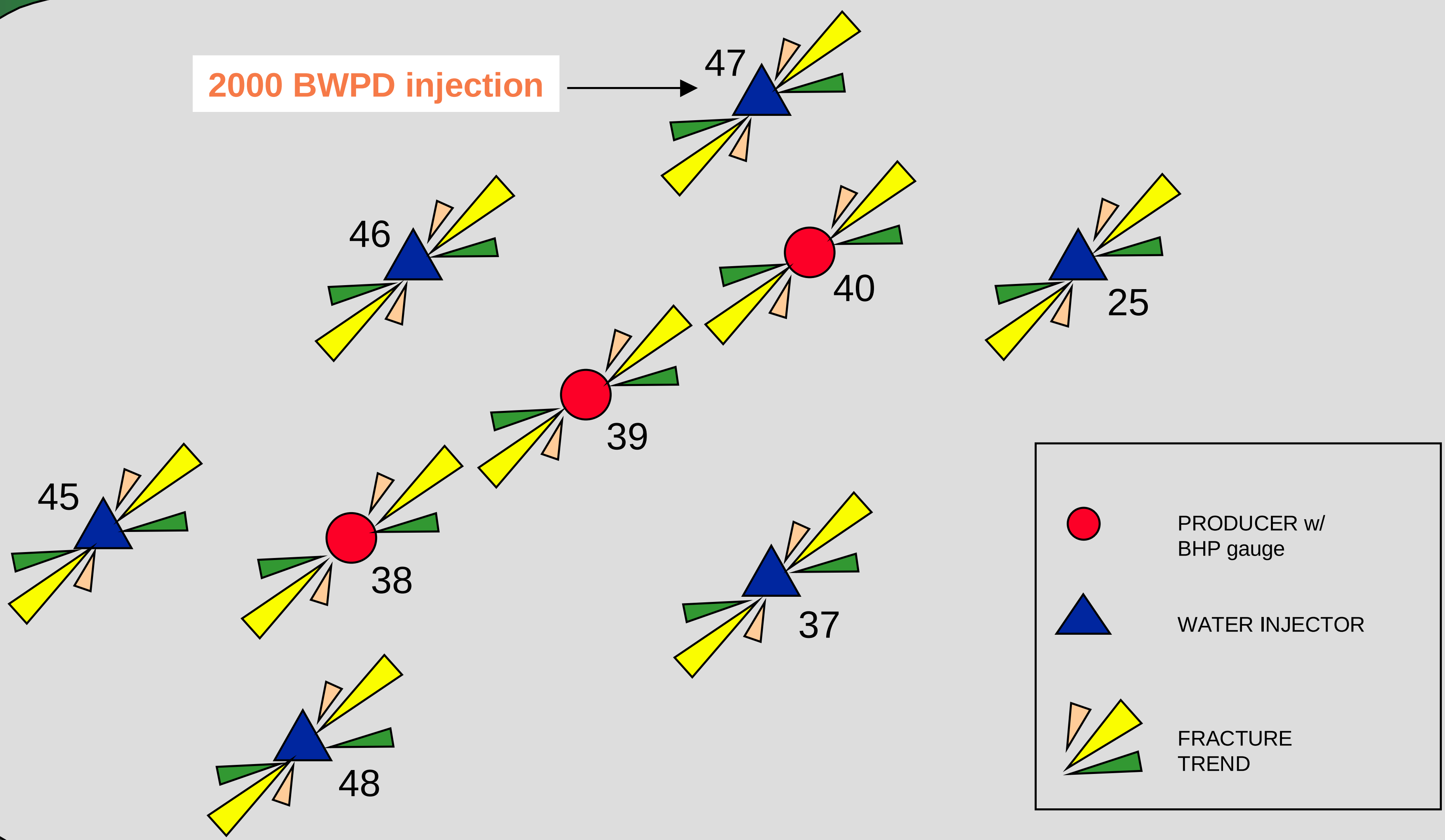
Facility Construction

Facility Construction

Current Field Testing

- Pulse (Interference) Test
  - provides information as to the fracture orientation, effective permeability and permeability anisotropy
    - in progress
- Step Rate Injection Test
  - determines the formation parting pressure
    - #47 WIW ~3200 psig bottom hole pressure
    - #46 WIW ~3050 psig bottom hole pressure
- Injection Profile Log
  - determines the injected fluid distribution
    - #47 WIW ~70% water into the 5U and 30% water into the 1U

Pulse Test



2000 BWPD injection
47
46
40
25
39
45
38
37
48
PRODUCER w/
BHP gauge
WATER INJECTOR
FRACTURE
TREND

Pulse Test
Pressure Response in Producers