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ANADARKO PETROLEUM CORPORATION
CORNELL UNIVERSITY PROJECT
MORTON COUNTY, KANSAS
CL FILE NO. 57151-17847
NMR FINAL REPORT

CORE LAB

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# ANADARKO PETROLEUM CORPORATION
# CORNELL UNIVERSITY PROJECT
# MORTON COUNTY, KANSAS
# CL FILE NO. 57151-17847
# NMR FINAL REPORT

CORE LAB

# PETROLEUM SERVICES

September 19, 1995

Anadarko Petroleum Corporation
17001 Northchase Drive
11th Floor, Anadarko Tower
Houston, Texas 77060
Attn: Mr. Warren Winters

Re: NMR Analysis Report
Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
CL File No. 57151-17847

Dear Mr. Winters:

A total of six (6) plug samples were drilled at points selected by Anadarko representatives. An analytical protocol provided by Anadarko representatives was followed for analysis of the samples.

The following documentation includes: Anadarko protocol dated October 11, 1994; a list of Houston laboratory personnel involved in this project; and the resultant data reported in tabular and graphical formats. The equipment used is also described. Petrographic analyses performed by the Carrollton laboratory were reported under separate cover.

We appreciate this opportunity to be of service. If we can be of further assistance, please do not hesitate to call.

Sincerely,

CORE LABORATORIES

Michael R. Long

Michael R. Long
Laboratory Supervisor

Core Laboratories, Inc.
5295 Hollister Road, Houston, Texas 77040, (713) 460-9600, Fax (713) 460-8275

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# ANALYTICAL PROTOCOL

All analysis was performed as described in the analytical protocol established by Anadarko representatives. Core Laboratories' Houston and Carrollton laboratories performed the analyses. The Anadarko protocol and the laboratory responsible for each procedure are listed below.

## PROCEDURES - NMR & SPECIAL CORE MEASUREMENTS

### Testing Sequence

*Sample Preparation*:

Houston Lab:

1. Drill 2 - 1.00 inch diameter samples from each selected depth and trim to achieve a length of 1.00 inch. Use 2% KCl brine as the bit lubricant. NOTE: high speed centrifuge capillary pressure will be performed on these samples and it is critical that minimal change occurs in the sample volume. Save end trim samples for petrographic analysis.

2. Visually examine each plug both with the naked eye and with a microscope. The samples to be used must be free of fractures and must be homogenous. If there is not at least one plug from each depth that passes the visual inspection, examine the core at that point and evaluate the potential to achieve an adequate plug. Consult Ray Sorenson about drilling replacement plugs.

3. Perform X-Radiography of plugs which pass visual inspection. Do a minimum of two views. The developed negatives are to be viewed by Core Laboratories' representatives and results communicated to Ray Sorenson before plugs are shipped to Carrollton.

4. Dimension each plug sample with digital calipers 6 times for length and 6 times for diameter. Average the values and use a bulk volume for comparison to renaturation bulk volume. Ship samples to Carrollton, attention Jim Shriver for next step. Wrap samples in Saran and foil and package carefully to avoid breakage. Use next day FedEx as timing is critical.

Carrollton Lab:

5. Load sample in core holder, flow clean and flow saturate at minimum confining stress. Miscible flow clean using methanol and then a simple brine (NaCl) matching the brine chemistry ppm supplied. Use a progression of methanol/brine as follows to saturate: 100% methanol to salt free then, 80/20, 60/40. 40/60, 20/80, to 100% brine saturation. Remove sample from core holder and vacuum pressure saturate.

6. Determine renaturation measurements, immersed weight ($W_i$), and saturated weight ($W_s$) determine the bulk volume ($V_b$) of the sample (density of saturant, $\rho_s$). A renaturation porosity will not be available until the end of the testing when the sample is dry.

$$V_b = (W_s - W_i)/\rho_s$$

A method will be provided to keep the fully saturated sample preserved between tests.

Houston Lab:

7. Submit the sample with renaturation data for NMR evaluation. Homogenous Field Only.

   Perform NMR @ 0.5, 1.2 Inner echo spacing. Report NMR porosity %, pore volume, $cm^3$, BVI and FFI to the core analysis laboratory. Provide data file on NMR run on 3.5" diskette.

8. Submit the saturated sample to the core analysis laboratory for special testing.

*Petrographic Analysis: -* To be performed as soon as sample selection is complete on end trims of selected samples.

9. Perform thin section preparation using fluorescent dye on one trim per sample submitted for petrographic analysis. Use general carbonate staining techniques.

Carrollton Lab:

10. Perform a general thin section description for each thin section (no point count). Do use the Epifluorescent technique to examine the sample for microporosity and microfractures. Provide a minimum of 4 microphotographs per sample, 2 magnifications with white light and 2 magnifications with UV light.

11. On another trim from each sample perform SEM. It is critical to know what the fluid in the pore network is in contact with. Use EDS to identify chemical elements and probable associated minerals. Provide a table of chemical elements and probable minerals that represents the pore system, specify relative frequency percentages. A minimum of one low magnification and one high magnification photomicrograph will be required. Additional photos are to be taken if needed to represent the materials lining the pore system.

12. Save part of the SEM trim end for potential mineral analysis if necessary.

*Resistivity Testing:*

13. Load sample in hydrostatic core holder to match reservoir stress ($P_h$ = hydrostatic pressure):

$$P_h = ((P_{ob} - P_r)/3)\cdot(1+\nu)/(1-\nu)$$

assume:
$P_{ob}$ = 2550 psi = overburden pressure (lithostatic gradient = 1.0 psi/ft.),
$P_r$ = 200 psi = reservoir pressure and,
$\nu$ = .26 = Poison's ratio

Thus, $P_h$ = 1330 psi

14. Perform $R_o$ measurements under two electrode conditions, use $\phi_{NMR}$ for an initial evaluation of F vs $\phi$ data. Provide an "m" value for the three samples.

15. Perform $R_t$ measurements under two electrode conditions. Desaturation external to the overburden cell is OK. The $R_t$ measurements must be made at the same overburden as the $R_o$ measurement. Desaturate to maximum pressure of 400 psi air/brine in a centrifuge using a blind rotor with a porous spacer at the down stream end of the plug sample. Desaturate the sample in steps and measure $R_t$ at each step so that an "n" value can be provided for each of the three samples.

16. Resaturate the sample in a vacuum pressure saturator to 100% saturation. Perform measurements to determine immersed weight and saturated weight as a cross check to the starting values. If saturated weight of the sample has changed by more that 0.1 mg, remeasure NMR on the fully saturated sample (repeat steps 7 and 8).

*Centrifuge Capillary Pressure:*

17. Perform high speed centrifuge capillary pressure (air/brine) measurements to a maximum of 400 psi.

18. As before the NMR values of porosity and pore volume can be used for evaluation computations. Report these initial capillary pressure curves to NUMAR. NUMAR will evaluate the data and recommend a pressure to use in step 20.

19. Resaturate the sample follow procedures in step 16.

20. Each sample will be centrifuged to a designated air/brine pressure as determined by NUMAR. Desaturate each sample to the assigned pressure using a porous spaced at the down stream end of the sample. Wrap the sample in Saran and place in an air-tight container.

Houston Lab:

21. Submit the sample with renaturation and $S_{wi}$% data for NMR evaluation. Homogenous Field Only. Perform NMR @ 0.5, 1.2 and 2.0 Inner echo spacing. Report NMR porosity %, pore volume, $cm^3$, to the core analysis laboratory. Provide data file on NMR run on 3.5" diskette.

22. Wrap sample in Saran Wrap and place in an air-tight container and return the core to the core analysis laboratory.

Carrollton Lab:

23. Load the sample in hydrostatic core holder and flow saturate with lab oil (no vacuum).

24. Perform $K_o$ @ $S_{wir}$ with a back pressure of 400 psi, maintaining a hydrostatic pressure approximating 1330 psi (adjust core holder pressure to compensate for the pore pressure in the sample).

25. Unload the sample and perform Dean-Stark analysis (correct $S_w$ for salty brine).

26. Dry the clean sample in a convection oven, at 240° F until a stable weight is achieved.

27. Determine grain volume, $cm^3$, via Boyle's Law using helium.

28. Determine pore volume, $cm^3$, at overburden 1330 psi.

29. Determine permeability md, Klinkenberg (measurement) corrected at overburden 1330 psi.

30. Determine bulk volume, $cm^3$, mercury immersion.

31. Report $K_\infty$ at overburden, $\phi$ at overburden and ambient, grain density, grain volume, bulk volume, pore volume overburden and ambient, as well as, $S_w$ at ambient.

*Mercury Injection Pore Size Distribution:*

Prior to performing Hg injection, a review of all the data should be performed.

32. Perform Hg injection to a maximum pressure 55,000 psi. Generate a drainage curve with associated pore throat size data. Take the sample back to zero pressure and record the final mercury saturation. An imbibition curve is not required. The final mercury saturation gives a crude estimation of trapped gas saturation.

# NUCLEAR MAGNETIC RESONANCE (NMR)

The NMR technique exploits nuclear paramagnetism of atoms and their interactions with applied magnetic fields. Hydrogen atom nuclei exhibit an intrinsic angular momentum or "spin". The spinning produces a magnetic field, the strength and direction of which are expressed in terms of a nuclear magnetic moment. The naturally occurring magnetic field can be altered using one or more induced magnetic fields. The changes in the natural magnetic field resulting from the induced fields are monitored and recorded. The transverse relaxation time ($T_2$) is measured at echo spacings designated by the client. The data is processed to obtain porosity values using Core Laboratories' multi-exponential model and techniques currently under development by Core Laboratories' R&D group.

## NMR TRANSVERSE ($T_2$) RELAXATION SIGNAL PROCESSING

The $T_2$ Signals for the three samples (1B, 2A and 3B) at two echoes spacing (0.5 and 1.2 ms) were process using the techniques currently being developed by our R&D group. As shown in the enclosed Table, porosity values obtained using the Core Laboratories multi-exponential model compare favorably with measured porosity. There is also a comparison of the Core Labs NMR porosity data with those obtained using the program resident in the NUMAR CORESPEC-1000. It clearly shows an improvement in the estimation capability.

Also shown in the enclosed Figures are the different form of the $T_2$ distribution curves obtained from the Core Labs program. Using Centrifuge Capillary pressure data in conjunction with the median $T_2$ of the 150 psi centrifuged samples, we determined that the mean value of $T_{2c}$ for determining BVI is about 10 ms( see figure).

The BVI and FFI computed using this cutoff are shown in the Table.

We do not have enough data to enable the development of the model for estimating permeability in this work.

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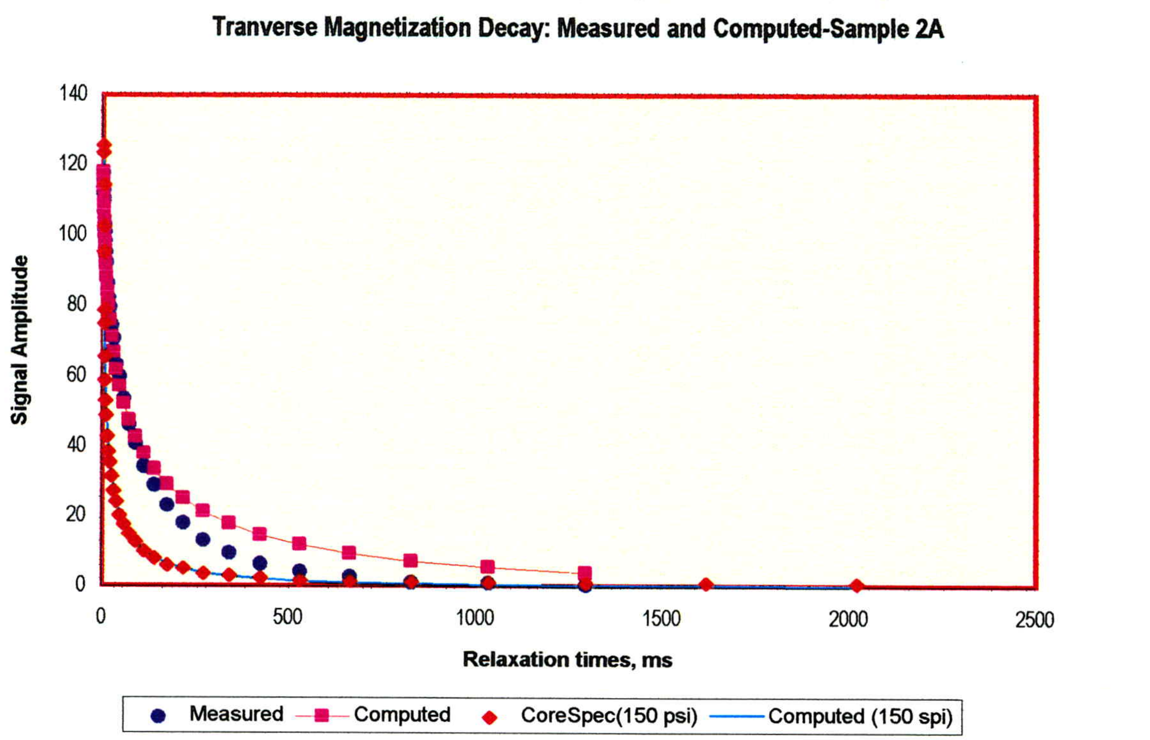
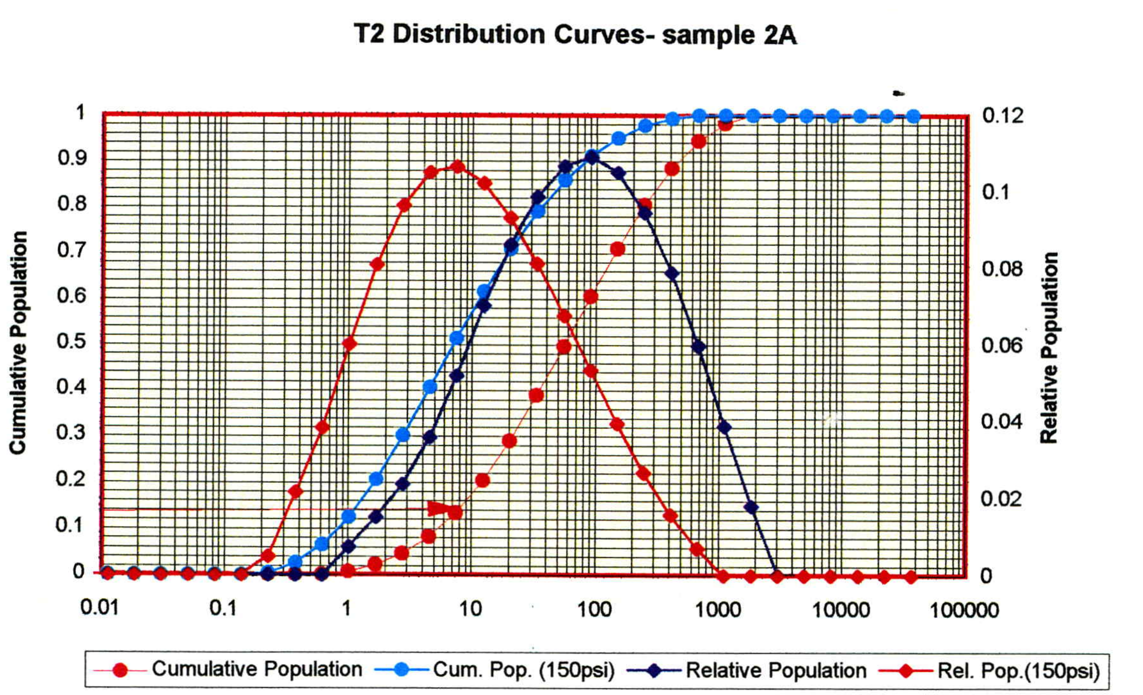
| Sample # | Echo SP | Cum. Pop (T2c=10ms) % | Archimedes BV cc | NMR PV cc | NMR BVI % | NMR FFI % | Core Helium $\phi$(%) | NMR $\phi$(%) CORELABS | NMR $\phi$(%) NUMAR | Diff PU CORELABS | Diff PU NUMAR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1B | 0.5 | 41 | 12.57 | 1.43298 | 4.674 | 6.726 | 11.5 | 11.400 | 7.900 | 0.111 | 3.6 |
| 2A | 0.5 | 17.5 | 12.45 | 1.73055 | 2.4325 | 11.468 | 14.6 | 13.900 | 13.300 | 0.713 | 1.26 |
| 3B | 0.5 | 22 | 12.48 | 1.52256 | 2.684 | 9.516 | 12.5 | 12.200 | 11.300 | 0.251 | 1.21 |
| | | | | | | | | | | | 0 |
| 1B | 1.2 | | 12.57 | 1.69695 | | | 11.5 | 13.500 | 7.700 | -2.041 | 3.84 |
| 2A | 1.2 | | 12.45 | 1.743 | | | 14.6 | 14.000 | 13.400 | 0.629 | 1.22 |
| 3B | 1.2 | | 12.48 | 1.6224 | | | 12.5 | 13.000 | 11.200 | -0.518 | 1.3 |


Tranverse Magnetization Decay: Measured and Computed-Sample 2A
Signal Amplitude
140
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
Relaxation times, ms
Measured
Computed
CoreSpec(150 psi)
Computed (150 spi)


T2 Distribution Curves- sample 2A
Cumulative Population
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.01
0.1
1
10
100
1000
10000
100000
Relative Population
0.12
0.1
0.08
0.06
0.04
0.02
0
Cumulative Population
Cum. Pop. (150psi)
Relative Population
Rel. Pop.(150psi)

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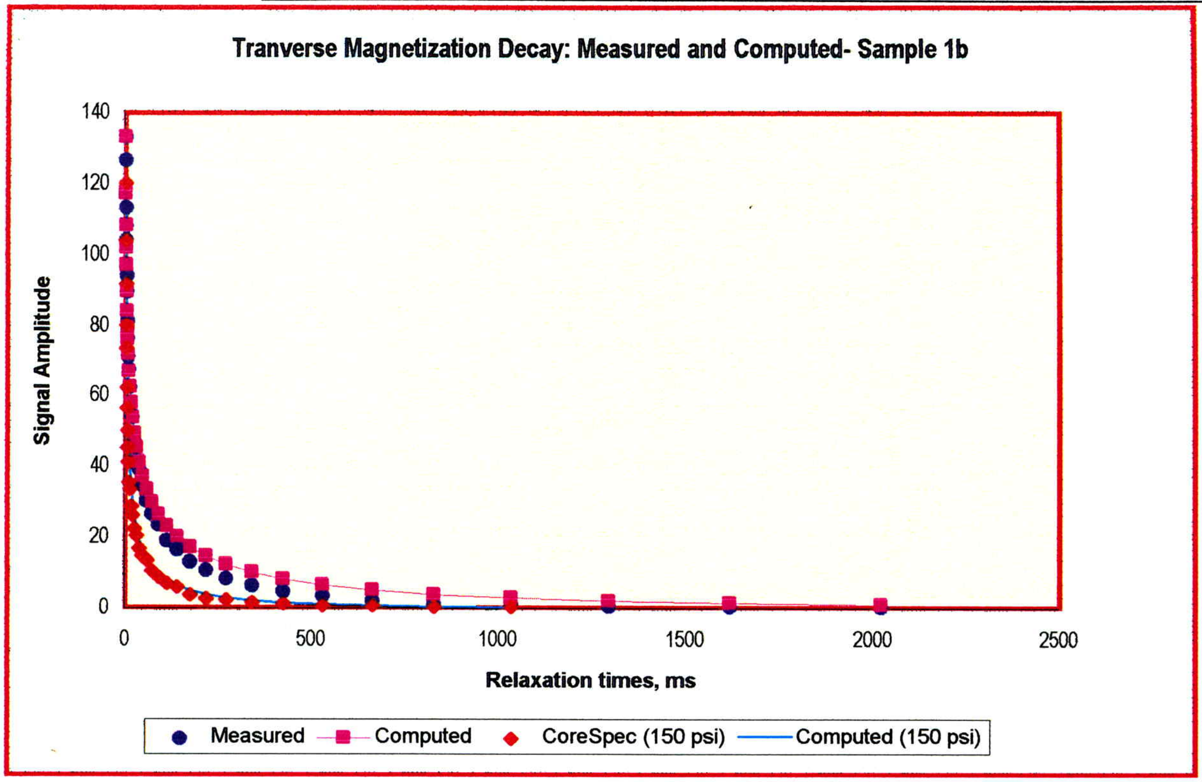


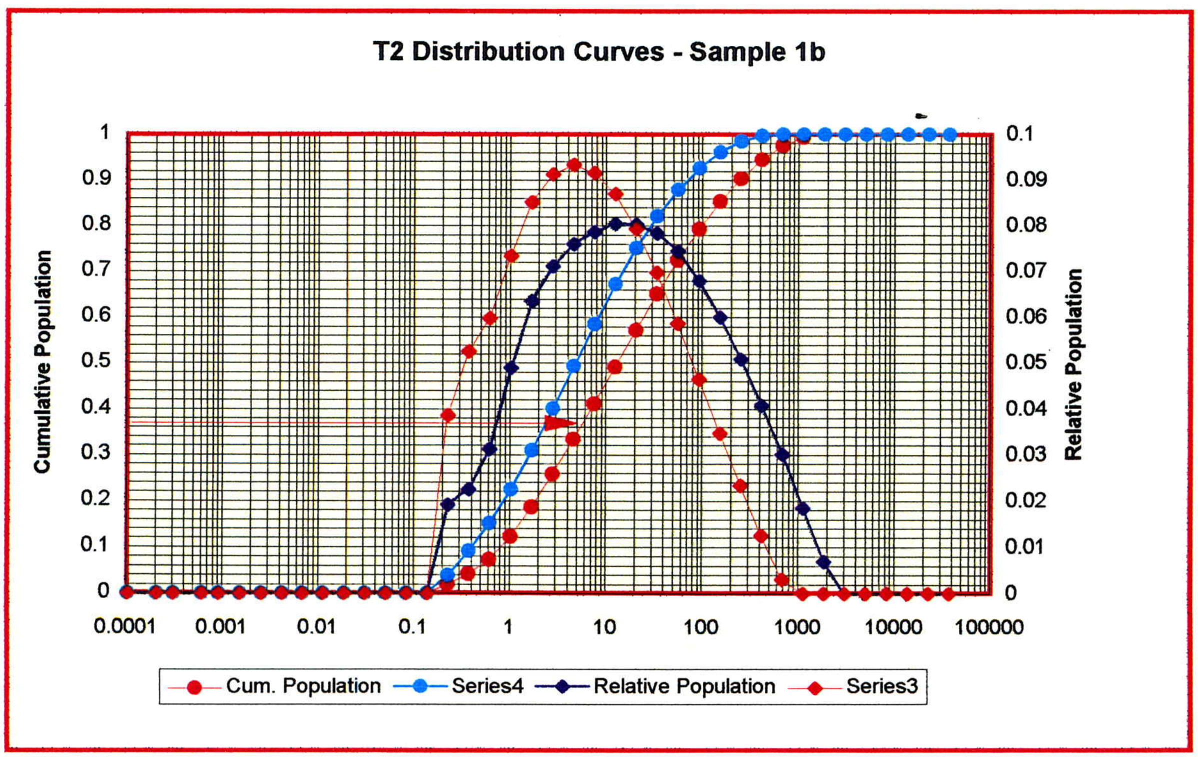

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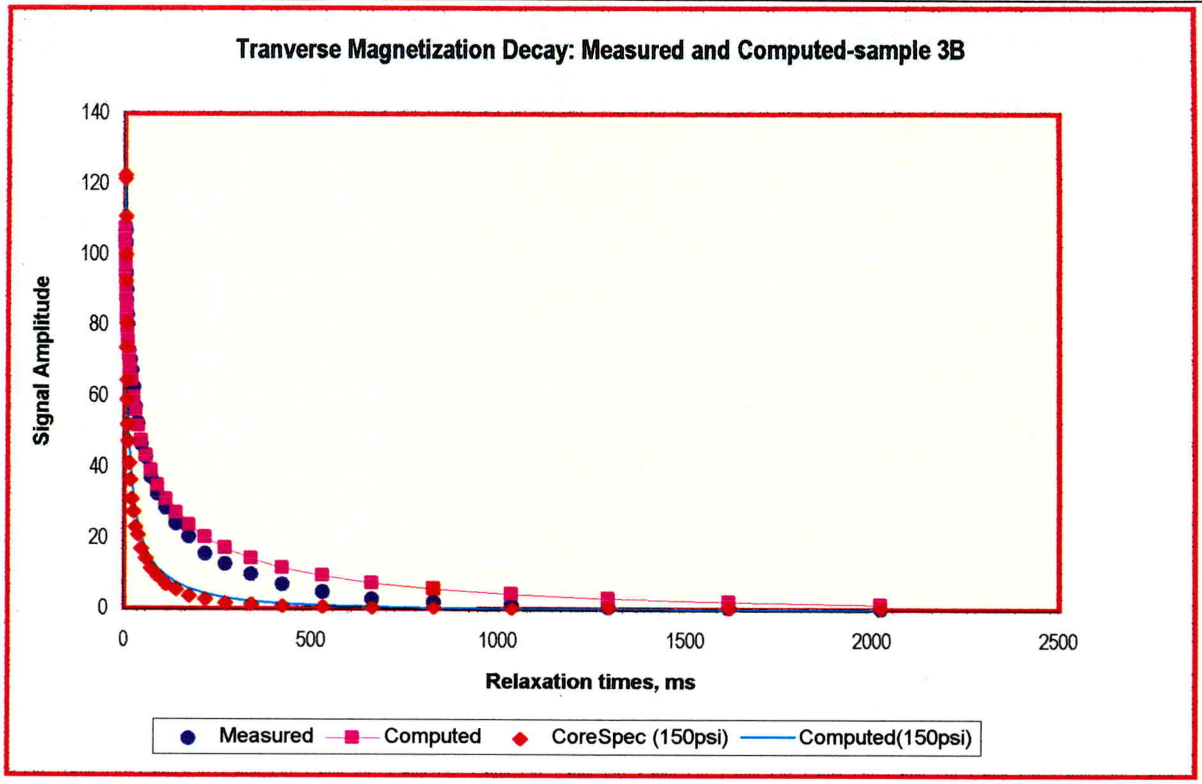


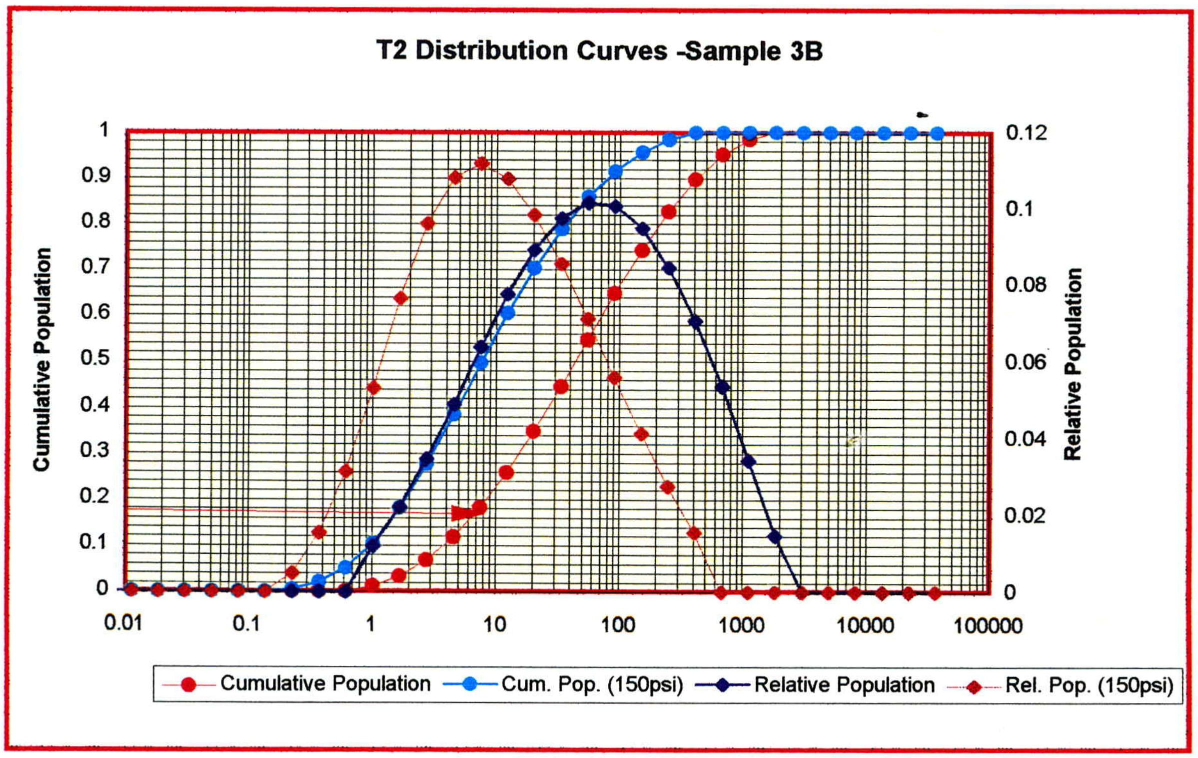



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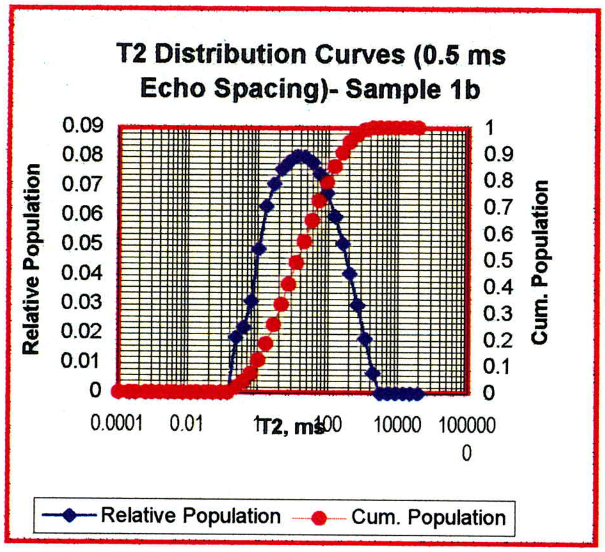


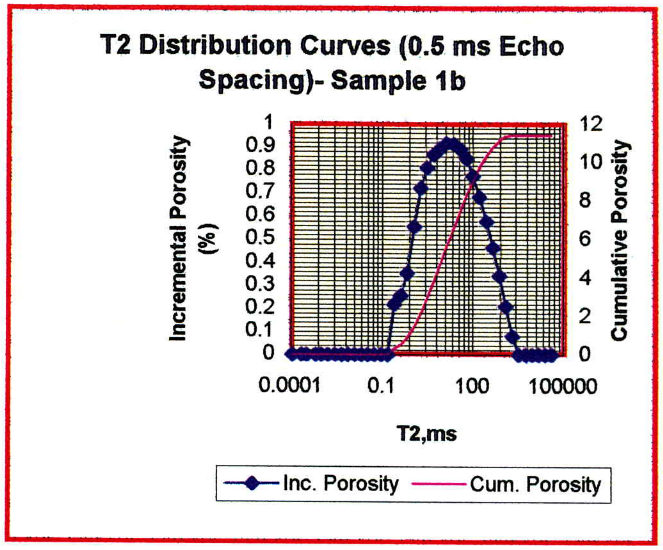


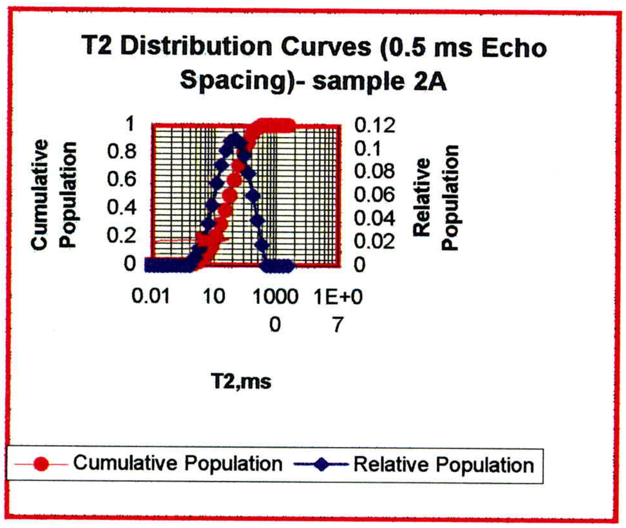


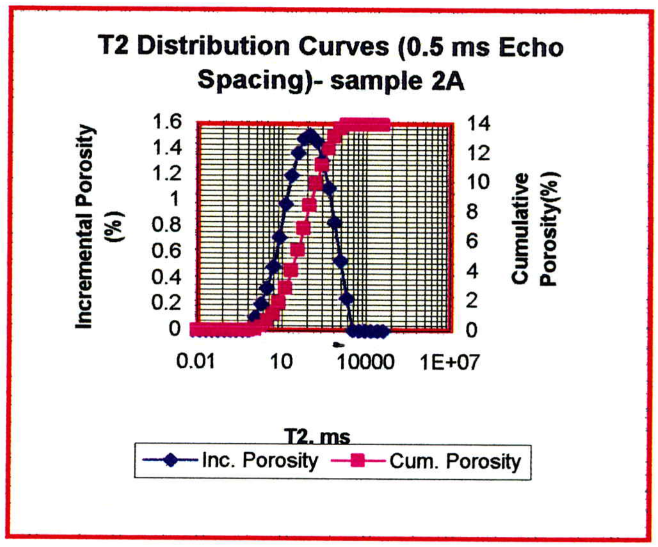


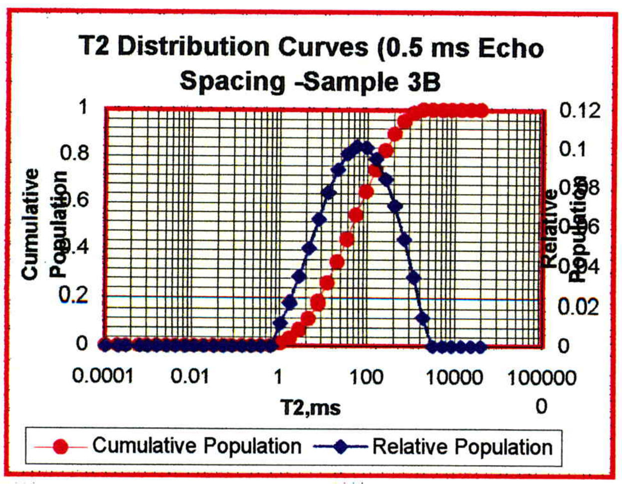


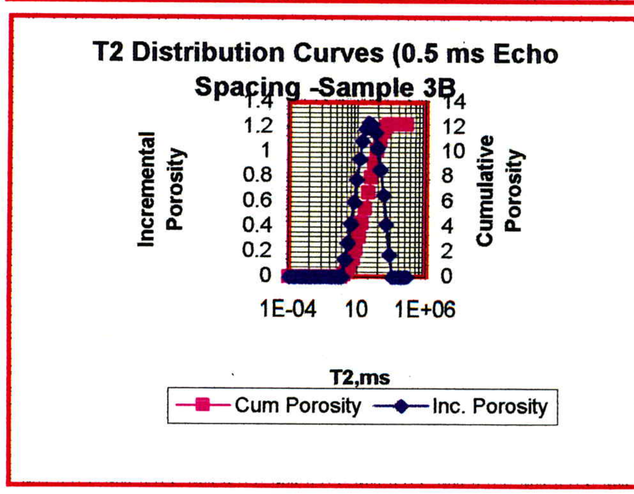


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Anadarko Petroleum Corporation
File: DAL-94226

## PARTICIPANTS PAGE
## (Carrollton)

| | |
|---|---|
| Basic Properties<br>Mercury Injection | Tommy Wallace |
| Effective Permeability to Oil | John Hibbard |
| Electrical Properties | Nabil Nashed |
| Report Preparation: Electrical Properties | Marilyn Black |
| Capillary Pressure<br>Carrollton Report Preparation | Jerry Warne |
| Final Review, Carrollton Report | Melanie Dunn |

525337

Anadarko Petroleum Corporation
File: DAL-94226

# PROJECT SUMMARY

Three samples were received for use in the Cornell University Project from Core Laboratories in Houston. The samples were miscibly extracted with methanol and saturated with 100.000 ppm sodium chloride (NaCl) brine. They then underwent two-electrode electrical property testing followed by capillary pressure testing. While at an terminal water saturation. the samples were saturated with oil and the effective permeability to oil at an initial water saturation determined. After all other tests were complete, the samples underwent high pressure mercury injection testing.

Between each of these steps, and in some cases in the midst of testing, the samples were sealed within containers to prevent dehydration and shipped to the Houston laboratory for NMR measurements at whatever brine saturation the samples had obtained at that point in testing. This ranged from full saturation to partial saturations following or during test procedures. Each time the samples were shipped back to the Carrollton laboratory to continue the test program.

- **Electrical Properties**

Two-electrode electrical property testing was performed on the three samples using a hydrostatic net confining pressure of 1330 psi, which was calculated as described in the electrical properties procedures. The resistivity ($R_o$) of the fully brine saturated samples was determined and Formation Factor calculated. Using this and sample porosity, the cementation exponent "m" was determined for each sample and as a composite value. Individual "m" values ranged from 2.01 to 2.08 while the composite was 2.05.

Resistivity index, the ratio of a sample at partial saturation to its resistivity at full saturation, was determined at four partial saturations for each sample. These values along with the saturation they were determined at, were used to calculate the saturation exponent "n" for each sample. A composite "n" value was also calculated for the three samples. Individual "n" values ranged from 1.76 to 2.48, with a composite value of 1.93.

- **Gas-Water Capillary Pressure**

Following resaturation, the three samples underwent gas-water capillary pressure testing using the centrifuge method. This was a primary drainage system in which the saturating brine was displaced by gas (air) at increasing rotational speeds giving equivalent displacement pressures ranging from 1 to 400 psi. Inlet-face water saturation values were calculated at the reported pressures using the methods of Hassler and Brunner; ("Measurement of Capillary Pressures in Small Core Samples", T.P. 1817, Petroleum Technology, March 1945, pages 114-123) and R.R. Rajan, ("Theoretically Correct Analytical Solution for Calculating Capillary Pressure-Saturation From Centrifuge Experiments") which was presented at the 27th SPWLA Conference Annual Symposium; June, 1986. Water saturations at the maximum displacement pressure of 400 psi ranged from 11.2 to 34.5 as a percentage of pore volume.

Additional testing was requested in which the samples were resaturated, then centrifuged at two equivalent displacement pressures with a saturated ceramic porous disc at the foot of each sample. The samples were centrifuged at speeds giving equivalent displacement pressures of (an average) 80 and 150 psi, with average residual saturations calculated gravimetrically. These data points were graphed with the capillary pressure data, with reasonable correlations in each case.

- **Effective Permeability to Oil**

Following the final centrifugation of the samples they were flushed with Isopar-L (a light laboratory oil) against backpressure until fully saturated. The terminal water saturation established during centrifuging was still in place. The effective permeability to oil at an initial water saturation was determined for each of the samples, ranging from 0.018 to 0.813 millidarcys.

- **High Pressure Mercury Injection**

When all other tests had been satisfactorily completed the three core samples were forwarded for high pressure mercury injection testing. Mercury was injected into each sample at pressures ranging from 3 to 50,000 psia. The data for each sample was corrected for conformance volume, then saturations were calculated at each injection pressure. The amount of mercury injected into the samples at the maximum injection pressure of 50,000 psia ranged from 99.4 to 99.8 percent of pore volume. The median pore throat entry size (50 percent larger, 50 percent smaller) ranged from 0.163 to 0.678 microns.

Also included are pore throat entry radii (in microns), conversion of the air-mercury injection pressure to pressures in other laboratory systems, and approximate height above free water for both oil and gas reservoirs. These heights can be considered only approximate as equation parameters were not measured and only "typical" values were available for calculations.

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# LABORATORY PROCEDURES

## Electrical Properties

Following flow saturation with 100,000 ppm the samples were ready for electrical properties testing. The net confining pressure to be used during testing was calculated in Houston as follows:

$$P_h = ((P_{ob} - P_r) \div 3) * ((1 + \upsilon) \div (1 - \upsilon))$$

assume:

| | | | | |
|---|---|---|---|---|
| $P_{ob}$ | = | overburden pressure | = | 2550 psi (lithostatic gradient = 1.0 psi/ft) |
| $P_r$ | = | reservoir pressure | = | 200 psi |
| $\nu$ | = | Poisson's Ratio | = | 0.26 |

Thus, $P_h$ = hydrostatic pressure = 1330 psi

- **Formation Factor, $R_o/R_w$**

1. The saturated samples were loaded into a two electrode hydrostatic system with 1330 psi net confining pressure.

2. The resistance of a known volume of the water to a constant electrical current was measured. The $R_w$ of the water was calculated at ambient temperature and adjusted to 25°C using Arp's equation.

3. Sample resistance was monitored continuously at ambient temperature to determine when electrical/ionic stability was achieved. To determine the formation resistivity factor of each sample, the electrical resistance measurements at 100 percent brine saturation were measured at 1000 Hertz and normalized to 25°C. Formation factor (FF) was computed using the formula:

$$FF = R_o \div R_w$$

4. A plot of formation factor versus porosity was used to determine the composite "m" value. A line was fit through the data points using a least squares linear regression, with the slope of the line defined as "m". The y-intercept of the line is the "a" used in Archie/Humble equations for calculations of water saturation. Individual cementation exponents, "m", were calculated using the formula:

$$\text{"m"} = [\log FF \div \log \text{porosity (fractional)}]$$

- **Resistivity Index, $R_t/R_o$**

5. Sample resistivity, $R_t$, was determined at several decreasing water saturations. Brine was displaced from the sample by centrifugation using a blind rotor with a porous spacer at the down stream end of the plug sample. The maximum pressure achieved was 400 psi.

6. All resistance values were obtained using a frequency of 1000 Hertz and 1330 psi confining pressure. The resistivity values, $R_t$ and $R_o$, were used to calculate the resistivity index, RI, at each saturation using the equation:

$$RI = R_t \div R_o$$

7. A least squares linear regression plot for resistivity index, RI, versus water saturation, $S_w$, for all samples yields a line whose slope defines the composite "n", 1.93. Individual saturation exponent values, "n", were calculated using the formula:

$$"n" = [\log RI \div \log S_w \text{ (fractional)}]$$

Electrical properties data are presented in tabular and graphical formats on the following pages.

# FORMATION RESISTIVITY FACTOR

2-Terminal

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| | |
|---|---|
| Saturant, ppm: | 100K ppm NaCl |
| Net Confining Stress, psi: | 1330 |
| Resistivity of Saturant, ohm-m @25°C: | 0.072 |
| Porosity Exponent (m) [Composite]: | 2.05 |
| Y-Intercept (a): | 1.00 |

| Sample Number | Depth, feet | Permeability, to Air, millidarcys | Porosity, fraction | Formation Factor | | Porosity Exponent m |
|---|---|---|---|---|---|---|
| | | | | Ro, ohm-m | FF | |
| 1B | 2530.2 | 0.070 | 0.115 | 6.51 | 90.47 | 2.08 |
| 2A | 2537.4 | 1.20 | 0.146 | 3.48 | 48.27 | 2.01 |
| 3B | 2541.7 | 0.248 | 0.125 | 5.03 | 69.90 | 2.04 |

$$FF = Ro / Rw = \frac{a}{\phi^m}$$

# FORMATION RESISTIVITY FACTOR

2-Terminal

1000 Hertz

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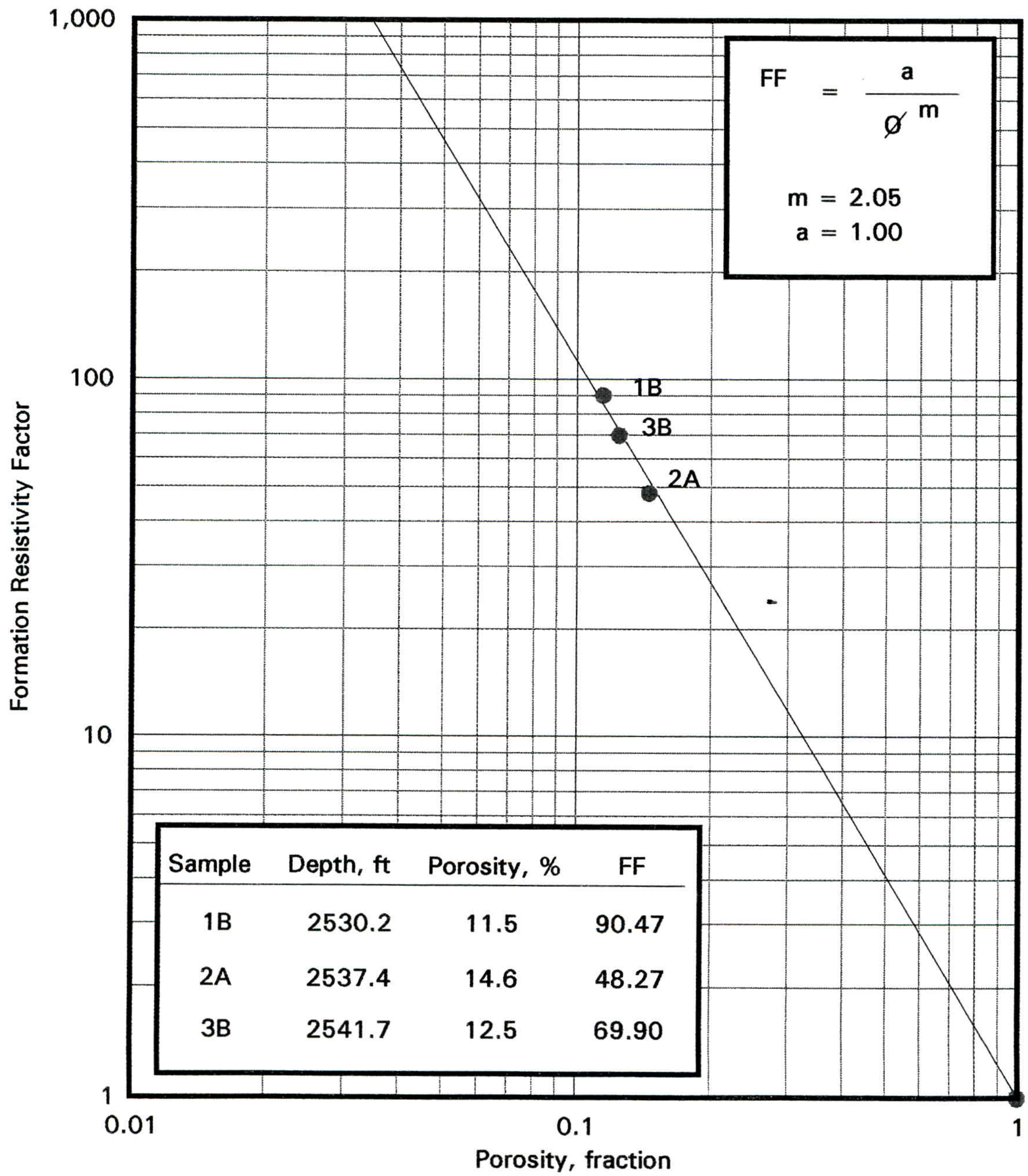
Composite of 3 Samples




| Sample | Depth, ft | Porosity, % | FF |
|---|---|---|---|
| 1B | 2530.2 | 11.5 | 90.47 |
| 2A | 2537.4 | 14.6 | 48.27 |
| 3B | 2541.7 | 12.5 | 69.90 |

**Core Laboratories**

# FORMATION RESISTIVITY INDEX
2-Terminal

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Cornell University Project
Morton County, Kansas
File: DAL-94226

| | |
|---|---|
| Saturant: | 100K ppm NaCl |
| Net Confining Stress, psi: | 1330 |
| Resistivity of Saturant, ohm-m @ 25°C: | 0.0720 |
| Porosity Exponent (m) [Composite]: | 2.05 |
| Y-Intercept (a): | 1.00 |
| Saturation Exponent (n) [Composite]: | 1.93 |

| Sample Number | Depth, feet | Permeability to Air, millidarcys | Porosity, fraction | Formation Resistivity Ro, ohm-m | Formation Resistivity FF | Porosity Exponent (m) | Brine Saturation fraction Vp | Resistivity Index (RI) | Saturation Exponent (n) |
|---|---|---|---|---|---|---|---|---|---|
| 1B | 2530.2 | 0.070 | 0.115 | 6.51 | 90.37 | 2.08 | 1.000 | 1.00 | 2.48 |
| | | | | | | | 1.000 | 1.10 | |
| | | | | | | | 0.917 | 1.41 | |
| | | | | | | | 0.749 | 2.24 | |
| | | | | | | | 0.534 | 4.46 | |
| 2A | 2537.4 | 1.20 | 0.146 | 3.48 | 48.27 | 2.01 | 1.000 | 1.00 | 2.00 |
| | | | | | | | 0.924 | 1.40 | |
| | | | | | | | 0.481 | 3.92 | |
| | | | | | | | 0.322 | 8.29 | |
| | | | | | | | 0.220 | 24.41 | |
| 3B | 2541.7 | 0.248 | 0.125 | 5.03 | 69.90 | 2.04 | 1.000 | 1.00 | 1.76 |
| | | | | | | | 0.942 | 1.32 | |
| | | | | | | | 0.615 | 2.25 | |
| | | | | | | | 0.391 | 5.14 | |
| | | | | | | | 0.241 | 12.64 | |

$$S_w = \sqrt[n]{\frac{FR_w}{R_t}}$$

# FORMATION RESISTIVITY INDEX

2-Terminal

1000 Hertz

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Cornell University Project
Morton County, Kansas
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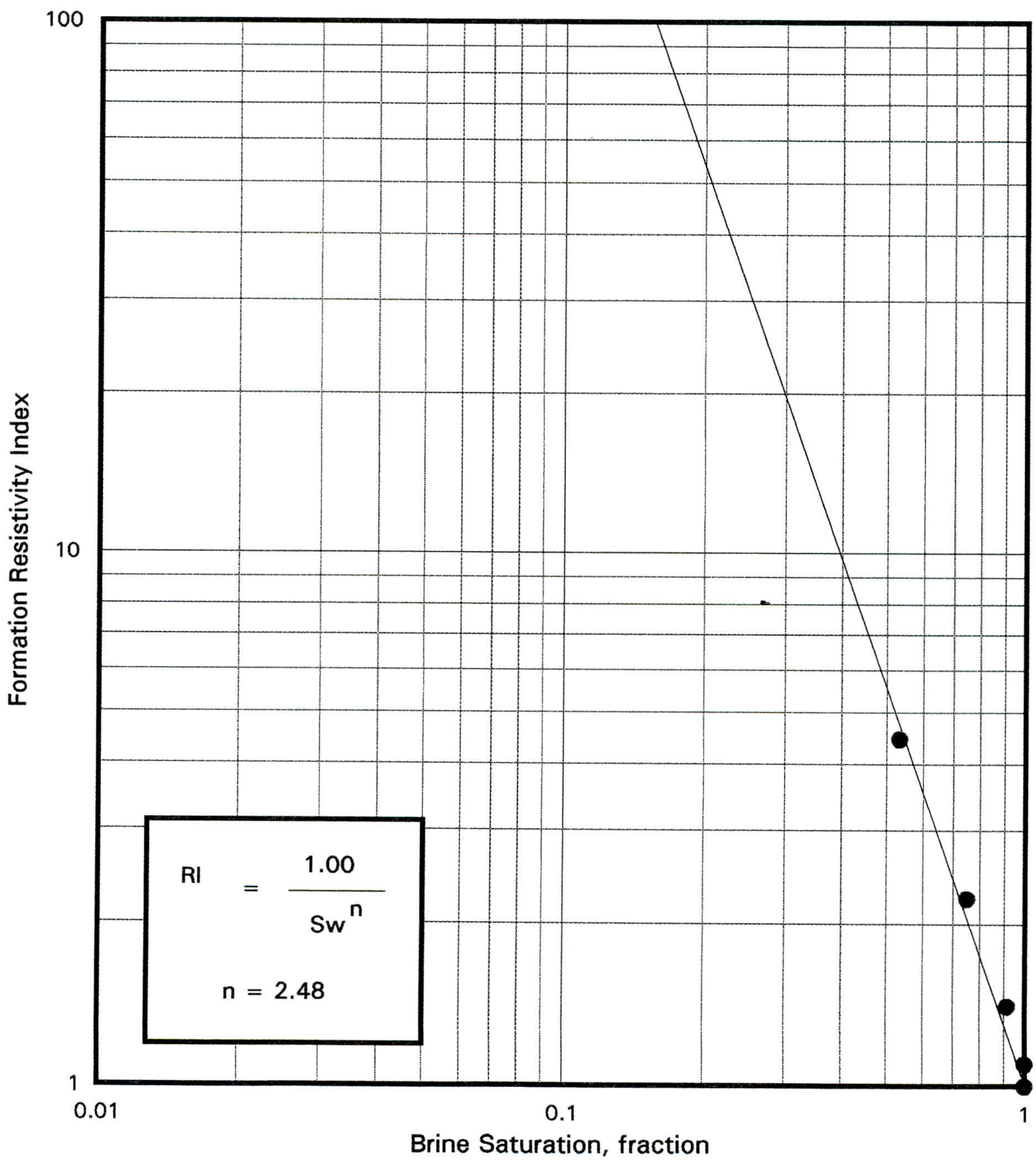
Sample Number: 1B
Depth, feet : 2530.2
Permeability to Air, md : 0.070
Porosity, fraction : 0.115

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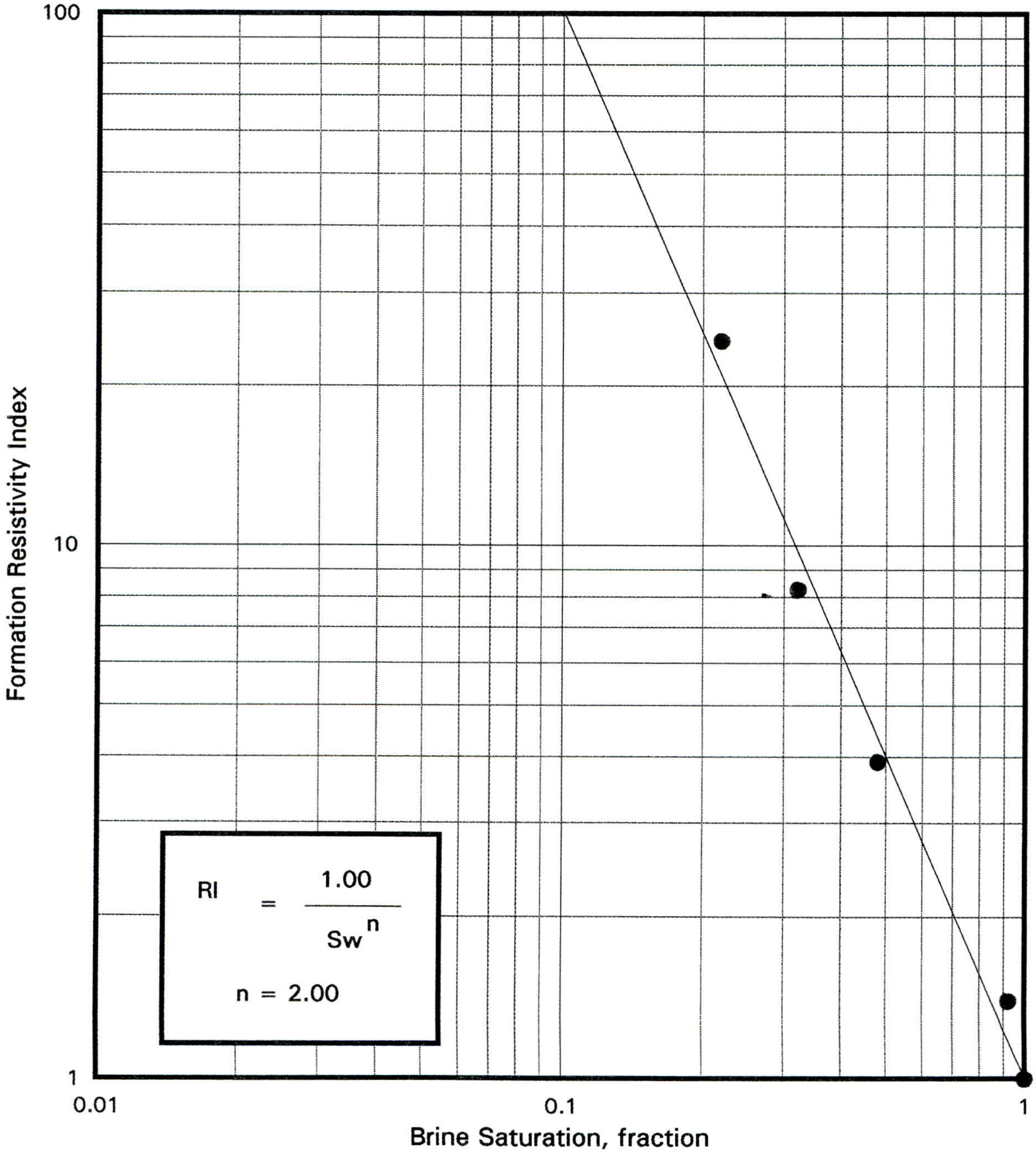
# FORMATION RESISTIVITY INDEX

2-Terminal
1000 Hertz

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

Sample Number: 2A
Depth, feet : 2537.4
Permeability to Air, md : 1.20
Porosity, fraction : 0.146



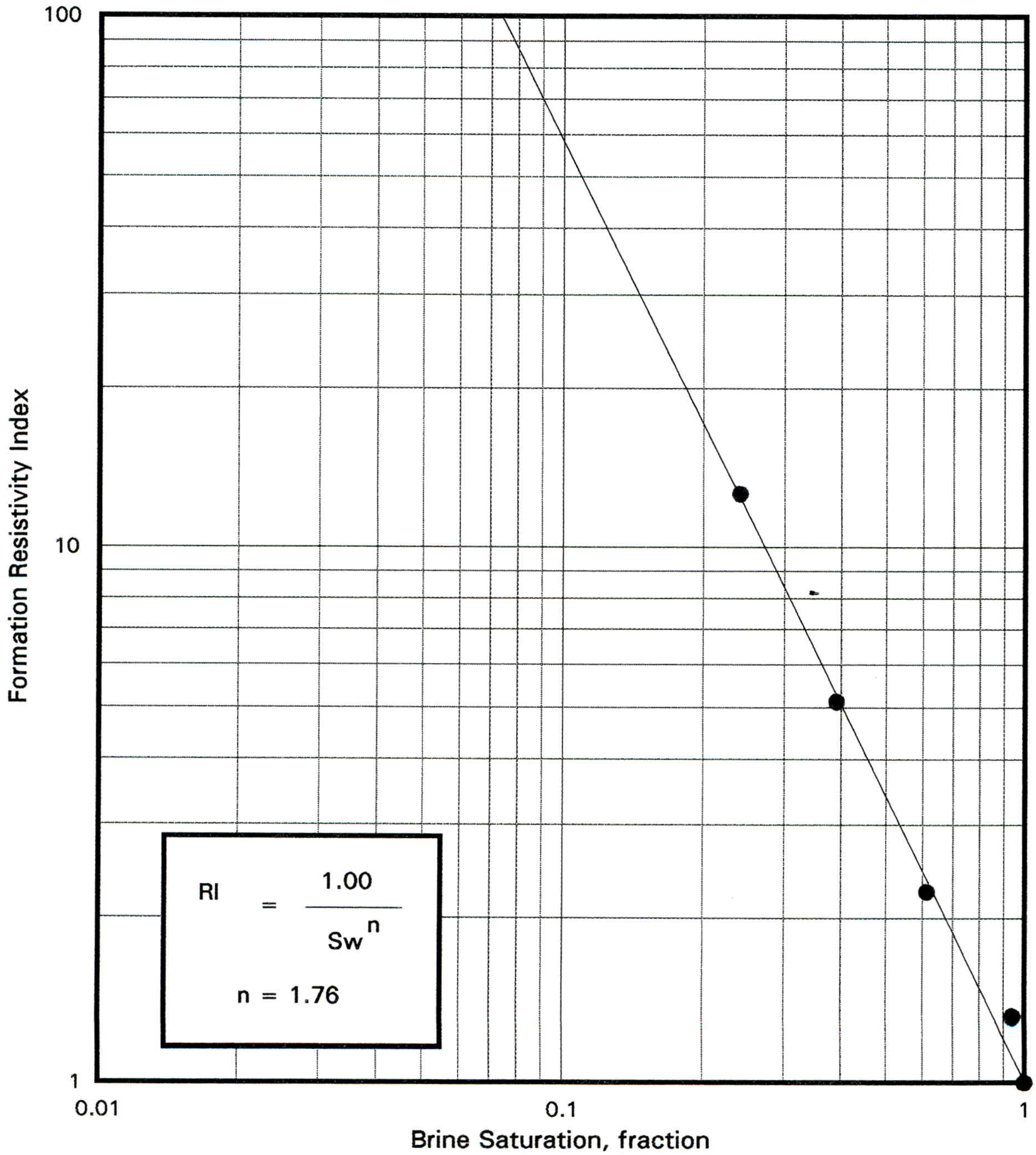

**Core Laboratories**

# FORMATION RESISTIVITY INDEX

2-Terminal
1000 Hertz

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

Sample Number: 3B
Depth, feet : 2541.7
Permeability to Air, md : 0.248
Porosity, fraction : 0.125

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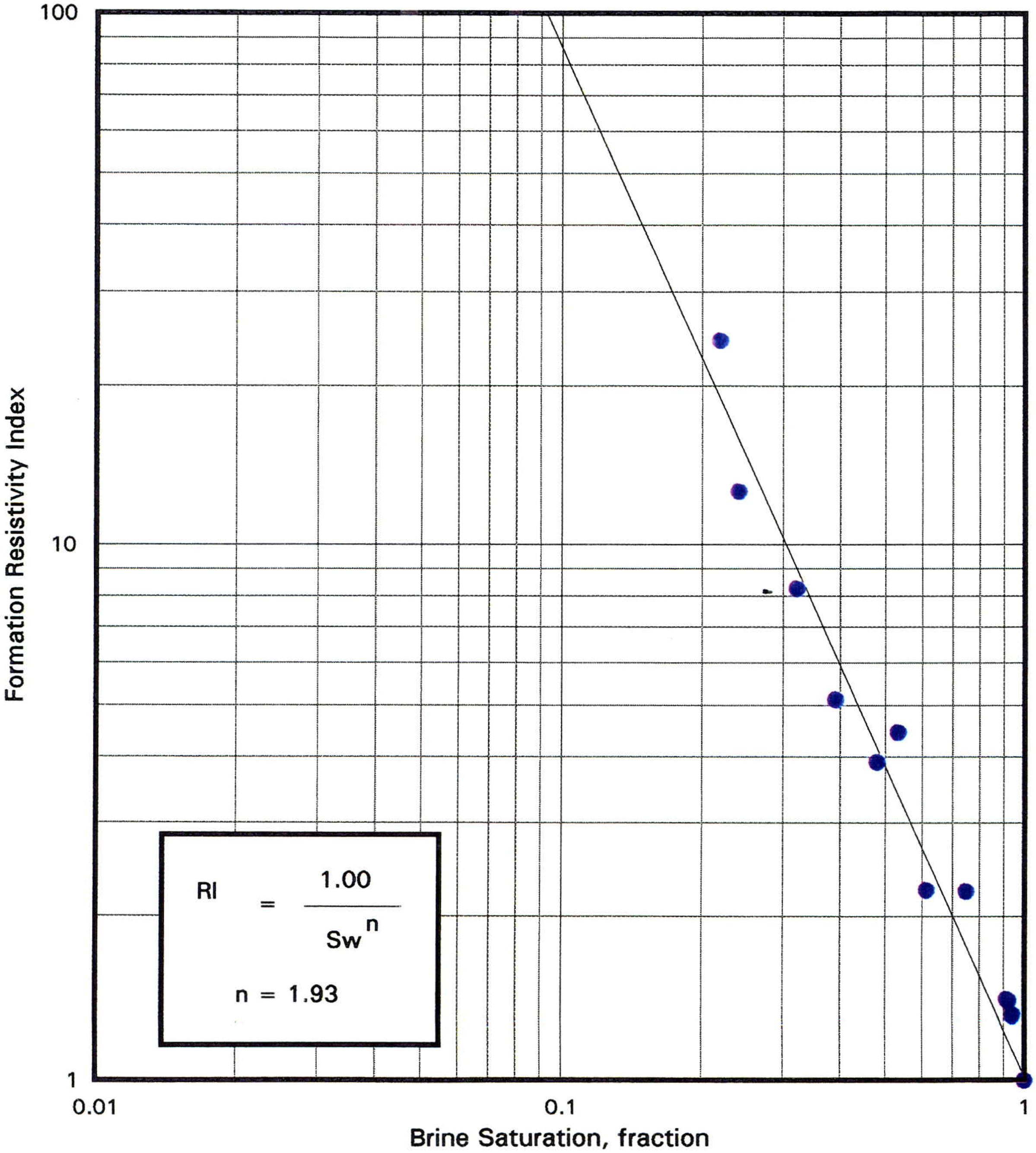
# FORMATION RESISTIVITY INDEX

2-Terminal

1000 Hertz

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

Composite Of 3 Samples




Core Laboratories

# LABORATORY PROCEDURES
## Gas-Water Capillary Pressure

Three, 1.0 inch diameter core plugs which were part of the Cornell University Project were selected for gas-water capillary pressure testing using the centrifuge method. Initially, testing was performed using NMR determined pore volumes for preliminary calculations. Final calculations were made following the measurement of sample basic properties which occurred following the completion of effective permeability to oil testing.

1. The samples were received from the Houston lab and were flow saturated with the 100,000 ppm NaCl brine.

2. Testing was performed at ambient conditions using a Beckman high speed Ultracentrifuge. The saturated samples were placed into the specially designed coreholders of a six-place centrifuge rotor head and subjected to nonstop centrifugation at rotational rates that were increased incrementally to generate equivalent displacement pressures ranging from 1 to 400 psi in a gas-displacing-water system.

3. Sufficient time was allowed at each rate of rotation for saturation equilibrium within the samples to be established. Equilibrium at each speed was determined by monitoring brine displacement until the rate of displacement was reduced to 0.001 or less pore volumes per hour over a nominal period of eight hours. Each speed took approximately 24 hours. Displaced brine volumes were read during centrifugation using a strobe unit mounted in the rotational chamber.

4. The desaturated samples were sent back to Houston for NMR measurements.

5. The samples were received back from Houston and resaturated with the NaCl brine.

6. The samples were loaded into the centrifuge again, this time with a saturated ceramic porous disc at the foot of each sample. They were centrifuged at a rotational speed calculated to give an average displacement pressure of 80 psi until all three samples achieved saturation equilibrium.

7. Average water saturations were calculated gravimetrically, using the initial saturated weight and the weight measured following unloading.

8. The samples were sealed within containers and shipped to Houston for NMR measurements.

9. The samples were received back from Houston and steps (6) and (7) repeated using an average displacement pressure of 150 psi.

10. The samples were sealed within containers and shipped to Houston for NMR measurements.

11. After receiving the samples from Houston they were saturated with oil and the effective permeability to oil at an initial water saturation was determined for each.

12. Following permeability to oil tests the samples underwent Dean-Stark extraction, then underwent further extraction in a glass, reflux soxhlet, first with hot toluene then with methanol.

13. After drying in a vacuum oven at 220°F, basic properties (grain density, permeability, and porosity) were determined for the dry samples.

14. Capillary pressure - saturation relationships were calculated for each sample using equilibrium displacement volumes and equivalent pressure data. Inlet-face saturation values were calculated based on the methods of Hassler and Brunner ("Measurement of Capillary Pressures in Small Core Samples" T.P. 1817, Petroleum Technology, March 1945, P. 114-123) and R.R. Rajan, ("Theoretically Correct Analytical Solution for Calculating Capillary Pressure-Saturation From Centrifuge Experiments"), which was presented at the 27th SPWLA Conference Annual Symposium; June, 1986.

The pressure range was selected to develop definitive curves relating saturation and pressure (height). To complete the relationship, appropriate conversion values must be input into the following equation:

$$Height_R = Pc_L * (T\cos\theta_R / T\cos\theta_L) \div (\rho_w - \rho_h)$$

where:

| | | |
|---|---|---|
| $Height_R$ | = | Height above free water, initial reservoir conditions |
| $Pc_L$ | = | Capillary pressure (laboratory) |
| $T\cos\theta_R$ | = | Gas-Water interfacial tension, initial reservoir conditions |
| $T\cos\theta_L$ | = | Gas-Water interfacial tension, laboratory |
| $\rho_w$ | = | Water density gradient, initial reservoir conditions |
| $\rho_h$ | = | Hydrocarbon density gradient, initial reservoir conditions |

The calculation converts laboratory pressure to reservoir pressure, with the reservoir value divided by the difference in the reservoir density gradients of the fluids. Using a fairly typical relationship, a laboratory gas-water capillary pressure of 100 psi would equate to a height of approximately 260 feet in an oil reservoir. This value can vary substantially however by using different input parameters.

## CAPILLARY PRESSURE

Centrifuge Method

**Gas-Water System**

Ambient Temperature

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

Displaced Phase: Water
Displacing Phase: Gas
Confining Stress, psi: 0

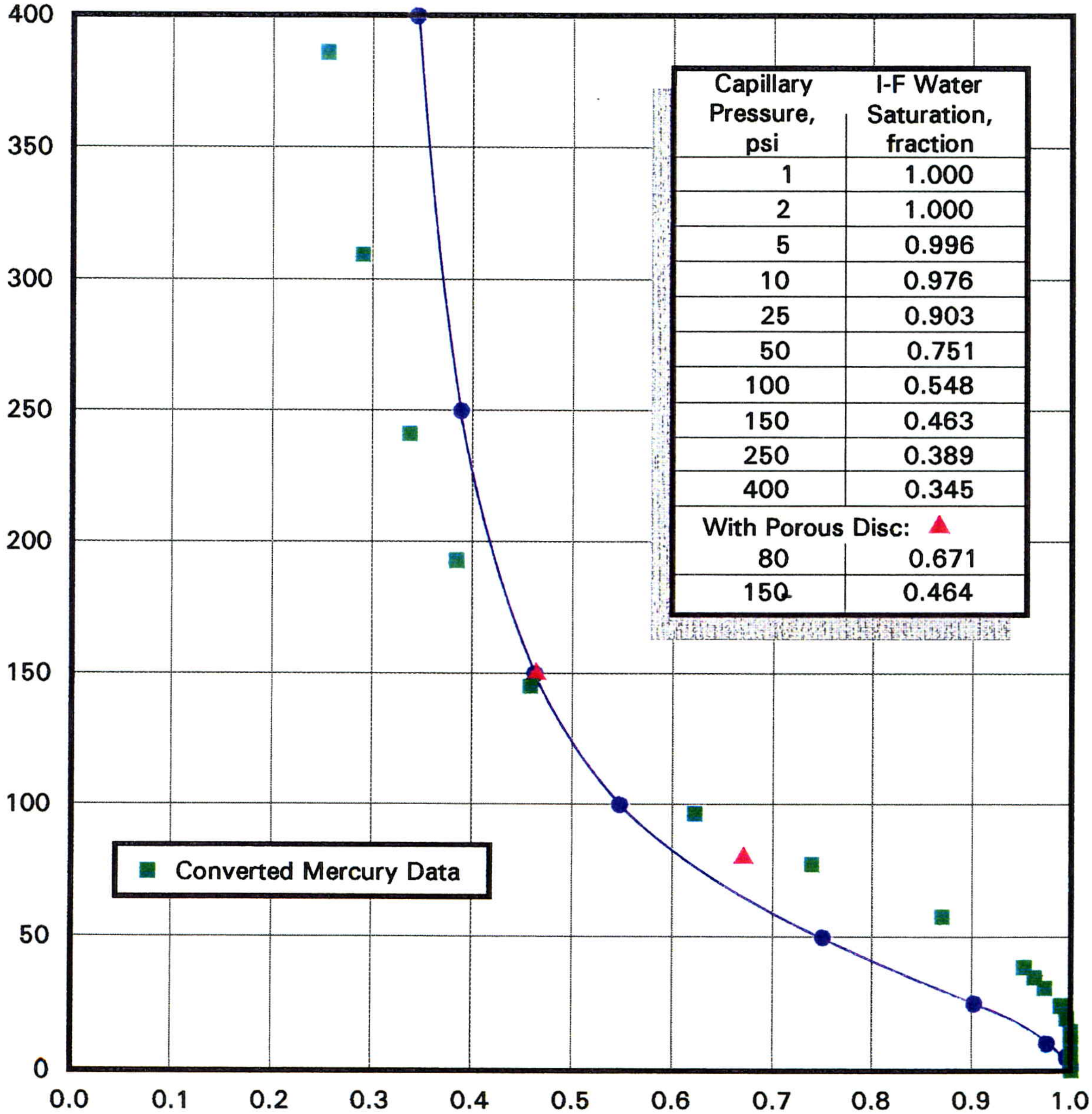
| Sample Number | Depth, feet | Permeability to Air, md | Porosity, fraction | Inlet-Face Water Saturation, fraction pore volume | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Capillary Pressure, psi: | 0 | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 150 | 250 | 400 |
| 1B | 2530.2 | 0.078 | 0.115 | 1.000 | 1.000 | 1.000 | 0.996 | 0.976 | 0.903 | 0.751 | 0.548 | 0.463 | 0.389 | 0.345 |
| 2A | 2537.4 | 1.33 | 0.146 | 1.000 | 1.000 | 1.000 | 0.990 | 0.894 | 0.434 | 0.259 | 0.170 | 0.130 | 0.116 | 0.112 |
| 3B | 2541.7 | 0.252 | 0.125 | 1.000 | 1.000 | 1.000 | 1.000 | 0.987 | 0.804 | 0.480 | 0.290 | 0.228 | 0.195 | 0.189 |

# GAS-WATER CAPILLARY PRESSURE

## Centrifuge Method

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

| | |
|---|---|
| Sample Number: | 1B |
| Sample Depth, feet: | 2530.2 |
| Initial Water saturation, fraction: | 1.000 |
| Permeability to Air, md: | 0.078 |
| Porosity, fraction: | 0.115 |
| Saturant: | 100,000 ppm NaCl Brine |




| Capillary Pressure, psi | I-F Water Saturation, fraction |
|---|---|
| 1 | 1.000 |
| 2 | 1.000 |
| 5 | 0.996 |
| 10 | 0.976 |
| 25 | 0.903 |
| 50 | 0.751 |
| 100 | 0.548 |
| 150 | 0.463 |
| 250 | 0.389 |
| 400 | 0.345 |
| With Porous Disc: ▲ | |
| 80 | 0.671 |
| 150 | 0.464 |

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# LABORATORY PROCEDURES
## Effective Permeability to Oil

Following the completion of capillary pressure testing, the samples were forwarded for measurements to determine the effective permeability to oil of each sample at the saturation which had been established following the 150 psi centrifugation with the porous disc.

1. Each partially saturated sample was loaded into a hydrostatic coreholder and a net confining pressure of 1330 psi applied.

2. Isopar-L laboratory oil was injected into each sample against a backpressure of 400 psi to displace air within the samples and achieve full liquid saturation.

3. At full saturation (indicated by termination of displaced air and a stable pressure drop across the sample) the oil flow was monitored as a function of time to determine effective permeability to the oil. This was accomplished using the equation:

$$K_o = 14700 * \frac{L \mu V}{PAT}$$

where:

| | | | | | |
|---|---|---|---|---|---|
| Ko | = | Permeability to Oil, millidarcys | P | = | Pressure, psi |
| L | = | Length, centimeters | A | = | Area, $cm^2$ |
| $\mu$ | = | viscosity, centipoise | T | = | Time, seconds |
| V | = | Volume, $cm^3$ | 14700 | = | unit conversion constant |

# EFFECTIVE PERMEABILITY TO OIL AT INITIAL WATER SATURATION

Anadarko Petroleum Corporation
Cornell University Project

Morton County, Kansa
File: DAL-94226

| Sample Number | Depth, feet | Permeability to Air, millidarcys | Porosity, fraction | Initial Water Saturation, fraction | Effective Permeability to Oil, millidarcys |
|---|---|---|---|---|---|
| 1B | 2530.2 | 0.078 | 0.115 | 0.464 | 0.018 |
| 2A | 2537.4 | 1.33 | 0.146 | 0.136 | 0.813 |
| 3B | 2541.7 | 0.252 | 0.125 | 0.226 | 0.092 |

# LABORATORY PROCEDURES
## Basic Properties

Preliminary calculations made during the course of the study which required a pore volume value were performed using pore volumes determined from initial and brine saturated NMR measurements of the samples. Throughout testing the samples were never extracted and dried until after effective permeability to oil was determined.

1. The samples underwent Dean-Stark extraction to remove Isopar-L and residual water.

2. The samples were loaded into a coreholder and flushed with methanol to remove inorganic salts left behind from the 100,000 ppm NaCl brine.

3. A vacuum oven set at 220 °F was used to dry the samples.

4. Mercury immersion bulk volumes were determined for each of the samples.

5. Each sample was loaded into a hydrostatic coreholder and a confining pressure of 800 psi applied. The AutoPorosimeter™ was used to inject helium from cylinders of known volume and pressure. Pore volume was calculated using Boyle's law. Grain volume was calculated by subtracting the pore volume from the bulk volume. Porosity was calculated as pore volume divided by bulk volume.

6. Dry weight was divided by grain volume to calculate grain density.

7. The confining pressure was increased to 1330 psi and the procedure repeated. The bulk volume was corrected for the decrease in pore volume to calculate porosity at the new confining pressure.

8. The samples were loaded into the CMS-300™ to determine Klinkenberg permeability at net confining pressures of 800 and 1330 psi. The CMS uses helium which is injected from cylinders of known pressure and volume. Klinkenberg permeability, $K_\infty$, was calculated as a function of pressure decay.

9. The samples were resaturated with the 100,000 ppm NaCl brine as a check on pore volume values, correlating extremely well with the 800 psi CMS-300™ values.

10. The samples were sent to NUMAR in Houston for NMR measurements.

11. After receiving the samples back from Houston the samples were flushed with methanol to remove the NaCl brine and redried in the vacuum oven.

# SUMMARY OF BASIC PROPERTIES

Anadarko Petroleum Corporation
Cornell University Project

Morton County, Kansas
File: DAL-94226

| Sample Number | Depth, feet | Pressure, psi | Permeability, millidarcys Klinkenberg | To Air | Porosity, fraction | NMR Porosity, fraction | Grain Density, gm/cc |
|---|---|---|---|---|---|---|---|
| 1B | 2530.2 | 800 | 0.067 | 0.078 | 0.115 | 0.077 | 2.71 |
| | | 1330 | 0.058 | 0.070 | 0.115 | | |
| Mercury | | *800 | | 0.081 | 0.119 | | |
| 2A | 2537.4 | 800 | 1.19 | 1.33 | 0.146 | 0.134 | 2.69 |
| | | 1330 | 1.17 | 1.20 | 0.146 | | |
| Mercury | | *800 | | 1.08 | 0.151 | | |
| 3B | 2541.7 | 800 | 0.222 | 0.252 | 0.125 | 0.112 | 2.70 |
| | | 1330 | 2.17 | 0.248 | 0.125 | | |
| Mercury | | *800 | | 0.240 | 0.128 | | |

* Mercury porosity determined at ambient pressure

AutoPore values were used for calculating test data.

| Sample Number | Depth, feet | Pressure, psi | Pore Volume CMS-300 | Archimedes | AutoPore * | NMR** | AutoPore*** |
|---|---|---|---|---|---|---|---|
| 1B | 2530.2 | ambient | | 1.44 | | 0.96 | 1.27 |
| | | 800 | 1.40 | | 1.45 | | |
| | | 1330 | 1.39 | | 1.44 | | |
| 2A | 2537.4 | ambient | | 1.86 | | 1.67 | 1.67 |
| | | 800 | 1.81 | | 1.82 | | |
| | | 1330 | 1.80 | | 1.82 | | |
| 3B | 2541.7 | ambient | | 1.54 | | 1.40 | 1.39 |
| | | 800 | 1.54 | | 1.56 | | |
| | | 1330 | 1.52 | | 1.56 | | |

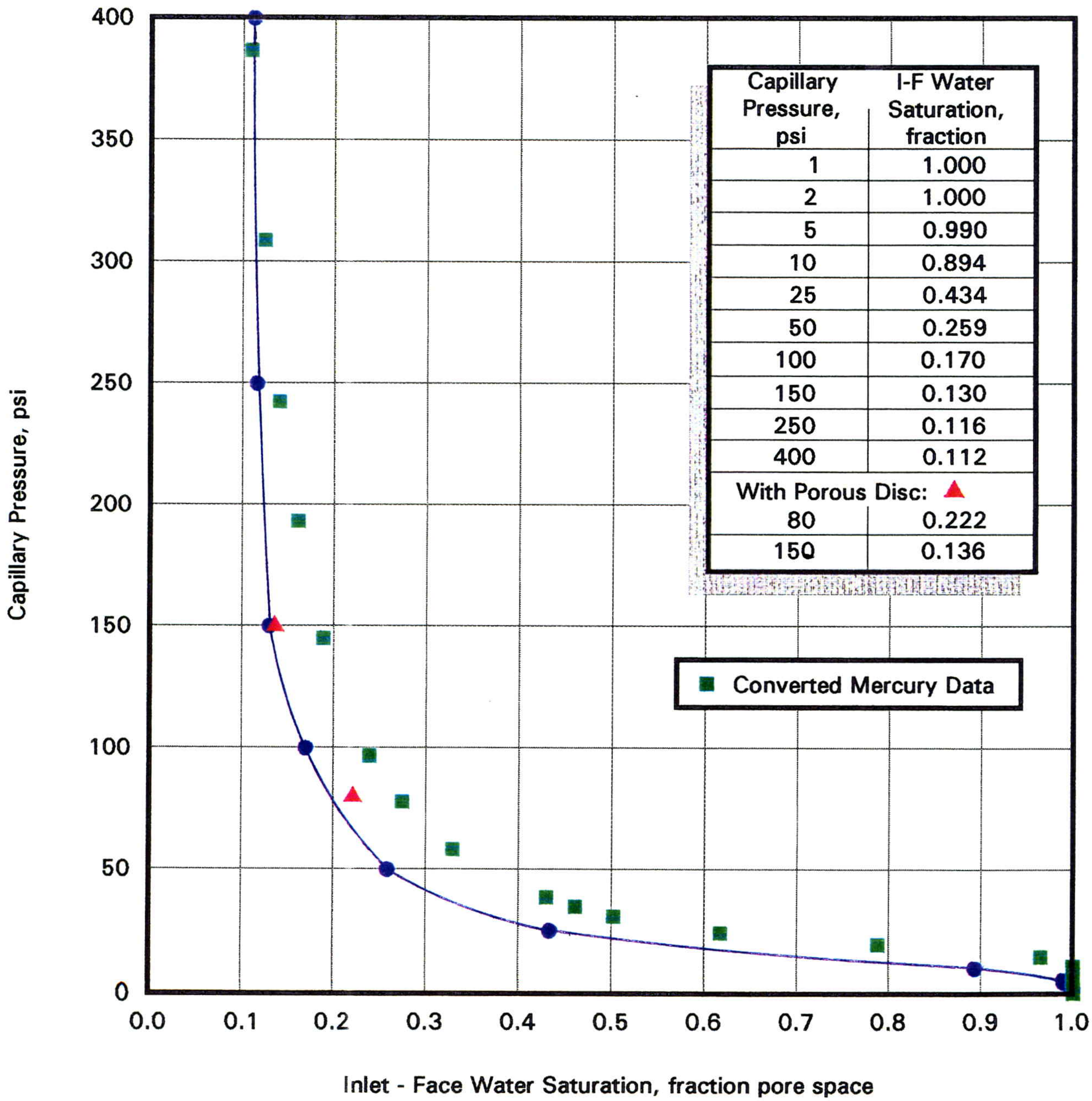
** 1.2 ms Interecho Spacing
*** After trimming slightly for mercury injection testing (bulk volume - grain volume)

# GAS-WATER CAPILLARY PRESSURE

Centrifuge Method

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

| | |
|---|---|
| Sample Number: | 2A |
| Sample Depth, feet: | 2537.4 |
| Initial Water saturation, fraction: | 1.000 |
| Permeability to Air, md: | 1.33 |
| Porosity, fraction: | 0.146 |
| Saturant: | 100,000 ppm NaCl Brine |




| Capillary Pressure, psi | I-F Water Saturation, fraction |
|---|---|
| 1 | 1.000 |
| 2 | 1.000 |
| 5 | 0.990 |
| 10 | 0.894 |
| 25 | 0.434 |
| 50 | 0.259 |
| 100 | 0.170 |
| 150 | 0.130 |
| 250 | 0.116 |
| 400 | 0.112 |
| With Porous Disc: ▲ | |
| 80 | 0.222 |
| 150 | 0.136 |

Core Laboratories

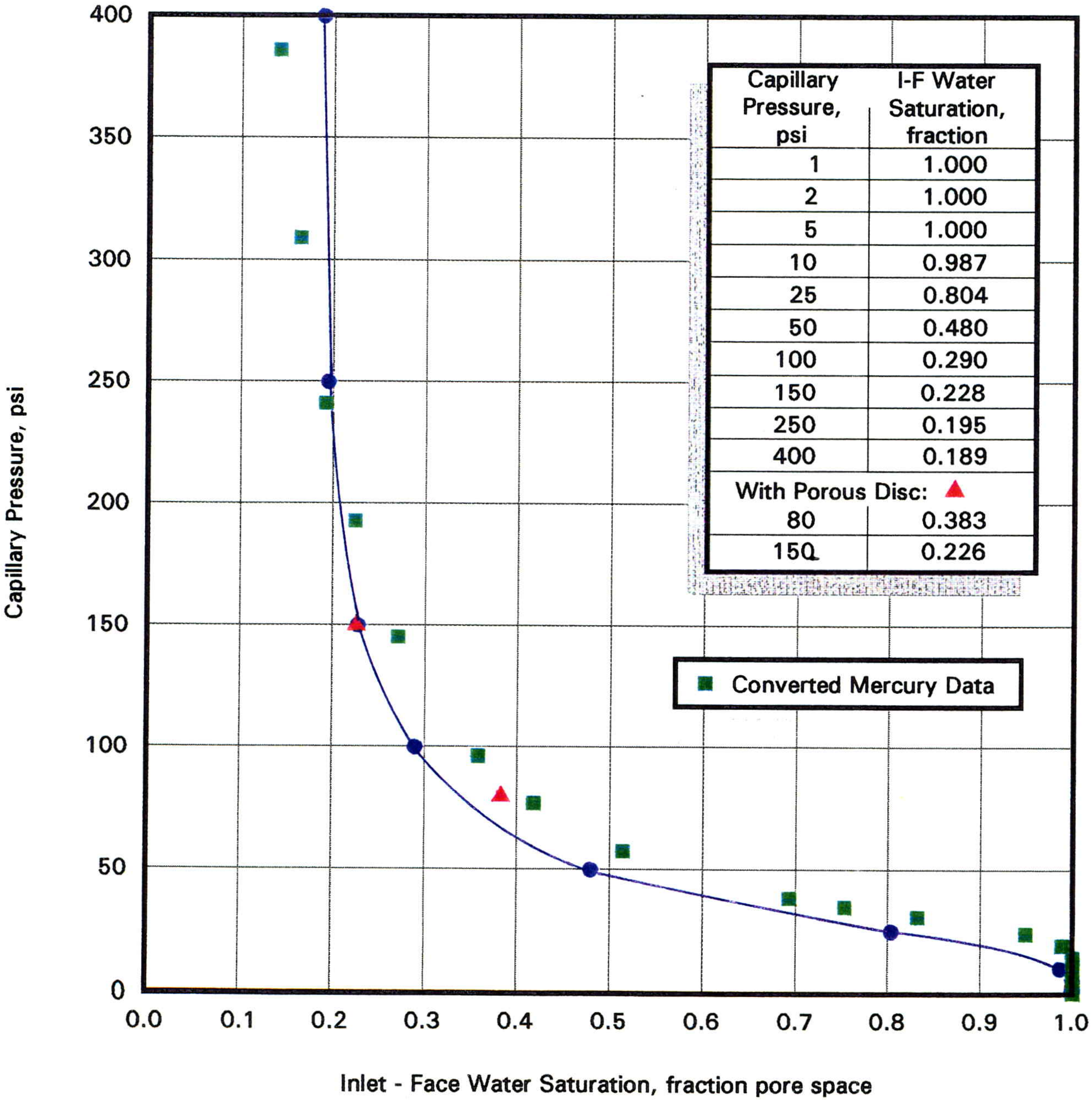
# GAS-WATER CAPILLARY PRESSURE

## Centrifuge Method

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

| | |
|---|---|
| Sample Number: | 3B |
| Sample Depth, feet: | 2541.7 |
| Initial Water saturation, fraction: | 1.000 |
| Permeability to Air, md: | 0.252 |
| Porosity, fraction: | 0.125 |
| Saturant: | 100,000 ppm NaCl Brine |

| Capillary Pressure, psi | I-F Water Saturation, fraction |
|---|---|
| 1 | 1.000 |
| 2 | 1.000 |
| 5 | 1.000 |
| 10 | 0.987 |
| 25 | 0.804 |
| 50 | 0.480 |
| 100 | 0.290 |
| 150 | 0.228 |
| 250 | 0.195 |
| 400 | 0.189 |
| With Porous Disc: ▲ | |
| 80 | 0.383 |
| 150 | 0.226 |




Core Laboratories

# LABORATORY PROCEDURES
## Mercury Injection

Following the completion of all other testing, the samples were submitted for high pressure mercury injection testing. This test had to be performed last as it is a destructive test, leaving residual mercury within the sample and therefore unfit for further testing.

1. Three core samples from the Cornell University Project were injected with mercury. The tests were performed using the Micromeritics Autopore II 9220, an automated, high pressure mercury injection device which operates at injection pressures of 0 to 50,000 psia.

2. Each test sample was loaded into a glass penetrometer consisting of a sample chamber attached to a mercury filled capillary stem with a cylindrical coaxial capacitor.

3. The sample/penetrometer assembly was weighed, then placed into the low pressure system of the apparatus.

4. The sample chamber was evacuated and filled with mercury, then the pressure was increased incrementally to atmospheric pressure. At atmospheric pressure the assembly was temporarily removed and re-weighed, then replaced into the high pressure side of the apparatus.

5. Pressures were increased incrementally to a maximum of 50,000 psia.

6. Time was allowed at each incremental pressure for saturation equilibrium. The volume of mercury injected at each pressure was determined by the change in capacitance of the capillary stem.

- **Pore Size Distribution**

Pore size distribution was calculated from the mercury injection test results. These data are typically used for pore geometry characterizations and comparisons. The distribution of pore throat sizes can often help to evaluate the results of other analyses performed on the same, or similar companion, samples. Textural effects and pore size distribution are major factors affecting "irreducible" water saturations, and hence the extent and height of a reservoir's transition zone. Pore entry radii were calculated using the formula:

$$Ri = \frac{2T * \cos\theta * C}{Pc}$$

where:

| | | |
|---|---|---|
| Ri | = | pore entry radius, microns |
| T | = | interfacial tension |
| $\theta$ | = | contact angle |
| C | = | unit conversion constant (to microns) = 0.145 |
| Pc | = | mercury injection pressure, psia. |

In general, pore throat radii can be divided into several categories which can be used in the classification and grouping of the test samples. Microporosity is often defined as pore throat radii of less than 0.50 microns. The following classification is utilized for this discussion:

| Classification Number | Pore Radius Classification | Pore Radius, microns Minimum | Maximum |
|---|---|---|---|
| 1 | sub-nano | <0.01 | 0.01 |
| 2 | nano | 0.01 | 0.05 |
| 3 | sub-micro | 0.05 | 0.25 |
| 4 | micro | 0.25 | 0.50 |
| 5 | meso | 0.50 | 2.5 |
| 6 | macro | 2.5 | 10. |
| 7 | super-macro | 10. | >10. |

These ranges have been included on the pore throat radii histograms.

- **J-Function and System Conversions**

Some of the additional data which are presented on the tabular pages are the "J - Function" and conversions of mercury injection results to gas-water, gas-oil, and oil-water data. Leverett J-Function values can be used to normalize data from different samples, converting all capillary pressure data to a universal curve which represents a specific formation or zone. J-Function values are calculated from capillary pressure (or mercury injection) data and basic sample properties using the following equation:

$$\text{J-Function} = \frac{0.2166 * Pc * \sqrt{(K/\phi)}}{(T * \cos\theta)}$$

where:

Pc = injection pressure, psia
T = interfacial tension, dyne/cm
$\theta$ = contact angle
K = permeability to air (or Klinkenberg), millidarcys
$\phi$ = porosity, fraction.

The factor "0.2166" is used to cancel the units and make "J" dimensionless. J-Function can not be calculated for samples for which no permeability value is determined.

Conversions of pressure from one fluid system to the others are calculated using the example formula:

$$Pc_{(g\text{-}w)} = Pc_{(meas.)} * \frac{(T * \cos\theta)_{g\text{-}w}}{(T * \cos\theta)_{(meas.)}}$$

where:

$Pc_{(g\text{-}w)}$ = Capillary pressure in a gas-water system
$Pc_{(meas.)}$ = Capillary pressure of the measured fluid system
T = interfacial tension
$\theta$ = contact angle

- **Height Above Free Water**

In order to calculate a corresponding height above free water for the mercury injection data, laboratory data are converted to equivalent reservoir oil-water or gas-water values and the appropriate fluid density gradients used. Ideally, the density gradients will correspond to reservoir values at initial reservoir temperature and pressure. Height values are meant only as estimated values when standard, "typical" parameters are used. While these values are often reasonable estimates, for more representative values actual parameter values should be input into the following equation:

$$\text{Height} = \frac{Pc_L * (T\cos\theta)_R / (T\cos\theta)_L}{(\rho_w - \rho_h)}$$

Where:

| | | |
|---|---|---|
| $Pc_L$ | = | Laboratory measured capillary pressure |
| $T\cos\theta_R$ | = | Interfacial tension * cosine of contact angle (reservoir) |
| $T\cos\theta_R$ | = | Interfacial tension * cosine of contact angle (laboratory) |
| $\rho_w$ | = | reservoir density gradient, water |
| $\rho_h$ | = | reservoir density gradient, hydrocarbon |

## SUMMARY OF CALCULATION PARAMETERS

| SYSTEM | (θ) CONTACT ANGLE | cosine CONTACT θ | (T) INTERFACIAL TENSION | T cosine θ |
|---|---|---|---|---|
| Laboratory | | | | |
| Gas-water | 0 | 1.0 | 72 | 72 |
| Oil-water | 30 | 0.866 | 48 | 41.6 |
| Gas-oil | 0 | 1.0 | 24 | 24 |
| Air-mercury | 140 | 0.765 | 485 | 371.5 |
| Reservoir | | | | |
| Oil-water | 30 | 0.866 | 30 | 26 |
| Gas-water | 0 | 1.0 | 50 | 50 |

DENSITY GRADIENTS

| | | |
|---|---|---|
| water | = | 0.433 |
| oil | = | 0.346 |
| gas | = | 0.100 |

# MERCURY INJECTION DATA SUMMARY

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

Sample Number: 1B
Depth, feet: 2530.2
Permeability to Air, md: 0.078
Porosity, fraction: 0.115

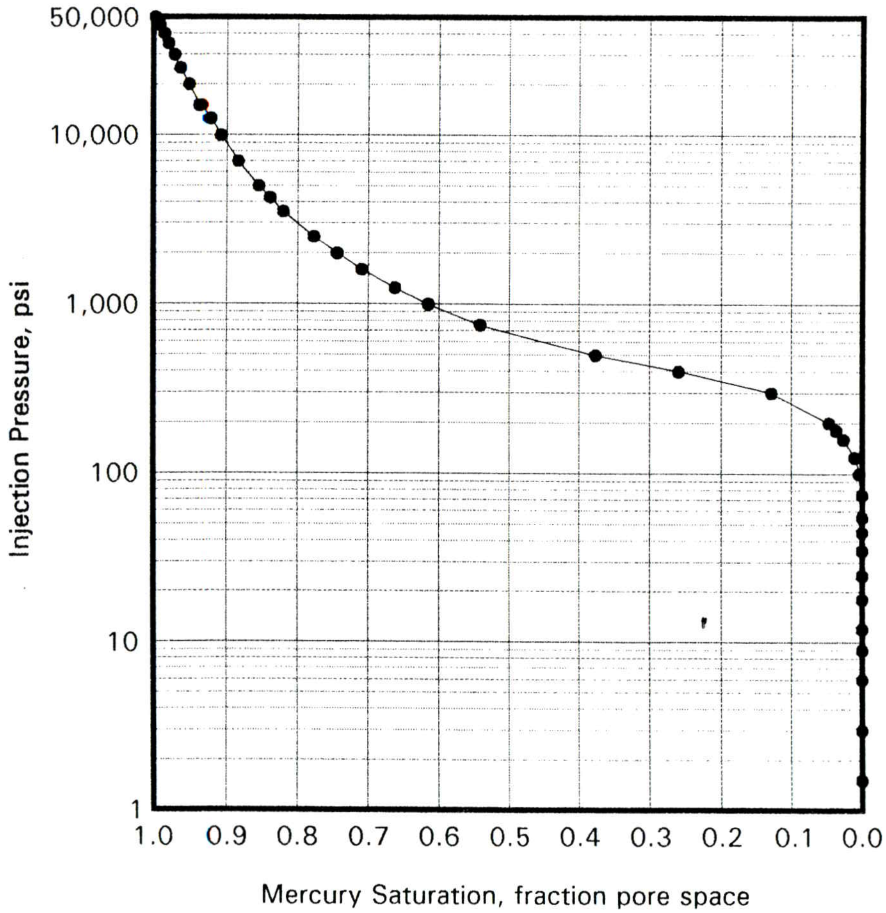
| Injection Pressure, psia | Mercury Saturation, fraction | 1.0-Mercury Saturation, fraction | Pore Radius, microns | J Function | Other Laboratory Systems | | | Estimated Height Above Free Water, ft | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Gas-Water, psia | Gas-Oil, psia | Oil-Water, psia | G-W | O-W |
| 3.0 | 0.000 | 1.000 | 36.4 | 0.001 | 0.58 | 0.19 | 0.34 | 1.2 | 2.4 |
| 6.0 | 0.000 | 1.000 | 18.3 | 0.003 | 1.2 | 0.39 | 0.67 | 2.4 | 4.8 |
| 9.0 | 0.000 | 1.000 | 12.2 | 0.004 | 1.7 | 0.58 | 1.0 | 3.6 | 7.2 |
| 12 | 0.000 | 1.000 | 9.13 | 0.006 | 2.3 | 0.77 | 1.3 | 4.8 | 9.6 |
| 18 | 0.000 | 1.000 | 6.09 | 0.009 | 3.5 | 1.2 | 2.0 | 7.3 | 14 |
| 25 | 0.000 | 1.000 | 4.38 | 0.012 | 4.8 | 1.6 | 2.8 | 10 | 20 |
| 35 | 0.000 | 1.000 | 3.13 | 0.017 | 6.8 | 2.3 | 3.9 | 14 | 28 |
| 45 | 0.000 | 1.000 | 2.43 | 0.022 | 8.7 | 2.9 | 5.0 | 18 | 36 |
| 55 | 0.000 | 1.000 | 1.99 | 0.026 | 11 | 3.5 | 6.1 | 22 | 44 |
| 75 | 0.000 | 1.000 | 1.46 | 0.036 | 14 | 4.8 | 8.4 | 30 | 60 |
| 100 | 0.004 | 0.996 | 1.10 | 0.048 | 19 | 6.4 | 11 | 40 | 80 |
| 124 | 0.010 | 0.990 | 0.878 | 0.060 | 24 | 8.0 | 14 | 50 | 100 |
| 159 | 0.027 | 0.973 | 0.686 | 0.077 | 31 | 10 | 18 | 64 | 128 |
| 180 | 0.037 | 0.963 | 0.608 | 0.086 | 35 | 12 | 20 | 73 | 145 |
| 199 | 0.047 | 0.953 | 0.548 | 0.096 | 39 | 13 | 22 | 81 | 160 |
| 299 | 0.129 | 0.871 | 0.366 | 0.14 | 58 | 19 | 33 | 121 | 240 |
| 400 | 0.261 | 0.739 | 0.273 | 0.19 | 77 | 26 | 45 | 162 | 321 |
| 498 | 0.378 | 0.622 | 0.219 | 0.24 | 97 | 32 | 56 | 201 | 401 |
| 749 | 0.542 | 0.458 | 0.146 | 0.36 | 145 | 48 | 84 | 303 | 602 |
| 996 | 0.616 | 0.384 | 0.110 | 0.48 | 193 | 64 | 111 | 403 | 801 |
| 1244 | 0.663 | 0.337 | 0.088 | 0.60 | 241 | 80 | 139 | 503 | 1000 |
| 1597 | 0.710 | 0.290 | 0.068 | 0.77 | 309 | 103 | 179 | 645 | 1284 |
| 1992 | 0.745 | 0.255 | 0.055 | 0.96 | 386 | 129 | 223 | 805 | 1601 |
| 2496 | 0.778 | 0.222 | 0.044 | 1.20 | 484 | 161 | 279 | 1009 | 2006 |
| 3497 | 0.821 | 0.179 | 0.031 | 1.68 | 678 | 226 | 391 | 1413 | 2810 |
| 4243 | 0.839 | 0.161 | 0.026 | 2.04 | 822 | 274 | 475 | 1715 | 3410 |
| 4992 | 0.856 | 0.144 | 0.022 | 2.40 | 967 | 322 | 559 | 2017 | 4012 |
| 6971 | 0.884 | 0.116 | 0.016 | 3.35 | 1351 | 450 | 780 | 2817 | 5603 |
| 9965 | 0.909 | 0.091 | 0.011 | 4.79 | 1931 | 644 | 1115 | 4027 | 8010 |
| 12467 | 0.923 | 0.077 | 0.0088 | 6.00 | 2416 | 805 | 1395 | 5039 | 10021 |
| 14964 | 0.936 | 0.064 | 0.0073 | 7.20 | 2900 | 967 | 1674 | 6048 | 12028 |
| 19975 | 0.950 | 0.050 | 0.0055 | 9.61 | 3871 | 1290 | 2235 | 8072 | 16055 |
| 24910 | 0.962 | 0.038 | 0.0044 | 11.98 | 4827 | 1609 | 2787 | 10067 | 20022 |
| 29874 | 0.971 | 0.029 | 0.0037 | 14.37 | 5789 | 1930 | 3343 | 12073 | 24012 |
| 34877 | 0.979 | 0.021 | 0.0031 | 16.78 | 6759 | 2253 | 3902 | 14095 | 28034 |
| 40002 | 0.985 | 0.015 | 0.0027 | 19.24 | 7752 | 2584 | 4476 | 16166 | 32152 |
| 44783 | 0.991 | 0.009 | 0.0024 | 21.54 | 8679 | 2893 | 5011 | 18098 | 35995 |
| 49838 | 0.997 | 0.003 | 0.0022 | 23.97 | 9658 | 3219 | 5576 | 20141 | 40059 |

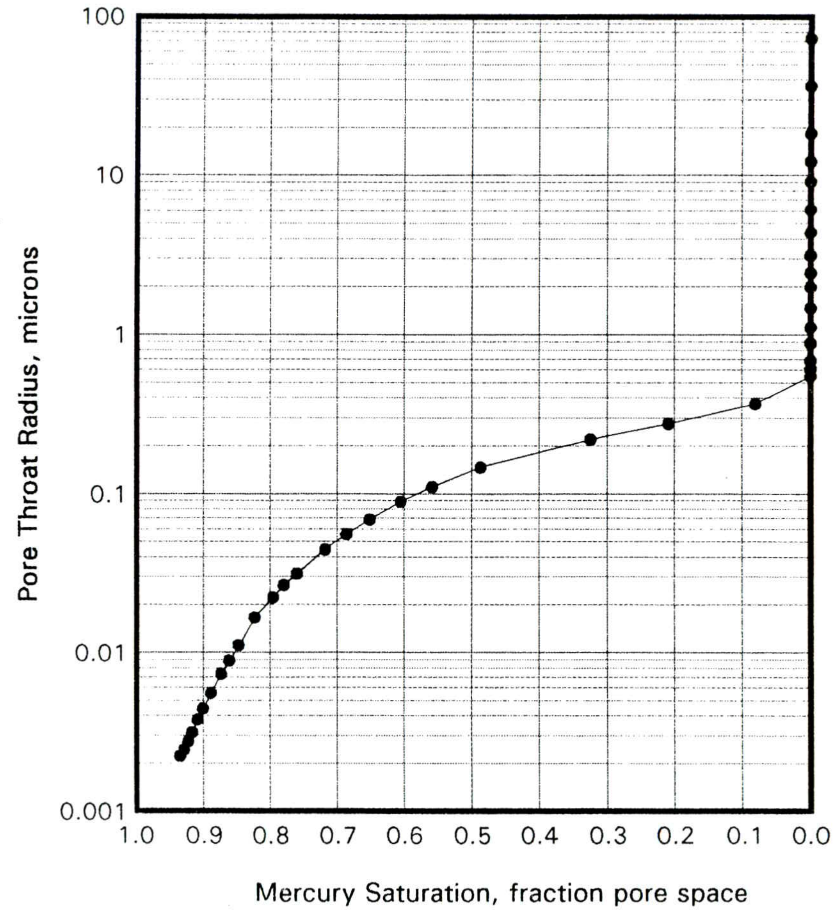
**Core Laboratories**

# MERCURY INJECTION --- PORE THROAT RADII

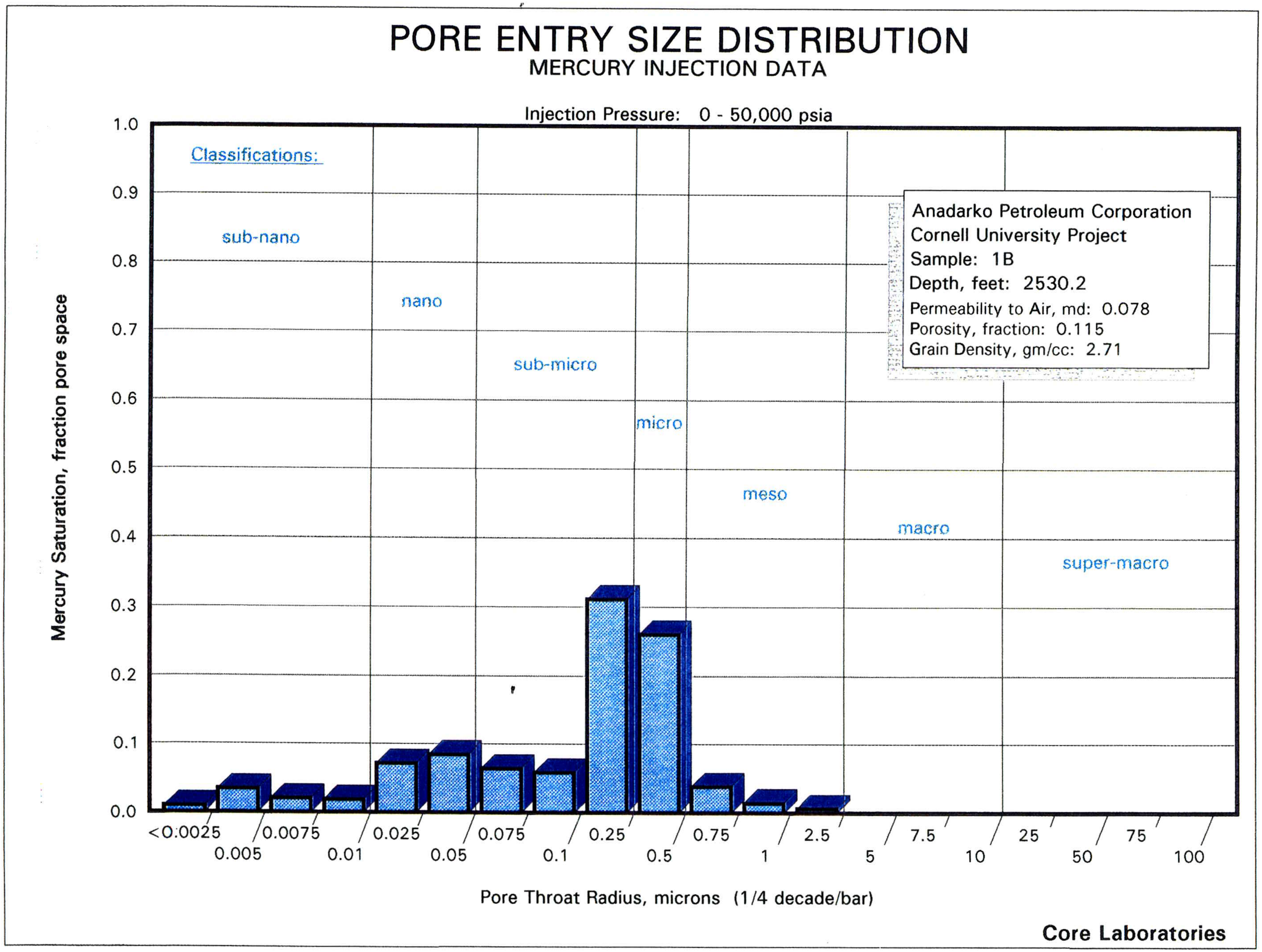
Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

| | |
|---|---|
| Sample Number: | 1B |
| Sample Depth, feet: | 2530.2 |
| Permeability to Air, md: | 0.078 |
| Porosity, fraction: | 0.115 |




**Core Laboratories**



PORE ENTRY SIZE DISTRIBUTION
MERCURY INJECTION DATA
Injection Pressure: 0 - 50,000 psia
Classifications:
sub-nano
nano
sub-micro
micro
meso
macro
super-macro
Anadarko Petroleum Corporation
Cornell University Project
Sample: 1B
Depth, feet: 2530.2
Permeability to Air, md: 0.078
Porosity, fraction: 0.115
Grain Density, gm/cc: 2.71
Mercury Saturation, fraction pore space
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
<0.0025
0.005
0.0075
0.01
0.025
0.05
0.075
0.1
0.25
0.5
0.75
1
2.5
5
7.5
10
25
50
75
100
Pore Throat Radius, microns (1/4 decade/bar)
Core Laboratories

# MERCURY INJECTION DATA SUMMARY

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

Sample Number: 2A
Depth, feet: 2537.4
Permeability to Air, md: 1.33
Porosity, fraction: 0.146

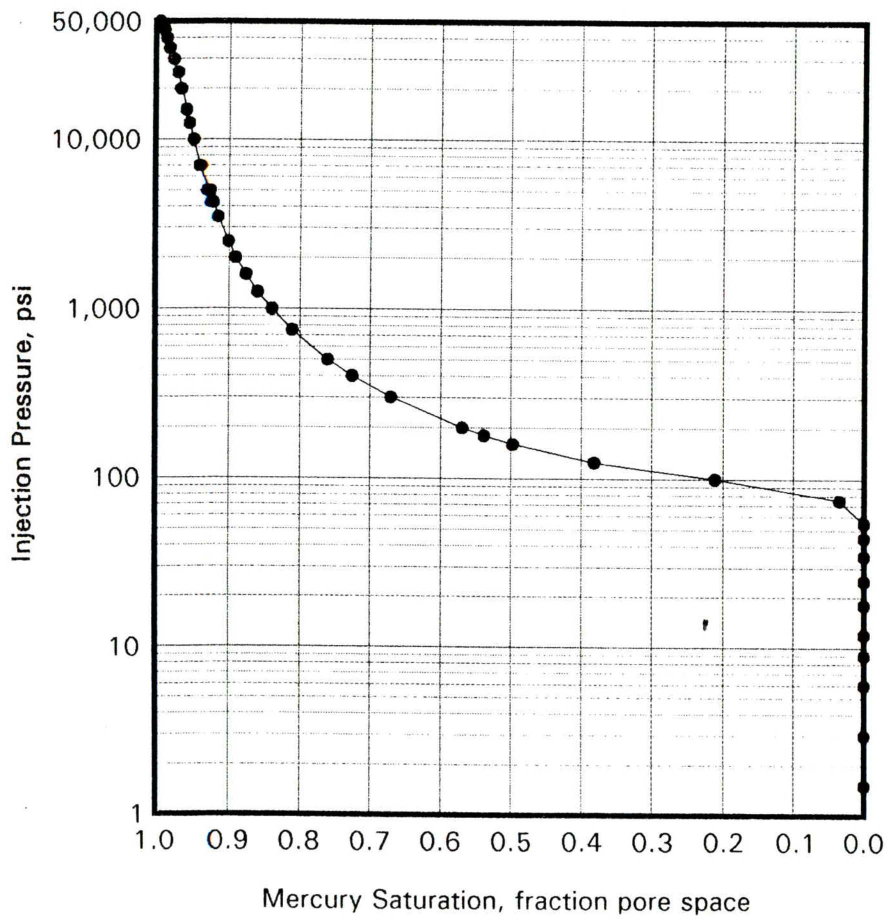
| Injection Pressure, psia | Mercury Saturation, fraction | 1.0-Mercury Saturation, fraction | Pore Radius, microns | J Function | Other Laboratory Systems | | | Estimated Height Above Free Water, ft | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Gas-Water, psia | Gas-Oil, psia | Oil-Water, psia | G-W | O-W |
| 3.0 | 0.000 | 1.000 | 36.4 | 0.005 | 0.58 | 0.19 | 0.34 | 1.2 | 2.4 |
| 6.0 | 0.000 | 1.000 | 18.3 | 0.011 | 1.2 | 0.39 | 0.67 | 2.4 | 4.8 |
| 9.0 | 0.000 | 1.000 | 12.2 | 0.016 | 1.7 | 0.58 | 1.0 | 3.6 | 7.2 |
| 12 | 0.000 | 1.000 | 9.13 | 0.021 | 2.3 | 0.77 | 1.3 | 4.8 | 9.6 |
| 18 | 0.000 | 1.000 | 6.09 | 0.032 | 3.5 | 1.2 | 2.0 | 7.3 | 14 |
| 25 | 0.000 | 1.000 | 4.38 | 0.044 | 4.8 | 1.6 | 2.8 | 10 | 20 |
| 35 | 0.000 | 1.000 | 3.13 | 0.062 | 6.8 | 2.3 | 3.9 | 14 | 28 |
| 45 | 0.000 | 1.000 | 2.44 | 0.079 | 8.7 | 2.9 | 5.0 | 18 | 36 |
| 55 | 0.000 | 1.000 | 1.99 | 0.097 | 11 | 3.5 | 6.1 | 22 | 44 |
| 75 | 0.035 | 0.965 | 1.46 | 0.13 | 14 | 4.8 | 8.4 | 30 | 60 |
| 100 | 0.212 | 0.788 | 1.09 | 0.18 | 19 | 6.4 | 11 | 40 | 80 |
| 125 | 0.383 | 0.617 | 0.876 | 0.22 | 24 | 8.1 | 14 | 50 | 100 |
| 159 | 0.498 | 0.502 | 0.686 | 0.28 | 31 | 10 | 18 | 64 | 128 |
| 179 | 0.539 | 0.461 | 0.609 | 0.32 | 35 | 12 | 20 | 72 | 144 |
| 199 | 0.570 | 0.430 | 0.548 | 0.35 | 39 | 13 | 22 | 81 | 160 |
| 301 | 0.672 | 0.328 | 0.363 | 0.53 | 58 | 19 | 34 | 122 | 242 |
| 402 | 0.726 | 0.274 | 0.272 | 0.71 | 78 | 26 | 45 | 162 | 323 |
| 500 | 0.761 | 0.239 | 0.219 | 0.88 | 97 | 32 | 56 | 202 | 401 |
| 747 | 0.811 | 0.189 | 0.146 | 1.32 | 145 | 48 | 84 | 302 | 601 |
| 997 | 0.839 | 0.161 | 0.110 | 1.76 | 193 | 64 | 112 | 403 | 801 |
| 1252 | 0.860 | 0.140 | 0.087 | 2.21 | 243 | 81 | 140 | 506 | 1006 |
| 1594 | 0.876 | 0.124 | 0.069 | 2.81 | 309 | 103 | 178 | 644 | 1281 |
| 1996 | 0.891 | 0.109 | 0.055 | 3.52 | 387 | 129 | 223 | 807 | 1604 |
| 2490 | 0.901 | 0.099 | 0.044 | 4.39 | 482 | 161 | 279 | 1006 | 2001 |
| 3484 | 0.916 | 0.084 | 0.031 | 6.14 | 675 | 225 | 390 | 1408 | 2800 |
| 4244 | 0.923 | 0.077 | 0.026 | 7.48 | 822 | 274 | 475 | 1715 | 3411 |
| 4988 | 0.928 | 0.072 | 0.022 | 8.79 | 967 | 322 | 558 | 2016 | 4010 |
| 6976 | 0.938 | 0.062 | 0.016 | 12.30 | 1352 | 451 | 780 | 2819 | 5607 |
| 9985 | 0.947 | 0.053 | 0.011 | 17.60 | 1935 | 645 | 1117 | 4035 | 8026 |
| 12476 | 0.953 | 0.047 | 0.0088 | 21.99 | 2418 | 806 | 1396 | 5042 | 10028 |
| 14936 | 0.957 | 0.043 | 0.0073 | 26.33 | 2894 | 965 | 1671 | 6036 | 12005 |
| 19958 | 0.965 | 0.035 | 0.0055 | 35.18 | 3868 | 1289 | 2233 | 8066 | 16042 |
| 24903 | 0.969 | 0.031 | 0.0044 | 43.90 | 4826 | 1609 | 2786 | 10064 | 20017 |
| 29898 | 0.975 | 0.025 | 0.0037 | 52.71 | 5794 | 1931 | 3345 | 12083 | 24032 |
| 34857 | 0.981 | 0.019 | 0.0031 | 61.45 | 6755 | 2252 | 3900 | 14087 | 28017 |
| 39997 | 0.985 | 0.015 | 0.0027 | 70.51 | 7751 | 2584 | 4475 | 16164 | 32149 |
| 44805 | 0.988 | 0.012 | 0.0024 | 78.98 | 8683 | 2894 | 5013 | 18107 | 36013 |
| 49862 | 0.994 | 0.006 | 0.0022 | 87.90 | 9663 | 3221 | 5579 | 20151 | 40078 |

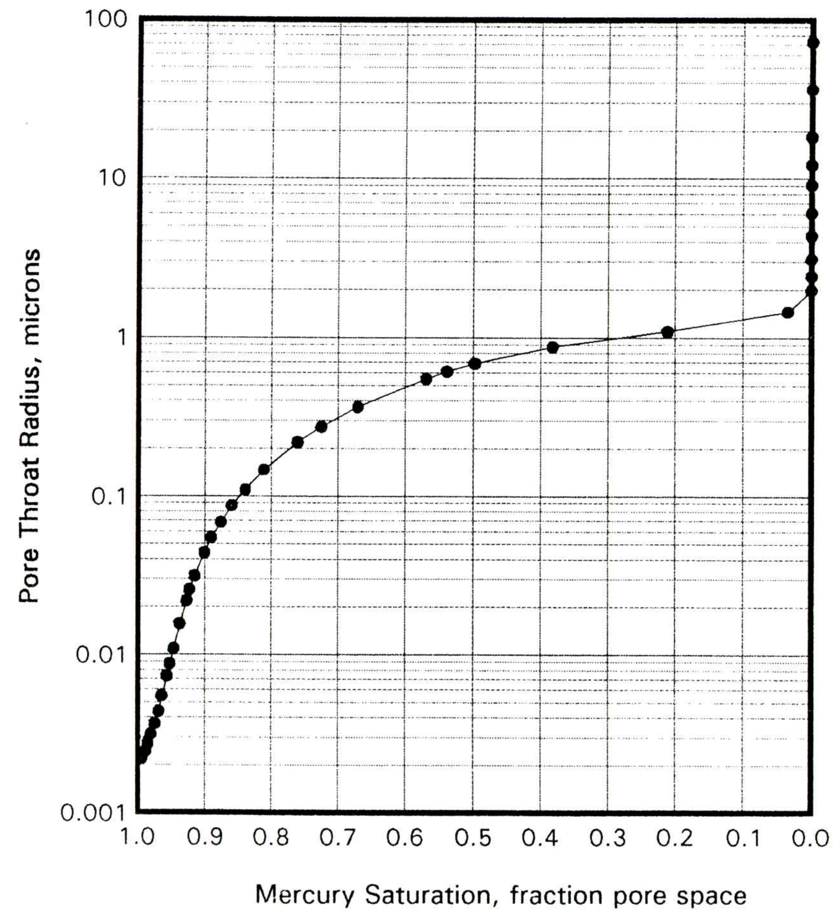
**Core Laboratories**

# MERCURY INJECTION --- PORE THROAT RADII

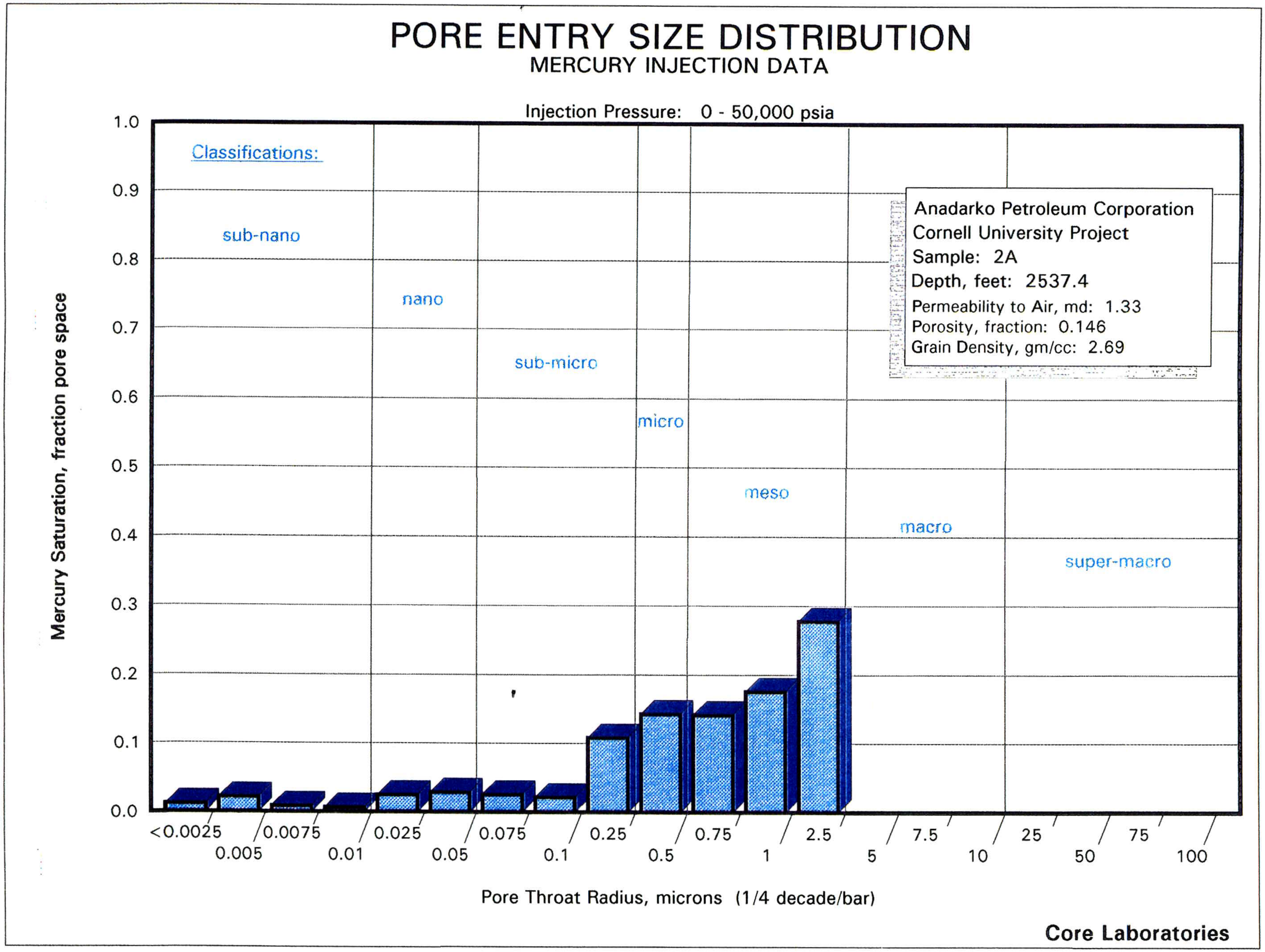
Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

| | |
|---|---|
| Sample Number: | 2A |
| Sample Depth, feet: | 2537.4 |
| Permeability to Air, md: | 1.33 |
| Porosity, fraction: | 0.146 |




**Core Laboratories**


PORE ENTRY SIZE DISTRIBUTION
MERCURY INJECTION DATA
Injection Pressure: 0 - 50,000 psia
Classifications:
sub-nano
nano
sub-micro
micro
meso
macro
super-macro
Anadarko Petroleum Corporation
Cornell University Project
Sample: 2A
Depth, feet: 2537.4
Permeability to Air, md: 1.33
Porosity, fraction: 0.146
Grain Density, gm/cc: 2.69
Mercury Saturation, fraction pore space
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
<0.0025
0.005
0.0075
0.01
0.025
0.05
0.075
0.1
0.25
0.5
0.75
1
2.5
5
7.5
10
25
50
75
100
Pore Throat Radius, microns (1/4 decade/bar)
Core Laboratories

# MERCURY INJECTION DATA SUMMARY

Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

Sample Number: 3B
Depth, feet: 2541.7
Permeability to Air, md: 0.252
Porosity, fraction: 0.125

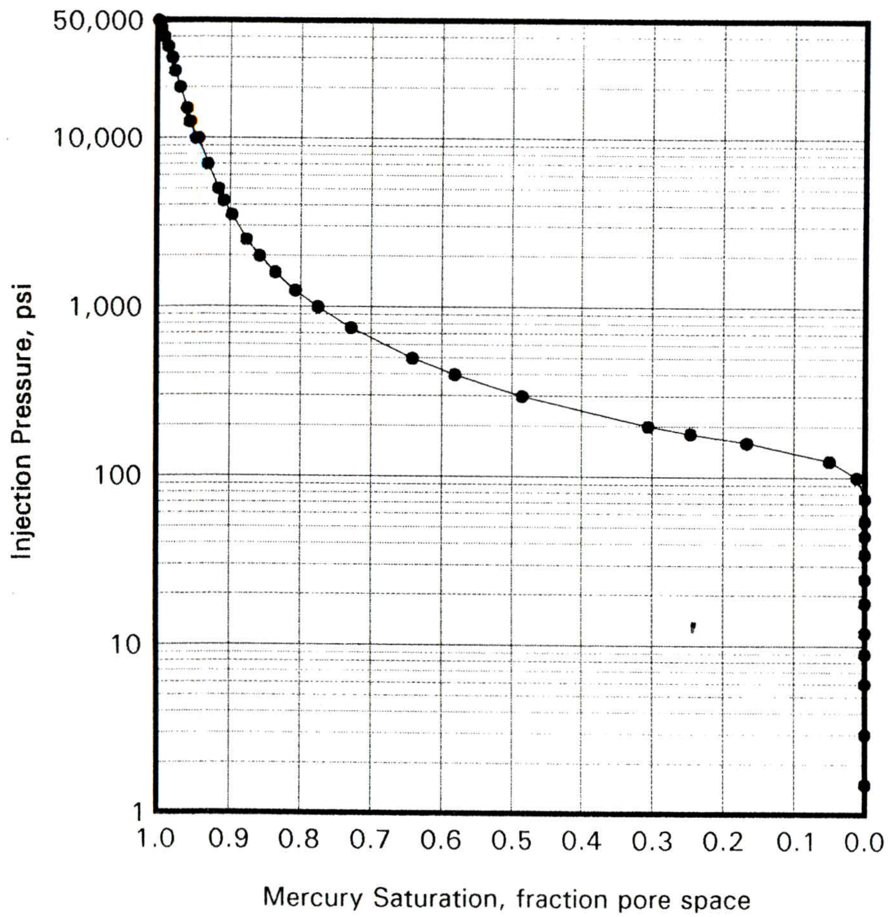
| Injection Pressure, psia | Mercury Saturation, fraction | 1.0-Mercury Saturation, fraction | Pore Radius, microns | J Function | Other Laboratory Systems Gas-Water, psia | Gas-Oil, psia | Oil-Water, psia | Estimated Height Above Free Water, ft G-W | O-W |
|---|---|---|---|---|---|---|---|---|---|
| 3.0 | 0.000 | 1.000 | 36.4 | 0.002 | 0.58 | 0.19 | 0.34 | 1.2 | 2.4 |
| 6.0 | 0.000 | 1.000 | 18.3 | 0.005 | 1.2 | 0.39 | 0.67 | 2.4 | 4.8 |
| 9.0 | 0.000 | 1.000 | 12.2 | 0.007 | 1.7 | 0.58 | 1.0 | 3.6 | 7.2 |
| 12 | 0.000 | 1.000 | 9.13 | 0.010 | 2.3 | 0.77 | 1.3 | 4.8 | 9.6 |
| 18 | 0.000 | 1.000 | 6.09 | 0.015 | 3.5 | 1.2 | 2.0 | 7.3 | 14 |
| 25 | 0.000 | 1.000 | 4.38 | 0.021 | 4.8 | 1.6 | 2.8 | 10 | 20 |
| 35 | 0.000 | 1.000 | 3.13 | 0.029 | 6.8 | 2.3 | 3.9 | 14 | 28 |
| 45 | 0.000 | 1.000 | 2.43 | 0.037 | 8.7 | 2.9 | 5.0 | 18 | 36 |
| 55 | 0.000 | 1.000 | 1.99 | 0.045 | 11 | 3.5 | 6.1 | 22 | 44 |
| 75 | 0.000 | 1.000 | 1.46 | 0.062 | 14 | 4.8 | 8.4 | 30 | 60 |
| 99 | 0.011 | 0.989 | 1.10 | 0.082 | 19 | 6.4 | 11 | 40 | 80 |
| 124 | 0.051 | 0.949 | 0.879 | 0.10 | 24 | 8.0 | 14 | 50 | 100 |
| 159 | 0.168 | 0.832 | 0.688 | 0.13 | 31 | 10 | 18 | 64 | 128 |
| 179 | 0.247 | 0.753 | 0.610 | 0.15 | 35 | 12 | 20 | 72 | 144 |
| 198 | 0.307 | 0.693 | 0.551 | 0.16 | 38 | 13 | 22 | 80 | 159 |
| 298 | 0.486 | 0.514 | 0.367 | 0.25 | 58 | 19 | 33 | 120 | 239 |
| 399 | 0.582 | 0.418 | 0.274 | 0.33 | 77 | 26 | 45 | 161 | 320 |
| 497 | 0.642 | 0.358 | 0.220 | 0.41 | 96 | 32 | 56 | 201 | 400 |
| 749 | 0.729 | 0.271 | 0.146 | 0.62 | 145 | 48 | 84 | 303 | 602 |
| 996 | 0.776 | 0.224 | 0.110 | 0.83 | 193 | 64 | 111 | 402 | 800 |
| 1243 | 0.808 | 0.192 | 0.088 | 1.03 | 241 | 80 | 139 | 503 | 999 |
| 1596 | 0.836 | 0.164 | 0.068 | 1.32 | 309 | 103 | 179 | 645 | 1283 |
| 1992 | 0.859 | 0.141 | 0.055 | 1.65 | 386 | 129 | 223 | 805 | 1601 |
| 2495 | 0.877 | 0.123 | 0.044 | 2.07 | 484 | 161 | 279 | 1008 | 2005 |
| 3496 | 0.898 | 0.102 | 0.031 | 2.90 | 678 | 226 | 391 | 1413 | 2810 |
| 4242 | 0.909 | 0.091 | 0.026 | 3.52 | 822 | 274 | 475 | 1714 | 3410 |
| 4991 | 0.917 | 0.083 | 0.022 | 4.14 | 967 | 322 | 558 | 2017 | 4012 |
| 6969 | 0.932 | 0.068 | 0.016 | 5.78 | 1350 | 450 | 780 | 2816 | 5601 |
| 9965 | 0.945 | 0.055 | 0.011 | 8.26 | 1931 | 644 | 1115 | 4027 | 8009 |
| 12467 | 0.955 | 0.045 | 0.0088 | 10.34 | 2416 | 805 | 1395 | 5038 | 10021 |
| 14964 | 0.958 | 0.042 | 0.0073 | 12.41 | 2900 | 967 | 1674 | 6047 | 12027 |
| 19974 | 0.968 | 0.032 | 0.0055 | 16.56 | 3871 | 1290 | 2235 | 8072 | 16055 |
| 24910 | 0.975 | 0.025 | 0.0044 | 20.66 | 4827 | 1609 | 2787 | 10067 | 20022 |
| 29874 | 0.979 | 0.021 | 0.0037 | 24.77 | 5789 | 1930 | 3342 | 12073 | 24012 |
| 34877 | 0.985 | 0.015 | 0.0031 | 28.92 | 6759 | 2253 | 3902 | 14095 | 28033 |
| 40001 | 0.990 | 0.010 | 0.0027 | 33.17 | 7752 | 2584 | 4476 | 16166 | 32152 |
| 44782 | 0.994 | 0.006 | 0.0024 | 37.14 | 8678 | 2893 | 5011 | 18098 | 35995 |
| 49837 | 0.998 | 0.002 | 0.0022 | 41.33 | 9658 | 3219 | 5576 | 20141 | 40058 |

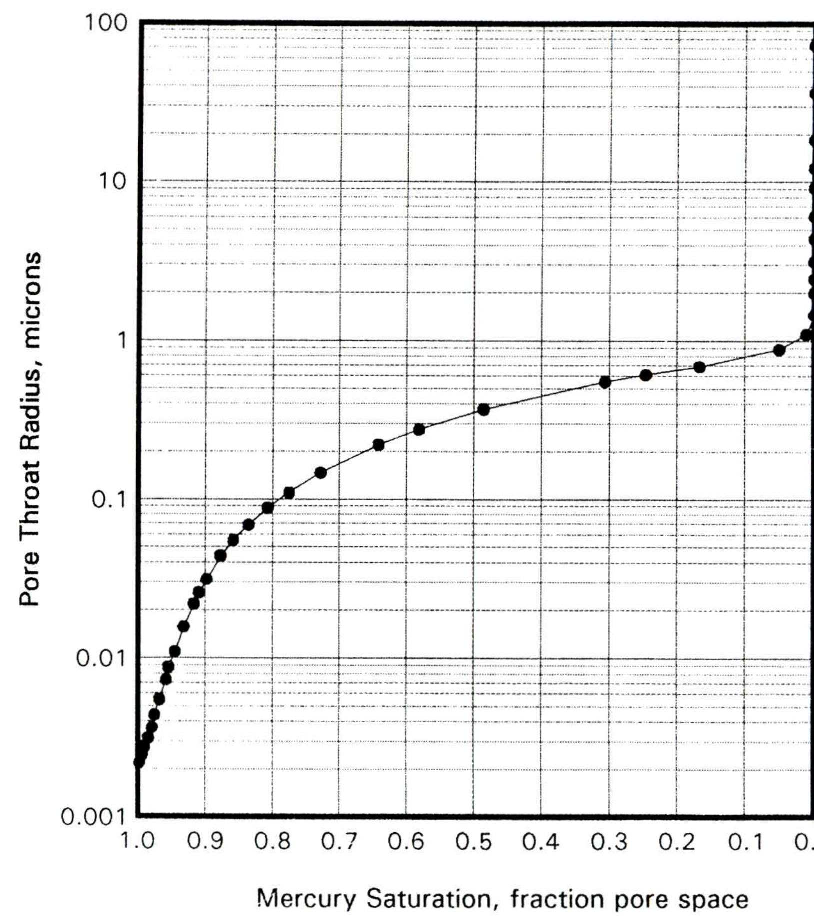
**Core Laboratories**

# MERCURY INJECTION --- PORE THROAT RADII

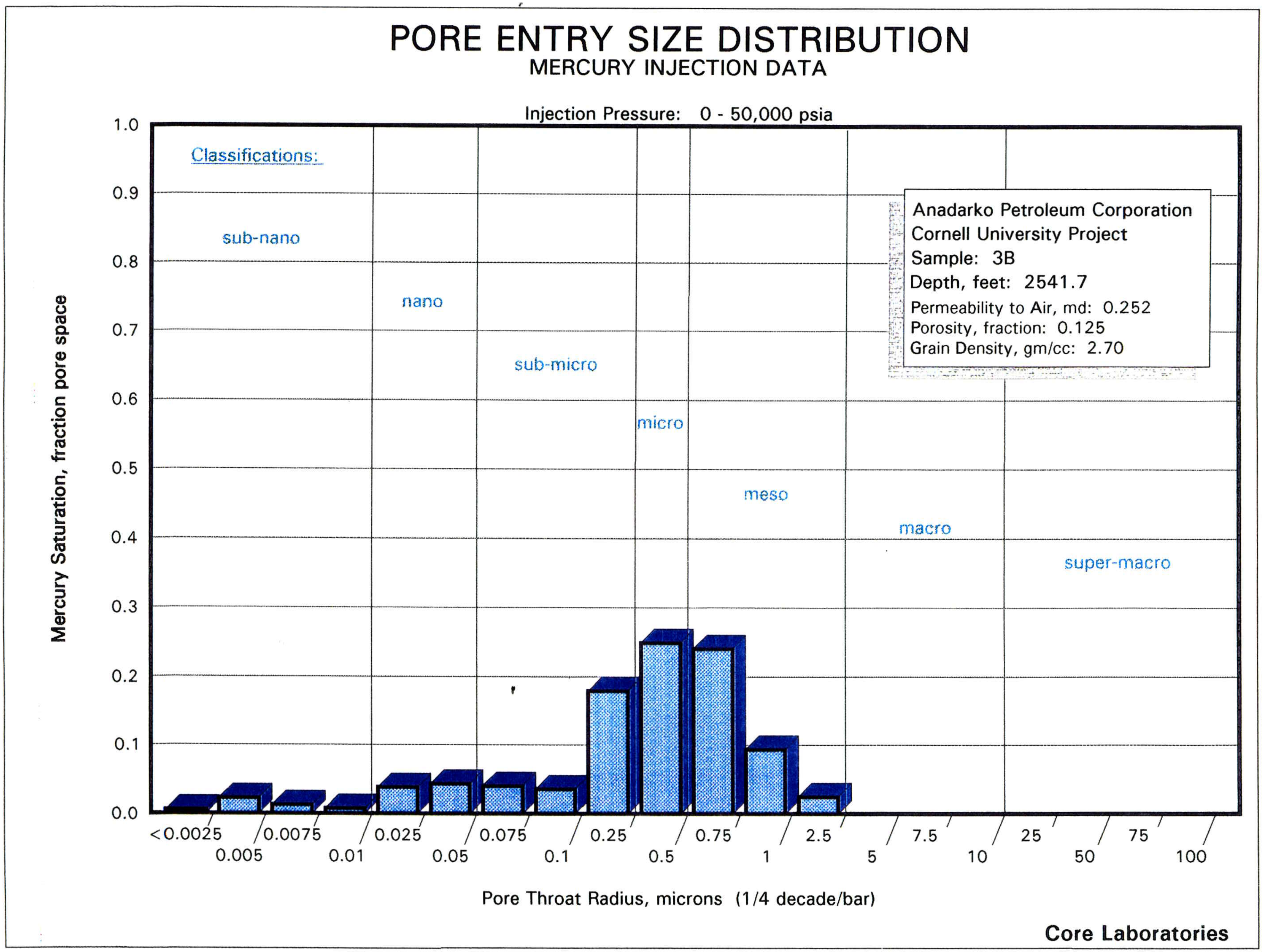
Anadarko Petroleum Corporation
Cornell University Project
Morton County, Kansas
File: DAL-94226

| | |
|---|---|
| Sample Number: | 3B |
| Sample Depth, feet: | 2541.7 |
| Permeability to Air, md: | 0.252 |
| Porosity, fraction: | 0.125 |




**Core Laboratories**



PORE ENTRY SIZE DISTRIBUTION
MERCURY INJECTION DATA
Injection Pressure: 0 - 50,000 psia
Classifications:
sub-nano
nano
sub-micro
micro
meso
macro
super-macro
Anadarko Petroleum Corporation
Cornell University Project
Sample: 3B
Depth, feet: 2541.7
Permeability to Air, md: 0.252
Porosity, fraction: 0.125
Grain Density, gm/cc: 2.70
Mercury Saturation, fraction pore space
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
<0.0025
0.005
0.0075
0.01
0.025
0.05
0.075
0.1
0.25
0.5
0.75
1
2.5
5
7.5
10
25
50
75
100
Pore Throat Radius, microns (1/4 decade/bar)
Core Laboratories

## APPENDIX A: LIST OF PROJECT ANALYSTS and PERSONNEL

PETROLEUM SERVICES MANAGER . . . . . . . . . . . . . . . . . . FEDERICA M. CURBY
LABORATORY SUPERVISOR . . . . . . . . . . . . . . . . . . . . . . . . . MICHAEL R. LONG
SENIOR PROJECT ANALYST . . . . . . . . . . . . . . . . . . . . . . . . . . JOSEPH A. WEIR
ANALYST . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . MIKE KOSTER
TECHNICAL SALES REPRESENTATIVE . . . . . . . . . . . . . . . . . . DOUG McELROY
SECRETARIAL . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . JANET PUFFER

# APPENDIX B: DISTRIBUTION OF FINAL REPORTS

## ANADARKO PETROLEUM CORPORATION
## CORNELL UNIVERSITY PROJECT
## MORTON COUNTY, KANSAS
## CL FILE NO. 57151-17847
## NMR FINAL REPORT

3 cc Anadarko Petroleum Corporation
17001 Northchase Drive
11th Floor, Anadarko Tower
Houston, Texas 77060
Attn: Mr. Warren Winters

1 cc Anadarko Petroleum Corporation
17001 Northchase Drive
11th Floor, Anadarko Tower
Houston, Texas 77060
Attn: Mr. Raymond P. Sorenson