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FOSSIL ENERGY

STUDY OF SONIC, NEUTRON AND DENSITY LOGGING OF LOW PERMEABILITY GAS SANDS

Final Report

By
J. S. Osoba
Clarence J. Raible

May 1982
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Work Performed Under Contract No. AC19-78BC00010

Texas A & M University
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Bartlesville Energy Technology Center
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TABLE OF CONTENTS

LIST OF FIGURES

PAGE

LIST OF TABLES

ABSTRACT

Gas accumulations in Lower Tertiary and Upper Cretaceous formations are the object of widespread exploration in the Tight Western Gas Sands. The complex lithology of these formations has hindered the usefullness of the sonic, density, and neutron logs. Current log evaluation practices assume a matrix density of 2.68 gm/cc and a matrix travel-time of 52.6 microseconds/ft. The neutron log is calibrated for a sandstone matrix. Conventional analysis yields inconsistent and often contradictory results.

Core and petrographic studies have been made on samples from Lower Tertiary and Upper Cretaceous formations in th Uinta Basin. Results indicated that a carbonate cement has filled much of the original porosity and altered the matrix density. Lower porosity samples tend to be heavily cemented and have matrix densities that approach, and even exceed, 2.68 gm/cc. Higher porosity samples tend to be lightly cemented and have matrix densities that approach 2.65 gm/cc.

Log analyses in the Uinta Basin, supplemented by core data, reveal that the higher porosity samples have matrix travel-times that approach 55.6 microseconds/ft. The presence of the carbonate cement does not decrease the matrix travel-times as expected. Laboratory measured matrix travel-times substantiate these conclusions. Log analyses also indicate the neutron log, when calibrated for a sandstone matrix, will not accurately evaluate the higher porosity, non-shaly sandstones.

Core and log analyses have been made on samples from the Upper Cretaceous Mesaverde formation in the Greater Green River Basin. The samples were obtained from two producing wells which encounter the Mesaverde at depths of 5000 and 12,000 feet. The resulting pressure and temperature difference caused the physical properties of the Mesaverde to vary widely within the Greater Green River Basin. Matrix density and matrix travel-time for the Mesaverde are very different for the two wells. Neutron log response also varies considerably.

INTRODUCTION

Large volumes of gas are trapped in low porosity, low permeability reservoirs in the Tight Western Gas Sands. The use of expensive stimulation techniques such as massive hydraulic fracturing requires that formation evaluation be as accurate as possible. The complex lithology of these reservoirs, though, has hindered the usefullness of the sonic, density, and neutron porosity logs. Without the accurate estimation of porosity generally provided by these logs, it is difficult to calculate water saturations and total gas in place.

Current log evaluation practices in the Tight Western Gas Sands assume a matrix density of 2.68 gm/cc and a matrix travel-time of 52.6 microseconds/ft. The neutron log is calibrated for a sandstone matrix. The results of a log analysis using these parameters are generally inconsistent. Each of the porosity logs should calculate the same values of porosity for non-shaly, completely water saturated sands if the values are correct. In these low permeability formations, however, sonic log porosities for clean sands, as indicated by the gamma ray log, tend to be higher than the porosities calculated by the density log and the neutron log. Neutron log porosities are generally higher than those calculated by the density log. The lack of agreement among the three logs is caused by using incorrect values for matrix density, matrix travel-time and matrix composition or by assuming that these values remain essentially constant for a given formation.

To gain a better understanding of matrix composition, petrographic studies have been made on samples from the Lower Tertiary Wasatch and the Upper Cretaceous Mesaverde sands in the Uinta Basin. Core and log analyses have also been used to examine the matrix densities and the matrix travel-times of these formations.

Core and log analyses have also been made on the Mesaverde formation in the Greater Green River Basin.

The names and locations of the wells studied are listed in Table 1.

TABLE 1

LOG AND CORE DATA

Natural Buttes 21
Section 15, T10S, R22E, Uintah County, Utah

Formation:	Wasatch/Mesaverde
Core Depth:	4441 - 4466 ft
	6405 - 6474 ft
	7423 - 7482 ft
	8425 - 8483 ft
	8510 - 8515 ft
Log Depth:	Top = 4444 ft
	Bottom = 8518 ft

River Bend Unit 11-17F
Section 17, T10S, R20E, Uintah County, Utah

Formation:	Mesaverde
Core Depth:	7286 - 7288 ft
	8230 - 8248 ft
	8283 - 8306 ft
	8355 - 8367 ft
	8443 - 8458 ft
Log Depth:	Top = 7293 ft
	Bottom = 8465 ft

Rainbow Resources No. 1-3 Federal
Section 3, T26N, R103W, Sweetwater County, Wyoming

Formation:	Mesaverde
Core Depth:	12398 - 12475 ft
	12483 - 12496 ft
	12633 - 12667 ft
	12688 - 12728 ft
	13419 - 13433 ft
	13476 - 13488 ft
Log Depth:	Top = 12390 ft
	Bottom = 13480 ft

Pacific Transmission Supply 24-19 Federal
Section 19, T33N, R114W, Sublette County, Wyoming

Formation:	Mesaverde
Core Depth:	5116 - 5121 ft
	5160 - 5166 ft
	5180 - 5220 ft
	5253 - 5266 ft
	5295 - 5322 ft
Log Depth:	Top = 5125 ft
	Bottom = 5331 ft

PETROGRAPHIC ANALYSIS - UINTA BASIN

Petrographic analyses have been performed on samples from two wells in the Uinta Basin. These wells are the Natural Buttes 21, located in Section 15, T10S, R22E, and the Shell No.7, located in Section 24, T10S, R23E. Both wells are located in Uintah County, Utah.

C.W. Keighin of the U.S. Geological Survey in Denver, Colorado, has studied 38 samples from the Mesaverde Group using petrographic thin sections and the scanning electron microscope[1]. The samples studied were cored from the Shell No. 7 well. The samples consist of a heterogeneous mixture of framework grains composed of quartz, chert, feldspar, plagioclase, and rock fragments. The original grains have been bound together primarily by carbonate cement. Small amounts of silica cement are also observed. The carbonate cement has also filled much of the original porosity. The present porosity of the samples is due to the leaching of the carbonate cement. Authigenic clays, primarily illite and kaolinite, tend to bridge the open pore spaces. Although the clays occupy only small amounts of space, their physical structure tends to greatly reduce permeability.

Ten samples from the Natural Buttes 21 core were analyzed in thin sections at Texas A&M University. The samples between 4400 feet and 6500 feet depth are from the Tertiary Wasatch formation. The samples between 7400 feet and 8550 feet depth are from the Upper Cretaceous Mesaverde formation. These samples had the same heterogeneous mixture of framework grains bound by a carbonate cement. The quartz fraction of each sample ranged from 24% to 48%, while the carbonate fraction ranged from 0% to 58%.

Core properties were also measured on each of the ten samples. Table 2 lists the porosity, matrix density, and percent carbonate for each sample. Figure 1 is a plot of matrix density versus percent carbonate. Clearly, the matrix density is a function of the amount of carbonate cement present. Figure 2 is a plot of porosity versus percent carbonate. Although this trend is not as distinct as in Figure 1, the porosity is also a function of the amount of carbonate present.

Petrographic analysis has given definition to the reservoir lithology. Conclusions from core and log analyses must take the general composition of the formations into account. These studies have indicated that the target formations are sandstone bodies that have been heavily cemented with carbonate material. The carbonate cement has filled much of the original porosity. Secondary porosity occurs where the cement has been leached. Both porosity and matrix density appear to be functions of the amount of carbonate cement present.

TABLE 2

PETROGRAPHIC ANALYSIS
Natural Buttes 21

Sample	Depth feet	Porosity %	Carbonate % of Matrix	Matrix Density gm/cc
1	4457	3.00	33	2.69
2	4459'4"	4.60	37	2.70
3	4465'10"	3.20	58	2.77
4	6472'1"	8.40	13	2.65
5	6472'9"	5.50	9	2.67
6	7425'6"	9.80	0	2.65
7	7463'8"	5.18	29	2.70
8	7481	6.80	42	2.72
9	8435'4"	5.60	31	2.70
10	8483	2.60	15	2.68

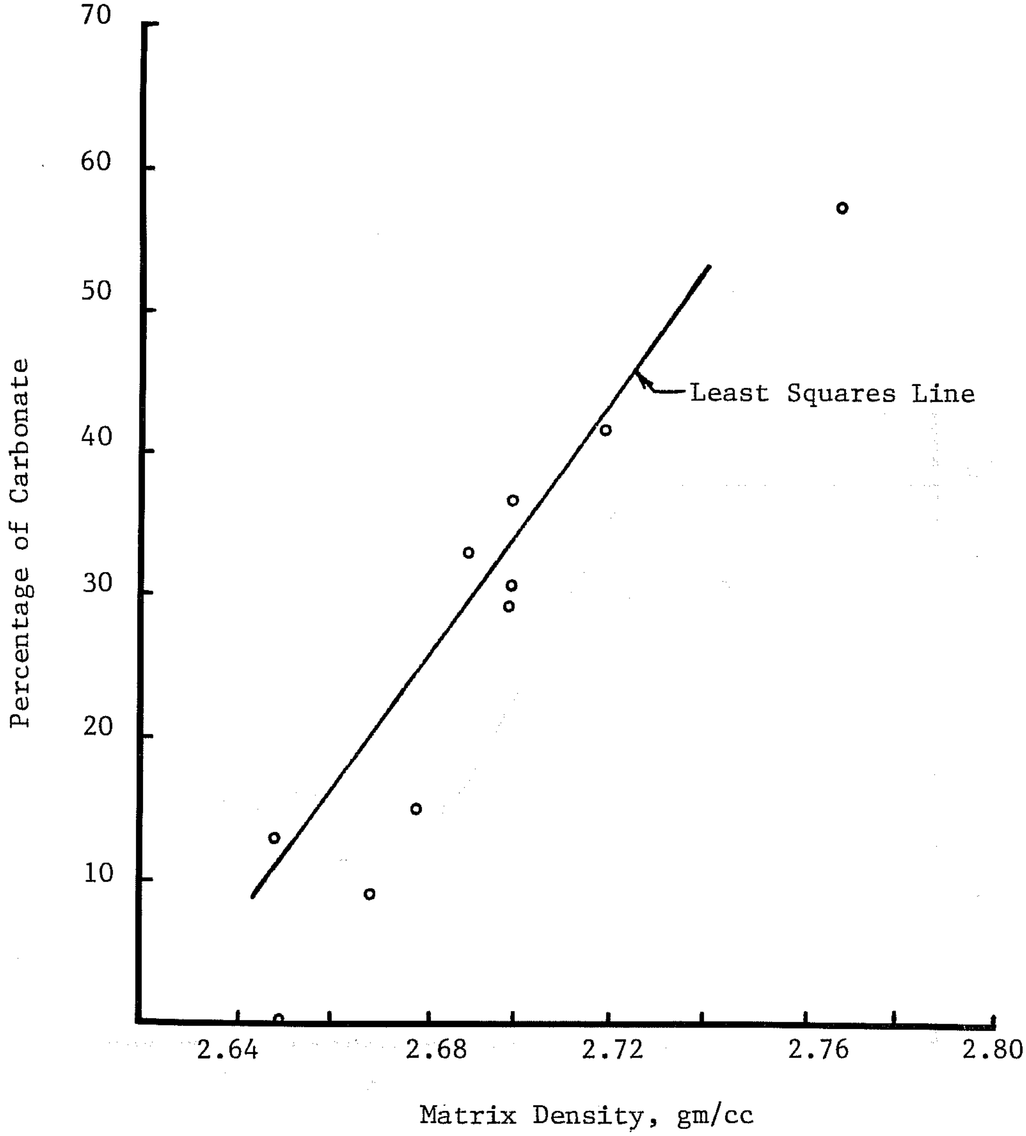


Figure 1.

Percentage of Carbonate
As Determined by Petrographic Analysis
vs Laboratory Derived Matrix Density

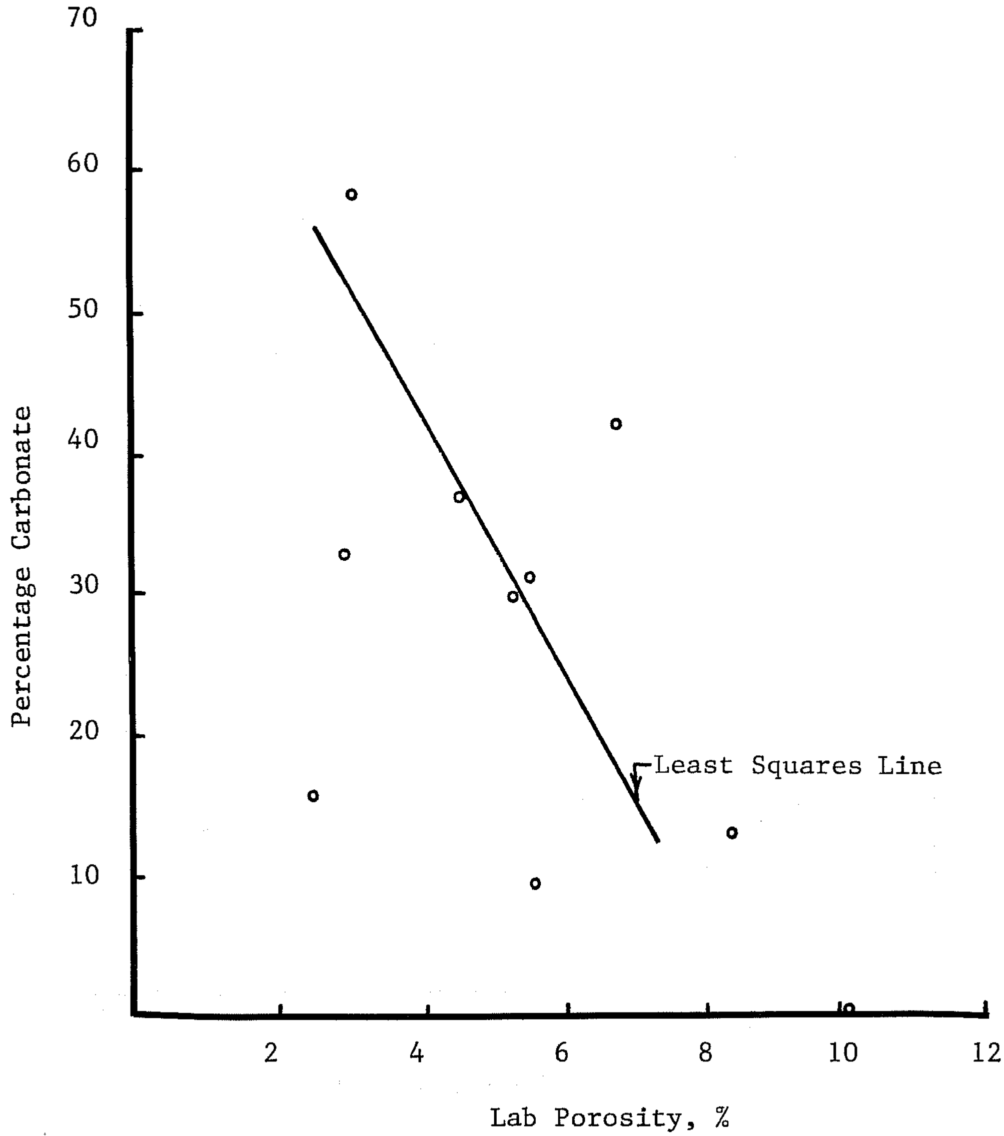


Figure 2.

Percentage of Carbonate
As Determined by Petrographic Analysis
vs Laboratory Derived Porosity

CORE ANALYSIS - UINTA BASIN

Measurements have been made on cores from two wells in the Uinta Basin. The cores were taken from the Natural Buttes 21 and the River Bend Unit 11-17F wells, which are located in Uintah County, Utah. The Natural Buttes core was analyzed at Texas A&M University. The River Bend Unit core was analyzed by Core Laboratories. In each case, porosity, permeability, and matrix density were measured. Matrix travel-time measurements were made on two samples from the Natural Buttes well.

Table 3 lists the data collected from the Natural Buttes core. Porosities were determined by use of a helium porosimeter and matrix volume cup. The permeabilities were determined by flowing helium at a constant pressure through a sample set in a Hassler sleeve. The permeabilities were not corrected for the Klinkenburg effect, nor were they measured at reservoir pressures. Matrix densities were calculated using the weight of the sample and the volume of the sample measured by the matrix volume cup. Matrix densities (Dm) were converted to bulk densities (Db) by the following:

$$Db = (1 - P)\,Dm + PDf \quad ..... \qquad \text{Eq (1)}$$

where P is the porosity of the sample and Df is the fluid density set at 1 gm/cc.

Figure 3 is a plot of bulk density versus porosity. Constant matrix density lines have been added to each plot. A "least squares" line has been drawn through the data. The trend of the data indicated that the higher porosity zones have matrix densities that approach 2.65 gm/cc. Lower porosity zones have matrix densities that approach, and exceed, 2.68 gm/cc. Figure 4 is a plot of porosity versus permeability. Permeabilities increase as porosity increases.

Table 4 lists the data collected from the River Bend Unit core. Bulk densities were also calculated for each of these samples. Figure 5 is a plot of bulk density versus porosity for the River Bend Unit core. Again, constant matrix density lines have been included and a "least squares" line drawn through the data. The variation of matrix density is not as sharp as in Figure 3, but the matrix densities of the higher porosity samples tend to approach 2.65 gm/cc. Figure 6 is a plot of permeability versus porosity for the River Bend well.

Table 5 lists the results of the matrix travel-time measurements on two samples from the Natural Buttes 21 well. The porosities of the samples were determined using the helium porosimeter and a matrix volume cup. Sample 3 had a porosity of 3.2% and Sample 4 had a porosity of 8.4%. Acoustic velocities were measured while the samples were under pressure. Each sample was saturated with brine and subjected to an effective pressure equivalent to the difference between the lithostatic and pore pressure of that sample. For Sample 4, the pressure used was 3607 psi. The measured velocities were converted to matrix travel-times. Sample 4, with a measured porosity of 8.4%, had a matrix travel-time of 56.8 microseconds/ft. Sample 3, with a measured porosity of 3.2%, had a matrix travel-time of 63.0 microseconds/ft.

TABLE 3

CORE DATA
Natural Buttes 21

Sample	Depth feet	Porosity %	Matrix Density gm/cc	Permeability to Air md
1	4441	5.2	2.72	0.232
2	4442	2.7	2.69	0.021
3	4457	3.0	2.69	0.033
4	4459	5.2	2.70	0.037
5	4461	5.0	2.70	0.029
6	4464	3.3	2.68	0.020
7	4466	4.2	2.70	0.024
8	6405	4.4	2.67	0.863
9	6406	6.2	2.68	0.050
10	6424	5.1	2.71	0.049
11	6472	8.5	2.65	0.390
12	6473	7.2	2.67	0.143
13	6474	10.8	2.65	0.572
14	7423	5.2	2.70	0.020
15	7424	5.9	2.73	0.035
16	7426	6.6	2.74	0.033
17	7427	7.5	2.72	0.069
18	7429	8.7	2.70	0.053
19	7430	9.0	2.68	0.083
20	7477	3.2	2.77	0.012
21	7478	3.2	2.72	0.015
22	7479	3.2	2.69	0.064
23	7481	5.6	2.70	0.099
24	7482	6.2	2.70	0.074
25	8425	4.1	2.64	0.031
26	8426	3.7	2.62	0.035
27	8434	9.8	2.68	0.040
28	8436	9.0	2.63	0.184
29	8437	9.5	2.64	0.158

TABLE 3 (continued)

Sample	Depth feet	Porosity %	Matrix Density gm/cc	Permeability to Air md
30	8438	9.3	2.65	0.132
31	8439	7.2	2.62	0.333
32	8483	2.6	2.67	0.030
33	8510	4.1	2.66	0.037
34	8512	4.3	2.65	0.076
35	8513	3.8	2.69	0.043
36	8514	6.4	2.68	0.069
37	8515	10.0	2.66	0.310

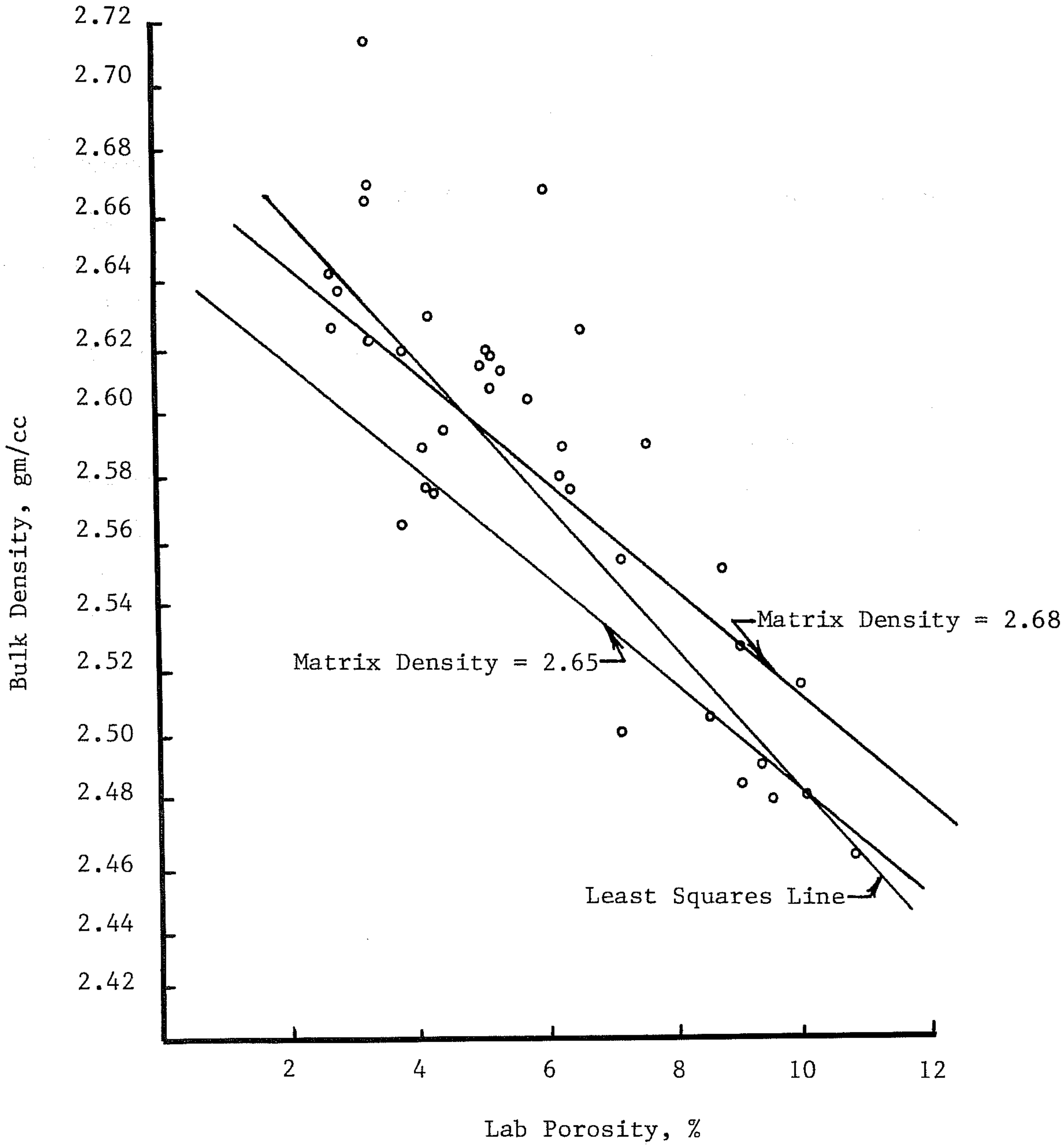


Figure 3.

Laboratory Derived Bulk Density
vs Laboratory Derived Porosity
Natural Buttes 21

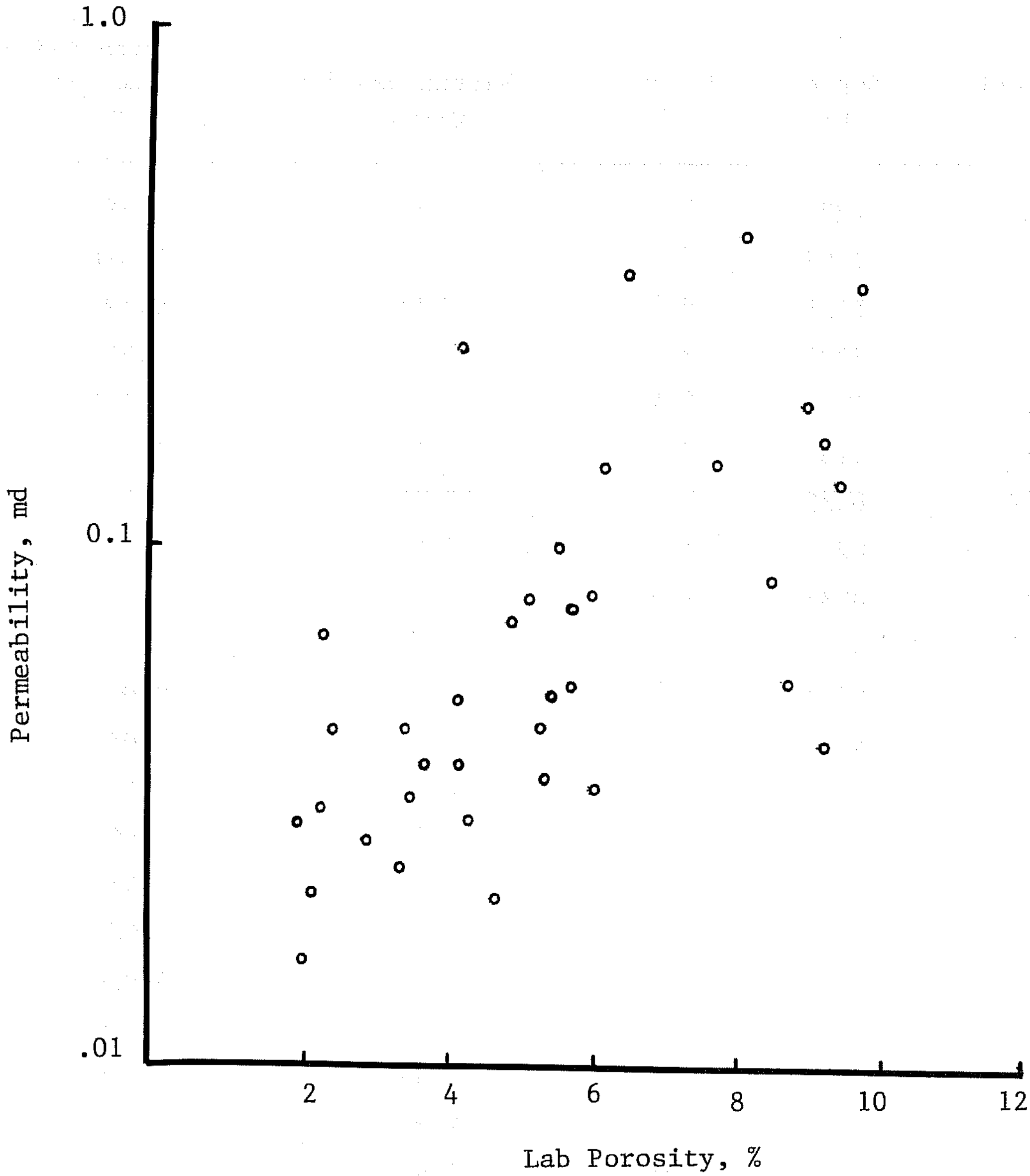


Figure 4.

Permeability to Helium vs
Laboratory Derived Porosity
Natural Buttes 21

TABLE 4

CORE DATA
River Bend Unit 11-17F

Sample	Depth feet	Porosity %	Matrix Density gm/cc	Permeability to Air md
1	7286	7.3	2.68	0.295
2	7287	7.2	2.67	0.398
3	7288	6.7	2.68	0.192
4	8230	9.6	2.68	0.329
5	8231	8.4	2.68	0.355
6	8232	7.2	2.68	0.177
7	8233	6.8	2.69	0.251
8	8235	5.9	2.68	0.105
9	8236	4.0	2.68	0.053
10	8237	5.8	2.70	0.104
11	8238	5.5	2.67	0.044
12	8241	4.9	2.71	1.050
13	8242	9.4	2.68	0.054
14	8244	3.1	2.70	0.001
15	8245	5.4	2.68	0.010
16	8246	1.3	2.72	0.003
17	8247	1.4	2.66	10.900
18	8248	3.7	2.65	0.160
19	8283	6.9	2.68	11.300
20	8284	7.5	2.68	0.012
21	8285	8.0	2.67	0.017
22	8286	8.3	2.66	0.935
23	8287	6.2	2.67	0.564
24	8288	6.1	2.67	9.440
25	8289	7.2	2.65	0.074
26	8291	7.6	2.67	0.152
27	8292	7.9	2.65	0.228
28	8293	7.7	2.67	0.357
29	8294	7.7	2.67	0.419

TABLE 4 (continued)

Sample	Depth feet	Porosity %	Matrix Density gm/cc	Permeability to Air md
30	8295	7.7	2.66	0.179
31	8296	7.7	2.67	0.899
32	8298	6.3	2.67	1.690
33	8305	7.4	2.68	0.122
34	8306	5.7	2.70	0.021
35	8355	7.8	2.67	0.186
36	8356	5.8	2.67	0.154
37	8357	7.7	2.65	0.486
38	8359	8.7	2.67	0.915
39	8360	7.8	2.67	0.864
40	8361	6.4	2.67	0.180
41	8362	8.8	2.67	0.564
42	8363	7.7	2.67	0.225
43	8364	8.4	2.63	0.414
44	8366	7.2	2.69	0.111
45	8367	6.8	2.67	0.093
46	8443	4.6	2.69	0.007
47	8447	1.0	2.68	0.014
48	8448	2.6	2.67	0.075
49	8449	5.8	2.68	0.085
50	8450	5.6	2.68	0.193
51	8451	2.7	2.69	11.000
52	8452	2.2	2.64	0.003
53	8457	8.1	2.68	0.163
54	8458	6.6	2.66	0.035

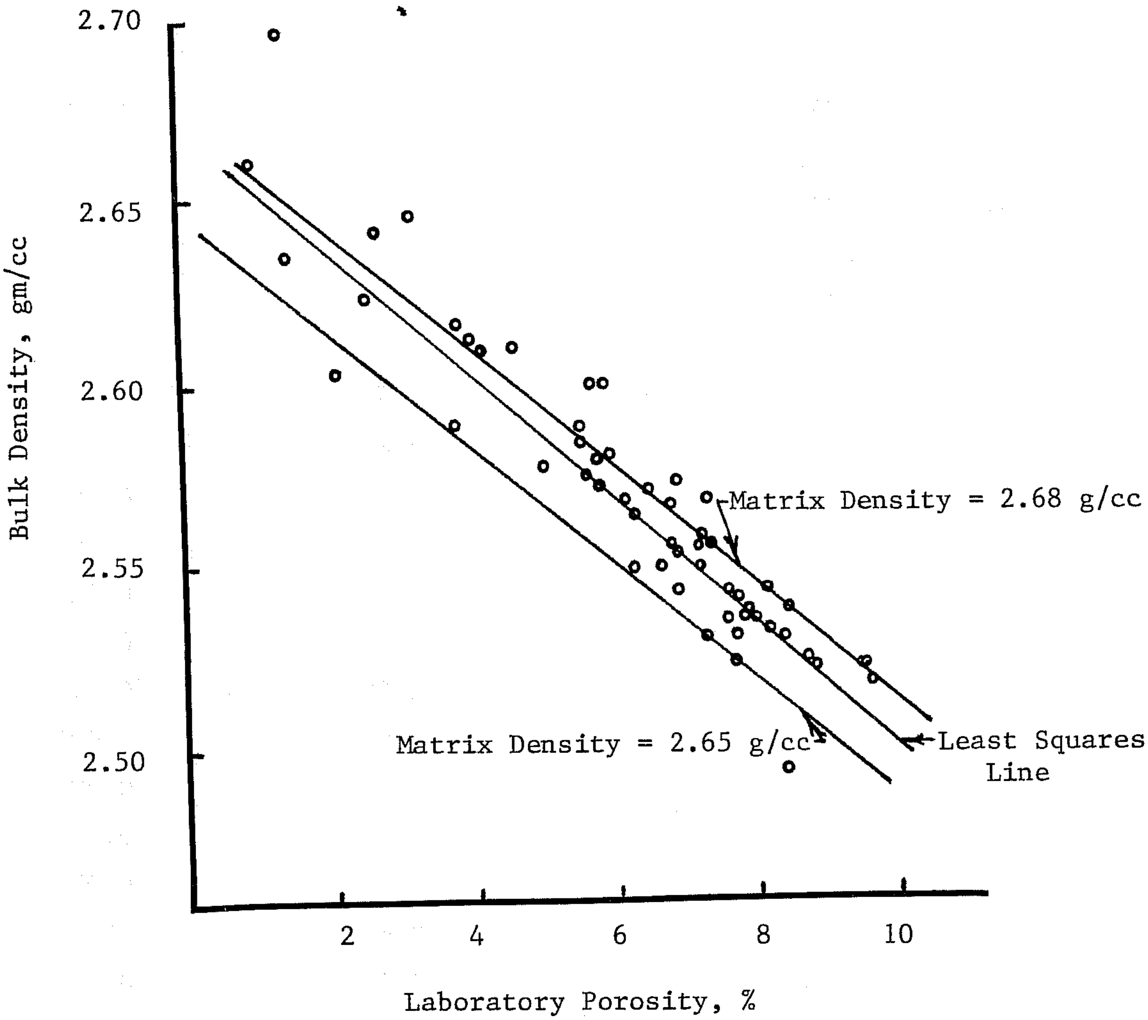


Figure 5.

Laboratory Derived
Bulk Density vs
Laboratory Derived Porosity
River Bend Unit 11-17F

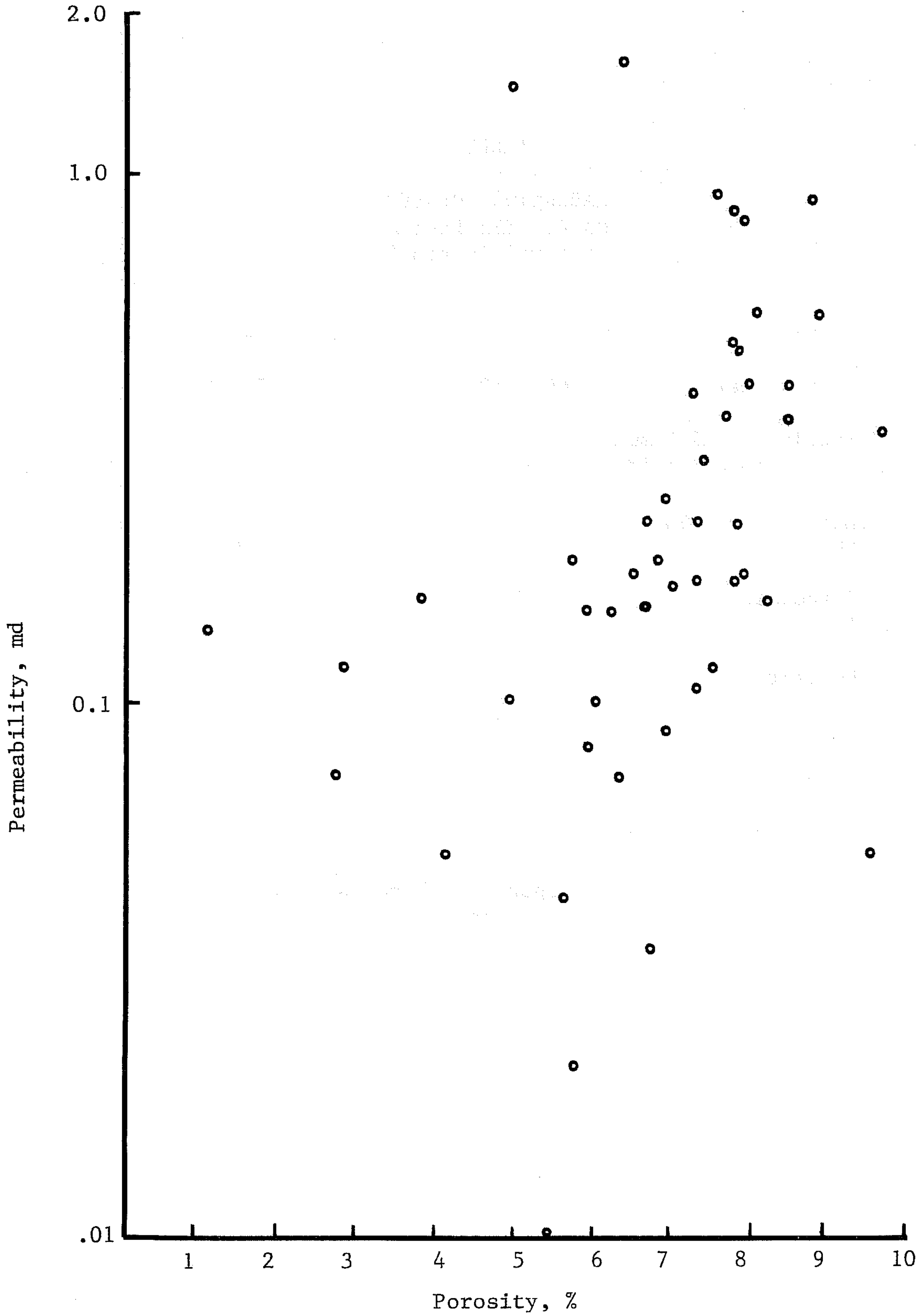


Figure 6.
Permeability to Helium versus Laboratory
Derived Porosity, River Bend Unit 11-17F

TABLE 5

LABORATORY MEASURED
MATRIX TRAVEL-TIMES
Natural Buttes 21

Sample *	3	4
Depth, feet	4465'10"	6472'1"
Matrix Travel-Time, microseconds/ft **	63.0	55.8
Matrix Density, gm/cc	2.77	2.65
Carbonate, % of Matrix	3.2	8.4
Porosity, %		

* Sample numbers correspond to those in Table 2.
** Measured matrix travel-times.

The core data listed in Tables 3 and 4 was used to evaluate the porosity logs for the Natural Buttes and River Bend Unit wells. Core depths were correlated to log depths and values were read for each sample. The depths listed in the tables are the core depths. All log values have been obtained from Schlumberger well logs, with depths corrected to core depth.

Natural Buttes 21

Log readings from the sonic, density, neutron, and gamma ray logs have been obtained for each of the samples. These values, along with the laboratory measured porosities, are listed in Table 6.

Figure 7 is a plot of the sonic log porosity versus the true (measured) porosity for each sample. A matrix travel-time of 52.6 microseconds/ft was used for the sonic log calculations All of the log porosities are greater than the measured porosities. This indicates that the assumed matrix travel-time of 52.6 microseconds/ft is too low. A corrected matrix travel-time was calculated for each sample using the log travel-time and the measured porosity of each sample. The log travel-times are listed in Table 6 and plotted in Figure 8. The corrected matrix travel-time (Tm') was calculated using the following equation:

$$Tm' = \frac{Tl - PTf}{(1 - P)} \quad \ldots\ldots \qquad \text{Eq (2)}$$

where Tl is the travel-time measured by the sonic tool, Tf is the fluid travel-time (assumed to be a constant 189 microseconds/ft), and P is the measured porosity of the sample.

Figure 9 shows the calculated matrix travel-time plotted against the measured porosity. A "least squares" line has been drawn through the data. The trend of the data indicates that the higher porosity samples have matrix densities that approach that of a clean sandstone (55.6 microseconds/ft). The lower porosity samples have matrix travel-times as high as 71.2 microseconds/ft. The laboratory measured matrix travel-times (listed in Table 5) are included in this figure.

The relatively high values for the calculated matrix travel-times are somewhat unexpected. The matrix densities that have been measured tend to be greater than 2.65 gm/cc. This is due to the presence of the carbonate cement, which has a matrix density close to that of dolomite. For this reason the matrix travel-times, which are known to be dependent on matrix density, would be expected to fall between the travel-times of dolomite and sandstone. Current practice in the Uinta Basin makes that assumption and uses 52.6 microseconds/ft. In effect, this is an assumption that the presence of a high density carbonate cement will lower the travel-time of a sandstone. The calculated matrix travel-times indicate just the opposite, and this is supported by the measured matrix travel-times.

TABLE 6

LOG PARAMETERS
Natural Buttes 21

Sample[1]	Lab Porosity %	Density[2] Porosity %	Sonic[3] Porosity %	Neutron Porosity %	Log Travel-Times micsec/ft	Calculated Matrix Travel-Times micsec/ft	Gamma Ray
1	5.20	3.30	7.60	13.50	63.00	56.10	65.00
2	2.70	4.50	8.70	14.00	64.50	61.00	70.00
3	3.00	2.10	9.10	13.00	65.00	61.40	77.00
4	5.20	4.20	7.60	10.00	63.00	56.10	65.00
5	5.00	3.90	7.30	10.50	62.50	55.80	68.00
6	3.30	3.90	8.00	12.00	63.50	59.20	75.00
7	4.20	3.30	9.10	12.00	65.00	59.60	68.00
8	4.40	4.80	12.80	20.00	70.00	64.50	80.00
9	6.20	7.70	9.10	16.00	65.00	56.80	70.00
10	5.10	3.60	12.00	19.00	69.00	62.60	82.00
11	8.50	11.90	12.80	12.00	70.00	58.90	52.00
12	7.20	11.30	15.70	17.00	74.00	65.10	75.00
13	10.80	11.90	18.90	24.00	78.50	65.10	90.00
14	5.20	2.90	7.30	10.00	62.50	55.60	38.00
15	5.90	1.20	8.40	10.50	64.00	56.20	40.00
16	6.60	8.30	10.90	11.50	67.50	58.90	45.00
17	7.50	7.10	10.90	11.00	67.50	57.60	43.00
18	8.70	8.00	11.30	11.50	68.00	56.50	50.00
19	9.00	9.20	14.90	15.00	73.00	61.50	55.00
20	3.20	.29	8.00	11.50	63.50	59.40	63.00
21	3.20	-.60	10.20	12.50	66.50	62.50	60.00
22	3.20	3.30	11.30	13.50	68.00	64.00	55.00
23	5.60	4.80	13.50	18.00	71.00	64.00	65.00
24	6.20	6.50	24.50	16.50	86.00	71.20	75.00
25	4.10	8.00	6.90	9.50	62.00	56.60	33.00
26	3.70	7.70	8.40	10.00	64.00	59.20	35.00
27	9.80	11.90	10.60	9.00	67.00	53.70	33.00
28	9.00	11.30	9.80	8.50	66.00	53.80	28.00

TABLE 6 (continued)

Sample[1]	Lab Porosity %	Density[2] Porosity %	Sonic[3] Porosity %	Neutron Porosity %	Log Travel-Times micsec/ft	Calculated Matrix Travel-Times micsec/ft	Gamma Ray
29	9.50	10.70	8.70	8.00	64.50	51.90	26.00
30	9.30	8.90	8.40	8.50	64.00	51.20	30.00
31	7.20	10.10	9.80	10.00	66.00	56.50	38.00
32	2.60	11.30	10.60	9.00	67.00	63.70	27.00
33	4.10	10.70	10.60	10.00	67.00	61.80	30.00
34	4.30	13.10	10.20	10.50	66.50	60.90	30.00
35	3.80	11.90	11.70	11.00	68.50	63.70	33.00
36	6.40	13.10	11.70	11.50	68.50	60.20	34.00
37	10.00	13.70	10.60	11.00	67.00	53.40	27.00

1 Depths of samples given in Table 3

2 Calculated using matrix density equal to 2.68 gm/cc.

3 Calculated using the data matrix travel-time equal to 52.6 microseconds/ft.

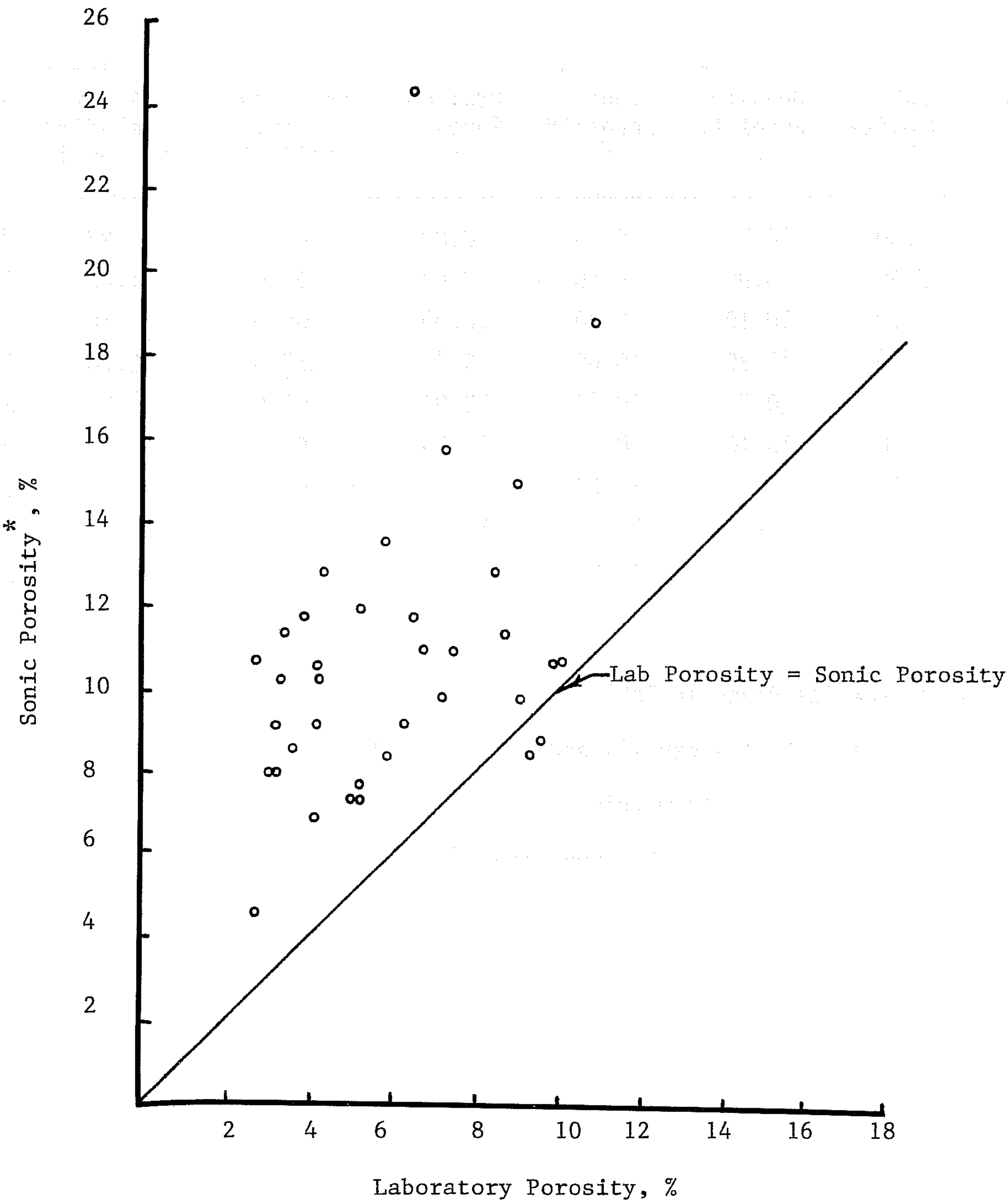


Figure 7.

Sonic Porosity vs
Laboratory Derived Porosity
Natural Buttes 21

* Calculated using a matrix travel-time of 52.6 micsec/ft.

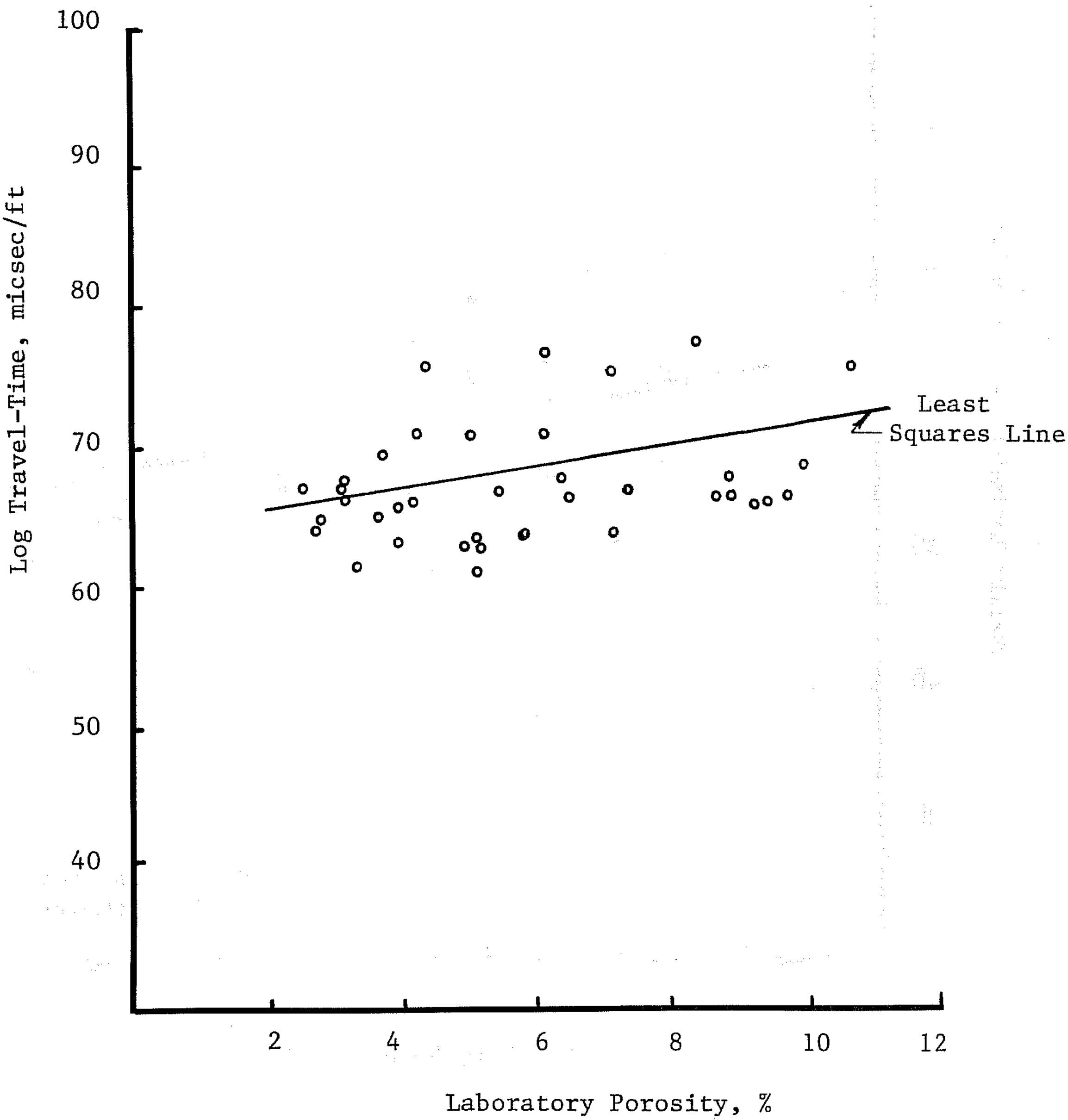


Figure 8.

Sonic Log Travel-Time
vs Laboratory Derived Porosity
Natural Buttes 21

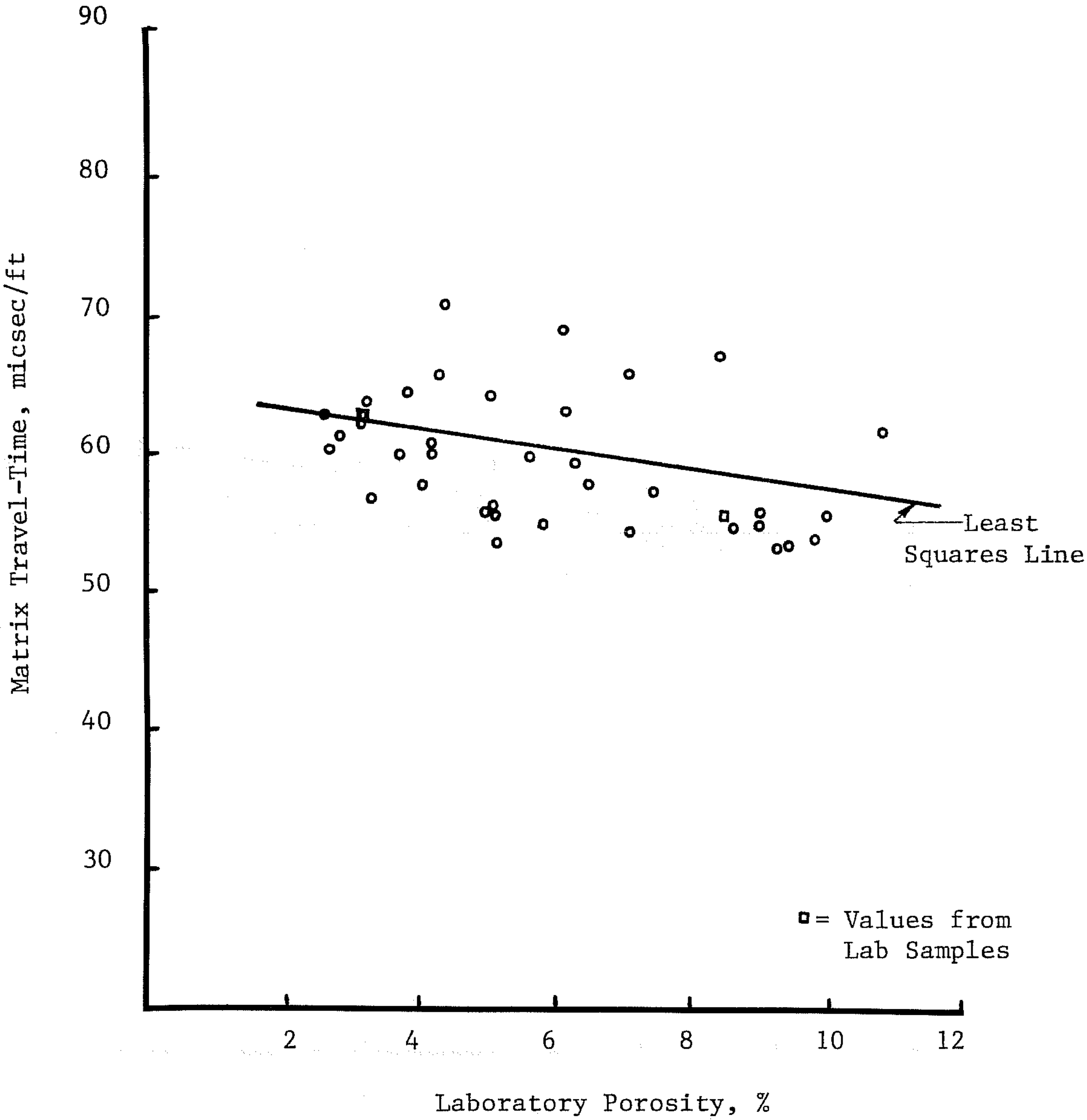


Figure 9.

Calculated Matrix Travel-Time
vs Laboratory Derived Porosity
Natural Buttes 21

The rate at which an acoustic compressional wave will pass through a substance is known to be a function of the density of that substance. The sonic log is based on this relationship. Geologic formations are not homogeneous substances, however, and the relationship becomes more complicated. Research done by Zanier and Overton[2] indicated that the composition of the framework grains determines the rate at which a compressional wave will travel through that formation. The compressional wave, which is the wave whose velocity is measured by the sonic log, will not be affected by the presence of a cementing material. In the case of the Natural Buttes 21, the framework grains are composed primarily of quartz, with varying amounts of rock fragments, feldspar and plagioclase present. Thus the matrix travel-times will not be affected by the presence of the carbonate cement. The correct matrix travel-time from a clean sandstone in the Natural Buttes should approach 55.6 microseconds/ft.

Figure 10 is a plot of the porosity recorded by the neutron log, calibrated for a sandstone matrix, versus the measured porosity for each sample. Also shown on this figure are the dolomite, limestone, and sandstone matrix lines. Since these samples have a sandstone matrix, the neutron log should give values for porosity that fall along the sandstone line. The higher porosity samples do tend to be located around the sandstone line. The lower porosity samples, which are more heavily cemented, tend to be located around the limestone and dolomite lines. The carbonate cement causes the neutron log to calculate values of porosity which are too high. Shaliness will produce the same effect on the neutron log. For the Natural Buttes 21, the neutron log will tend to give accurate values of porosity for clean, lightly cemented sandstones.

River Bend Unit 11-17F

The same procedure has been used to evaluate the porosity logs from the River Bend Unit well. Table 7 contains the log values read for each of the core data points. The laboratory measured porosities and calculated matrix travel-times are included. No measured travel-times are available for the River Bend Unit core.

Figure 11 is a plot of sonic log porosities versus measured porosities. (Sonic porosity was calculated using as assumed matrix travel-time of 52.6 microseconds/ft). Again sonic log porosities are greater than the measured porosities, indicating that the assumed matrix travel-time is too low. Figure 12 is a plot of log travel-times versus measured porosity. Figure 13 is a plot of calculated matrix travel-times versus measured porosity. Again, matrix travel-times tend to decrease and approach 55.6 microseconds/ft as the porosity increases.

Figure 14 is a plot of neutron log porosity versus measured porosity. The high porosity samples tend toward the sandstone line. The low porosity samples are located around the limestone and dolomite lines.

Clean Sand Analysis

The next step in the investigation was to eliminate the effects of shaliness. The gamma ray log was used to pick the samples that contained no shale. A maximum gamma ray reading of 45 API units was used as the

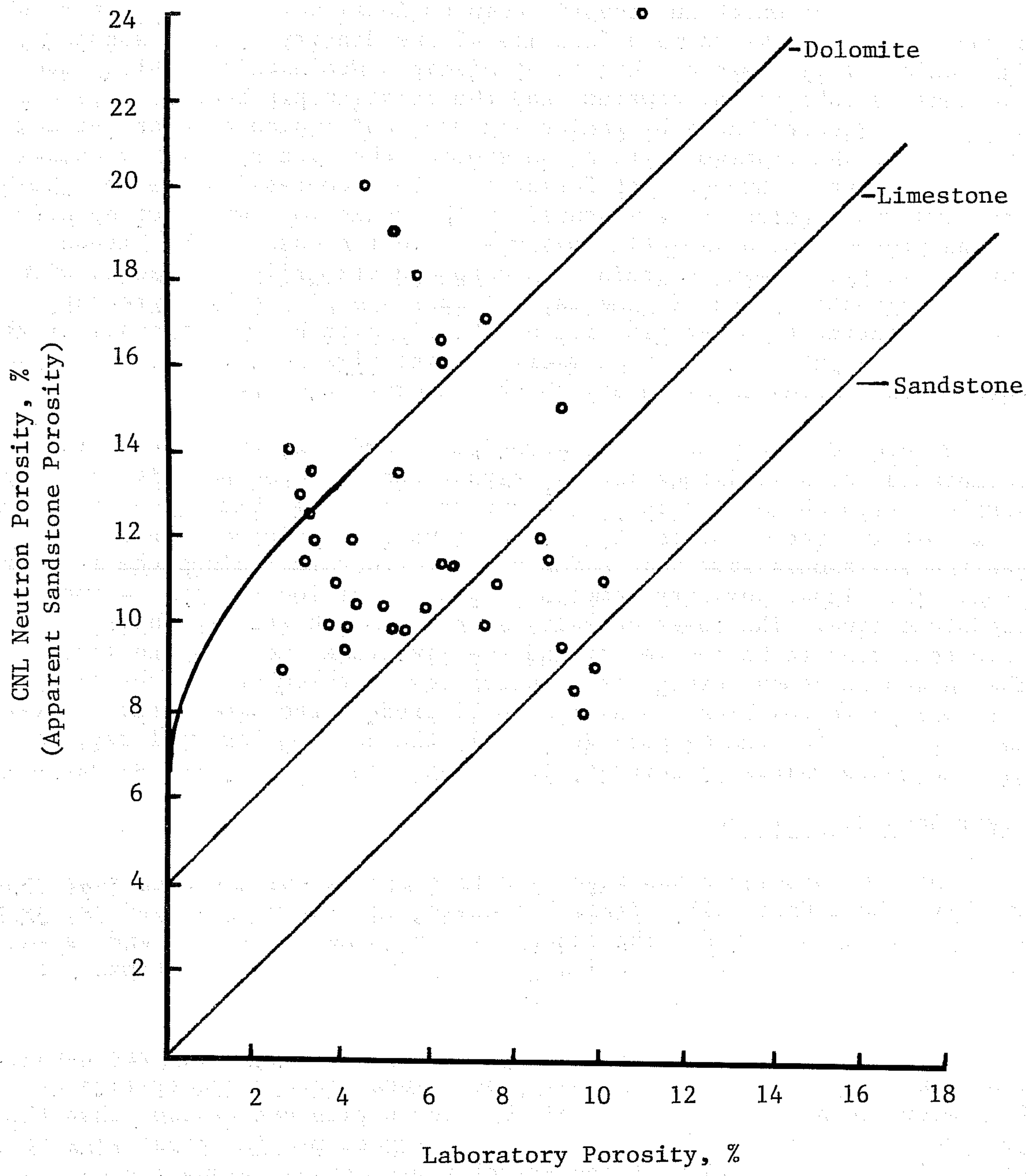


Figure 10.

Neutron Log Porosity vs
Laboratory Derived Porosity
Natural Buttes 21

TABLE 7

LOG ANALYSIS
River Bend Unit 11-17F

Sample[1]	Lab Porosity %	Density[2] Porosity %	Sonic[3] Porosity %	Neutron Porosity %	Log Travel-Times micsec/ft	Calculated Matrix Travel-Times micsec/ft	Gamma Ray
1	7.30	10.00	8.50	13.00	64.20	54.40	30.00
2	7.20	11.50	8.00	14.50	63.50	53.80	25.00
3	6.70	9.50	8.50	14.00	64.20	55.20	35.00
4	9.60	13.50	13.50	11.00	71.00	58.50	50.00
5	8.40	14.50	12.50	11.00	69.70	58.80	30.00
6	7.20	13.50	10.50	9.00	67.00	57.50	38.00
7	6.80	6.00	8.00	10.00	63.50	54.30	49.00
8	5.90	5.00	6.00	11.00	61.00	53.00	56.00
9	4.00	9.00	5.50	12.00	60.00	54.60	59.00
10	5.80	7.50	6.00	14.00	61.00	53.10	52.00
11	5.50	7.00	6.00	14.50	61.00	53.60	45.00
12	4.90	15.00	17.50	19.50	76.50	70.70	105.00
13	9.40	10.50	12.00	19.00	69.00	56.50	85.00
14	3.10	11.00	11.50	18.00	68.50	64.60	75.00
15	5.40	19.00	15.00	20.00	73.00	66.40	92.00
16	1.30	38.00	23.00	19.00	84.00	82.60	103.00
17	1.40	24.00	21.00	17.50	81.00	79.50	97.00
18	3.70	3.00	14.50	20.00	72.00	67.50	112.00
19	4.10	4.50	8.50	11.50	64.20	58.90	60.00
20	3.70	12.00	9.00	12.00	65.00	60.20	45.00
21	6.90	13.00	11.50	11.50	68.50	59.60	50.00
22	7.50	13.50	11.00	12.00	68.00	58.20	42.00
23	8.00	10.00	11.00	12.50	68.00	57.50	50.00
24	8.30	11.50	10.50	12.00	67.00	56.00	52.00
25	6.20	11.00	10.50	11.50	67.00	58.90	38.00
26	6.10	10.00	11.00	11.50	68.00	60.10	40.00
27	7.20	12.00	10.50	12.00	67.00	57.50	45.00
28	7.60	12.00	11.00	12.00	68.00	58.00	37.00

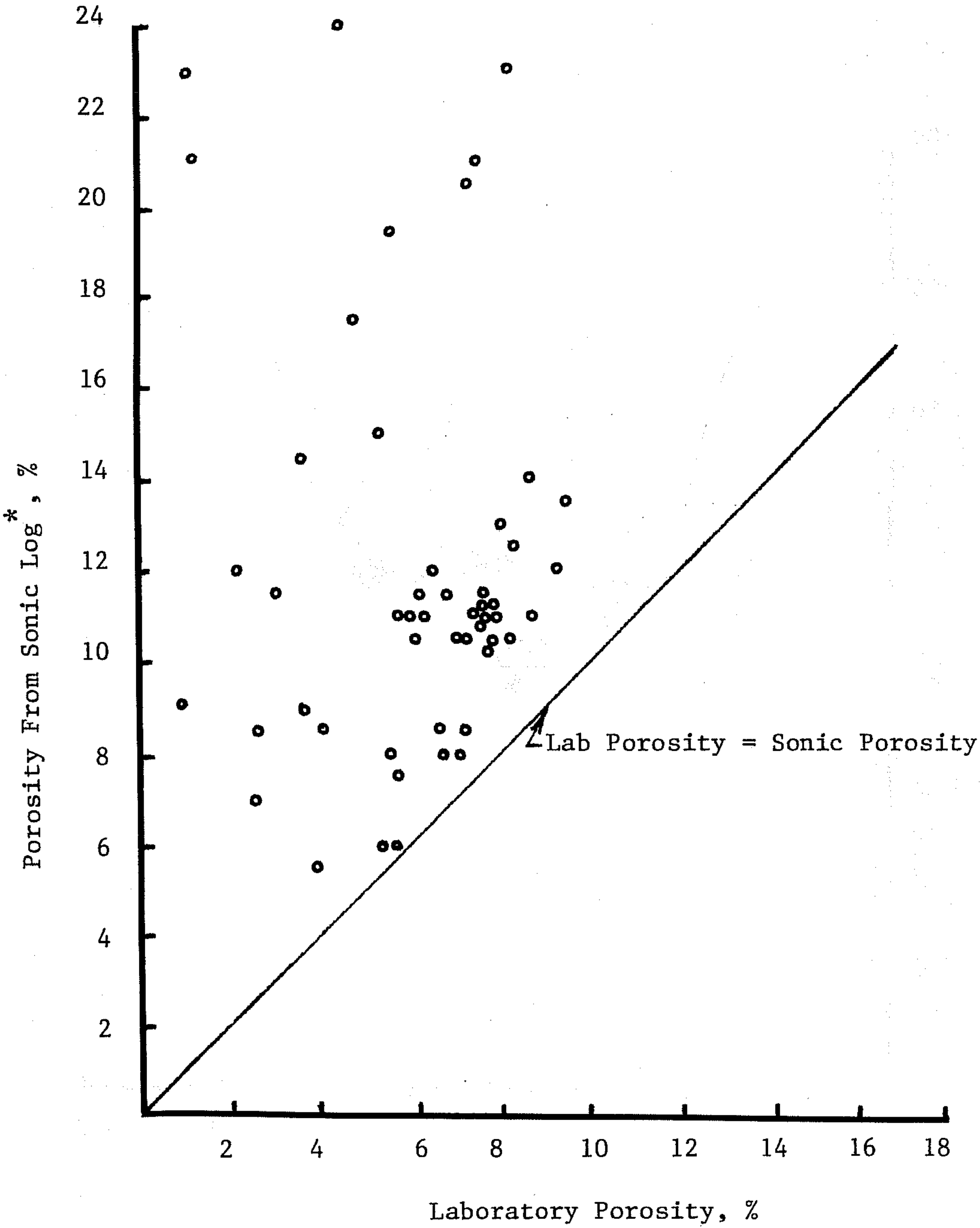
TABLE 7 (continued)

Sample[1]	Lab Porosity %	Density[2] Porosity %	Sonic[3] Porosity %	Neutron Porosity %	Log Travel-Times micsec/ft	Calculated Matrix Travel-Times micsec/ft	Gamma Ray
29	7.90	10.50	10.50	12.00	67.00	56.50	25.00
30	7.70	11.00	11.00	13.00	68.00	57.90	37.00
31	7.70	11.50	11.00	14.00	68.50	57.90	52.00
32	6.30	7.50	11.50	12.00	68.50	60.40	53.00
33	7.40	10.00	20.50	18.00	80.50	71.80	75.00
34	5.70	30.00	19.50	16.00	79.00	72.40	68.00
35	7.80	11.00	10.50	10.50	67.00	56.70	38.00
36	5.80	12.00	11.00	10.00	68.00	60.50	38.00
37	7.70	14.50	11.50	12.50	68.50	58.40	32.00
38	8.70	13.50	11.00	12.00	68.00	56.50	35.00
39	7.80	11.50	11.00	12.50	68.00	57.80	46.00
40	6.40	13.00	11.00	12.50	68.00	59.70	45.00
41	8.80	11.00	14.00	12.50	72.00	60.70	42.00
42	7.70	10.50	21.00	15.00	81.00	72.00	45.00
43	8.40	8.00	23.00	18.00	84.00	74.40	52.00
44	7.20	4.50	25.50	21.00	87.50	79.60	122.00
45	6.80	30.00	30.00	19.50	102.00	95.60	105.00
46	4.60	30.00	24.00	22.00	85.50	80.50	105.00
47.	1.00	5.50	9.00	11.00	65.00	63.70	68.00
48	2.60	7.00	7.00	18.00	62.00	58.60	53.00
49	5.80	6.50	7.50	16.50	63.00	55.20	47.00
50	5.60	5.50	8.00	19.00	63.50	56.10	53.00
51	2.70	15.00	8.50	26.00	64.20	60.70	82.00
52	2.20	30.00	12.00	25.00	69.00	66.30	135.00
53	8.10	10.00	13.50	10.00	71.00	60.60	53.00
54	6.60	13.00	12.00	9.50	69.00	60.50	50.00

1 Sample numbers correspond to the sample numbers of Table 4

2 Calculated using matrix density equal to 2.68 gm/cc

3 Calculated using matrix travel-time equal to 52.6 microseconds per foot



*Calculated using matrix travel-time of 52.6 micsec/ft.

Figure 11.

Porosity From Sonic Log
vs Laboratory Derived Porosity
River Bend Unit 11-17F

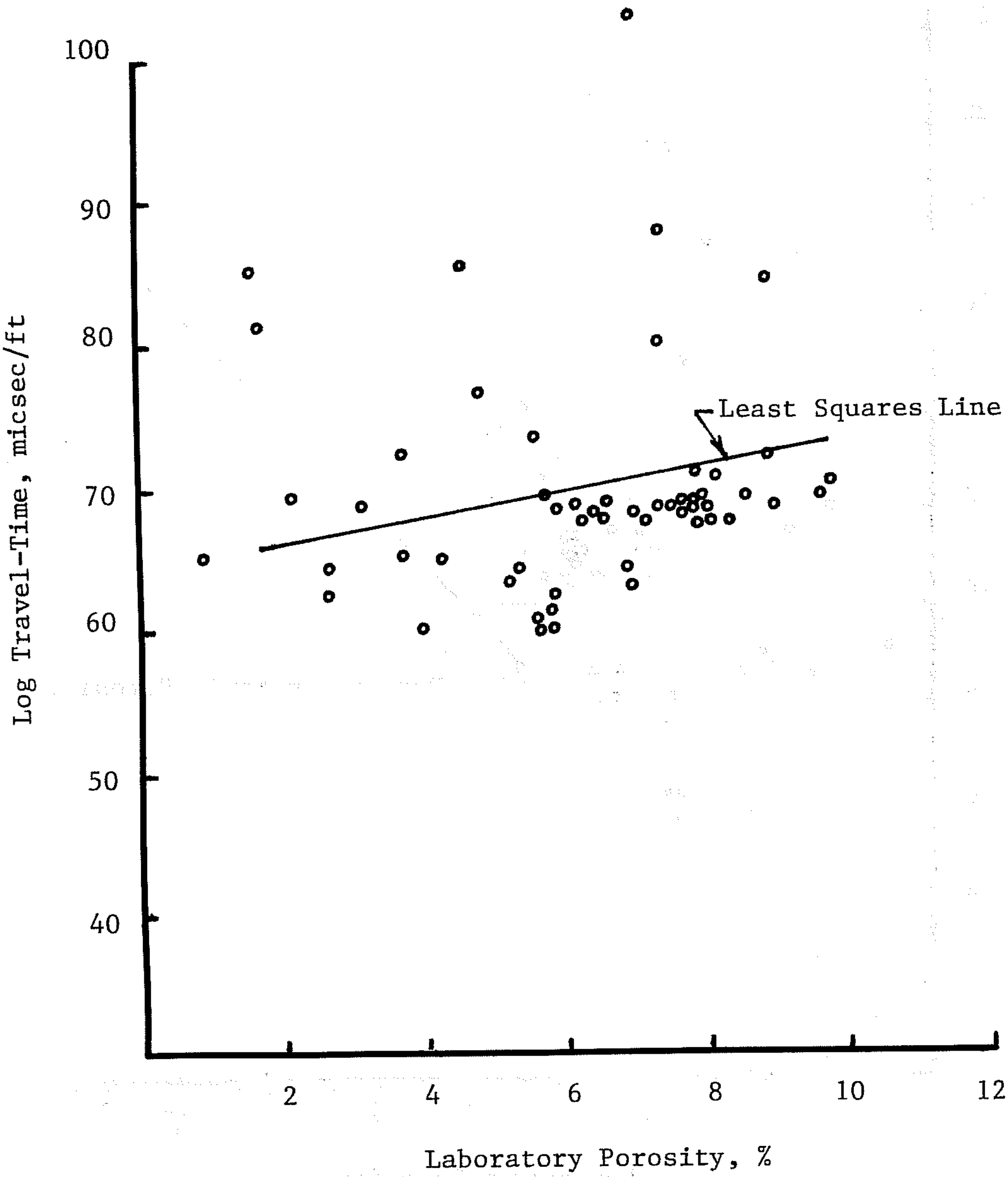


Figure 12.

Sonic Log Travel-Times
River Bend Unit 11-17F

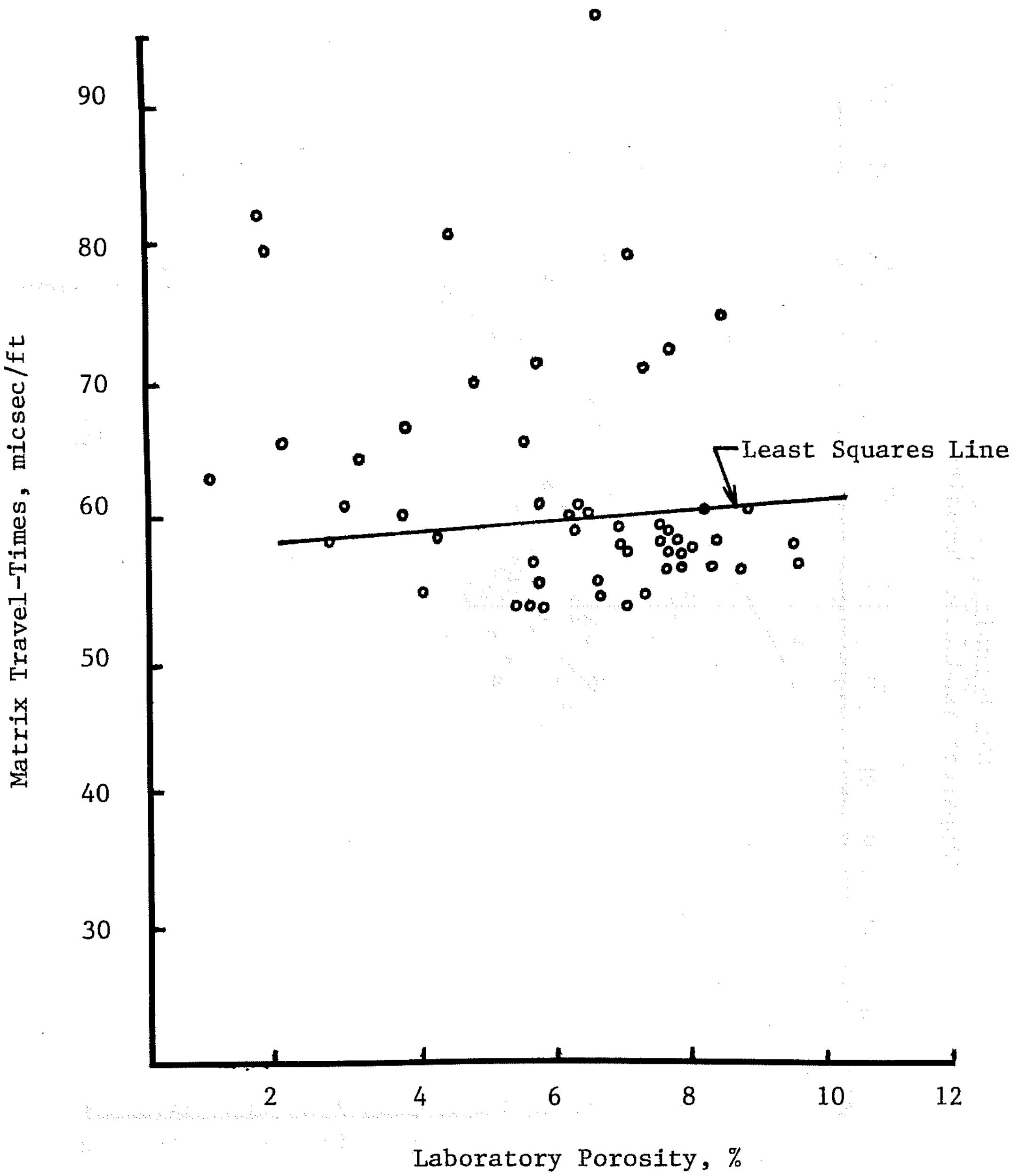


Figure 13.

Calculated Matrix Travel-Times
River Bend Unit 11-17F

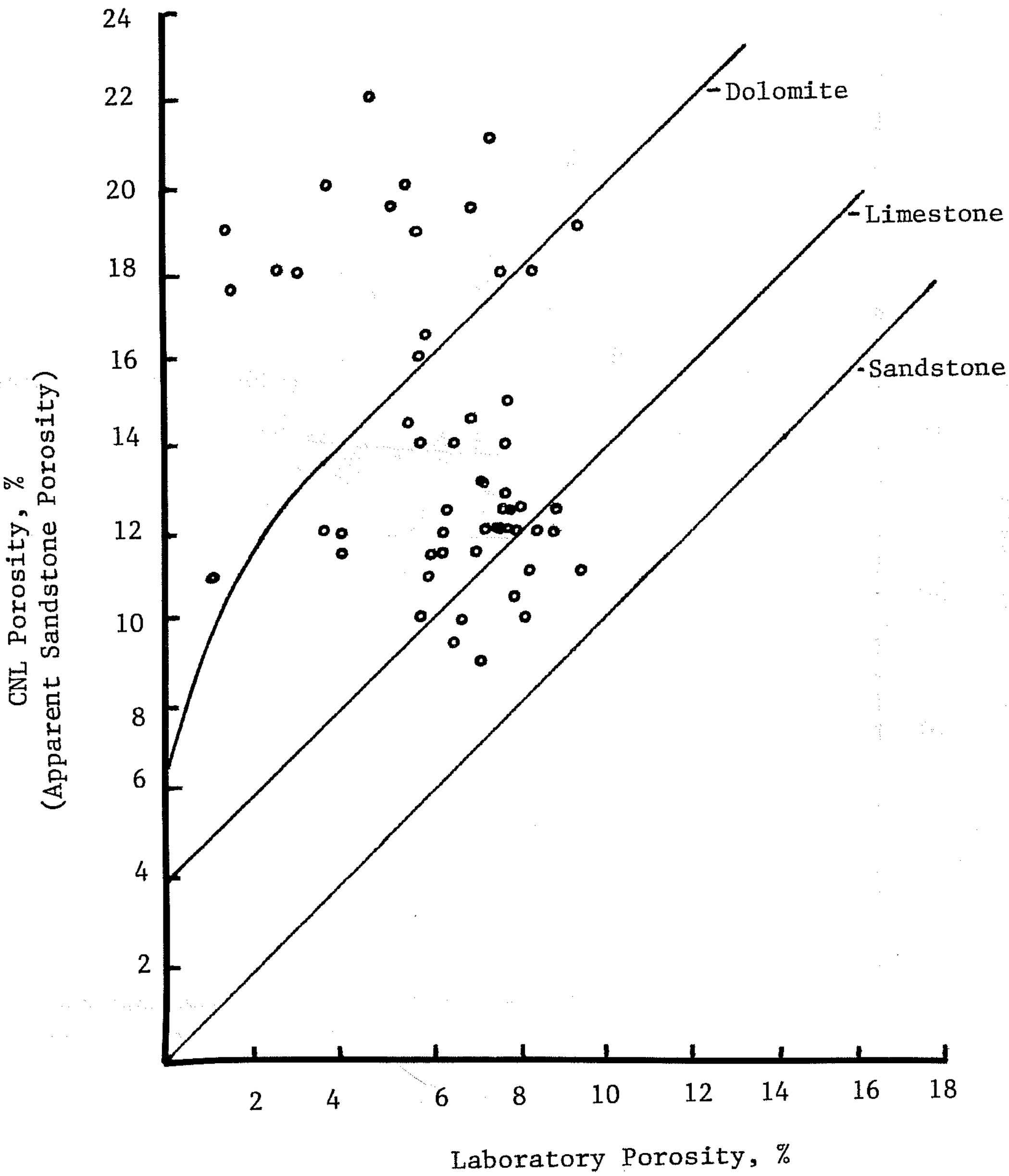


Figure 14.

Neutron Log Porosity vs
Laboratory Derived Porosity
River Bend Unit 11-17F

cutoff. The samples with a gamma ray reading of less than 45 API units have been designated "clean sands". Tables 8 and 9 contain the samples that are considered to be clean sands. Included in the tables are values for depth, laboratory measured porosity, calculated bulk density, log bulk density, log travel-time, calculated matrix travel-time and neutron porosity.

Calculated bulk densities have been plotted against laboratory porosities in Figure 15 for the Natural Buttes 21 and River Bend Unit wells. Figure 15 is very similar to Figures 3 and 5. Lower porosity samples tend to have matrix densities that approach 2.65 gm/cc. The scatter of the data also indicated that the density log cannot be effectively evaluated using a constant matrix density.

Log travel-times and calculated matrix times are plotted in Figures 16 and 17. Calculated matrix travel-times tend to decrease with increasing porosity. The higher porosity samples have matrix travel-times that approach 55.6 microseconds/ft.

Neutron log porosities are plotted in Figure 18. Most of the samples tend to fall between the limestone and dolomite composition lines.

Examination of clean, non-shaly data supports the observations that matrix densities and matrix travel-times are variable for these formations. Higher porosity samples tend to the same density and travel-time as sandstone. Based on these observations, the neutron log should also correctly evaluate higher porosity zones when calibrated for a sandstone matrix. As Figure 18 indicates, however, this trend is not readily apparent.

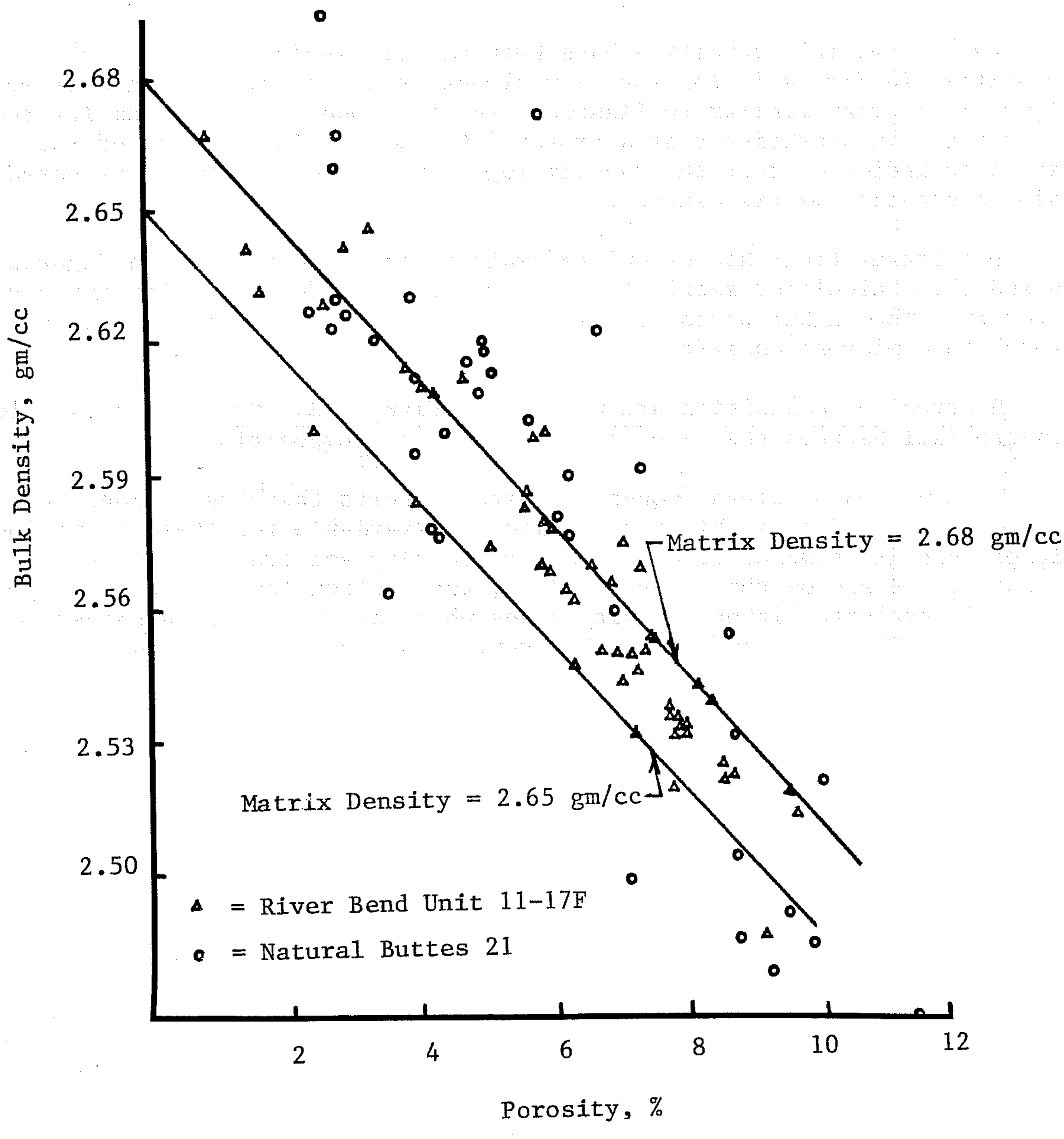


Figure 15.

Laboratory Derived Bulk Density
vs Laboratory Derived Porosity
Uinta Basin Wells

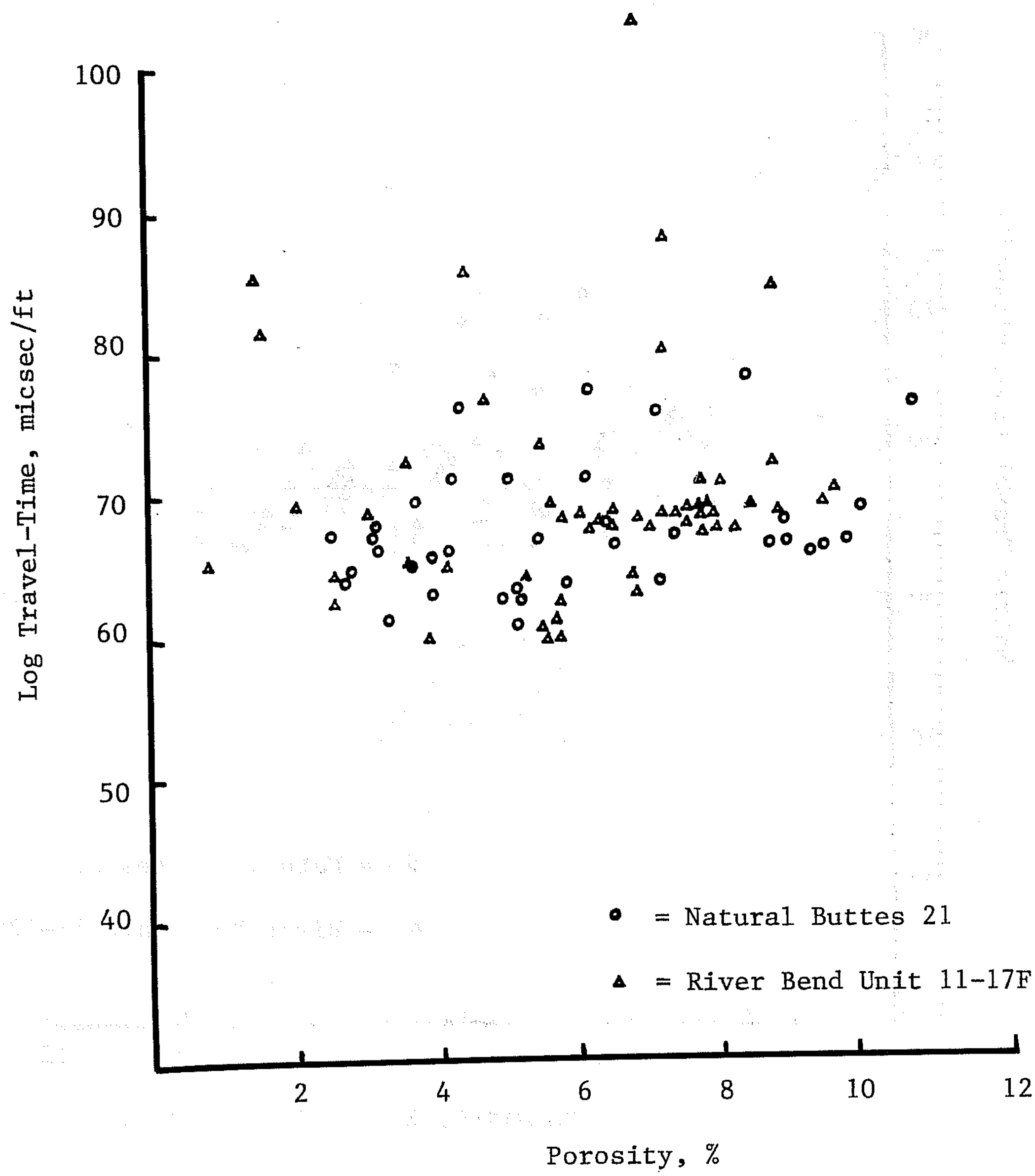


Figure 16.

Log Travel-Time vs
Laboratory Derived Porosity
Uinta Basin Wells

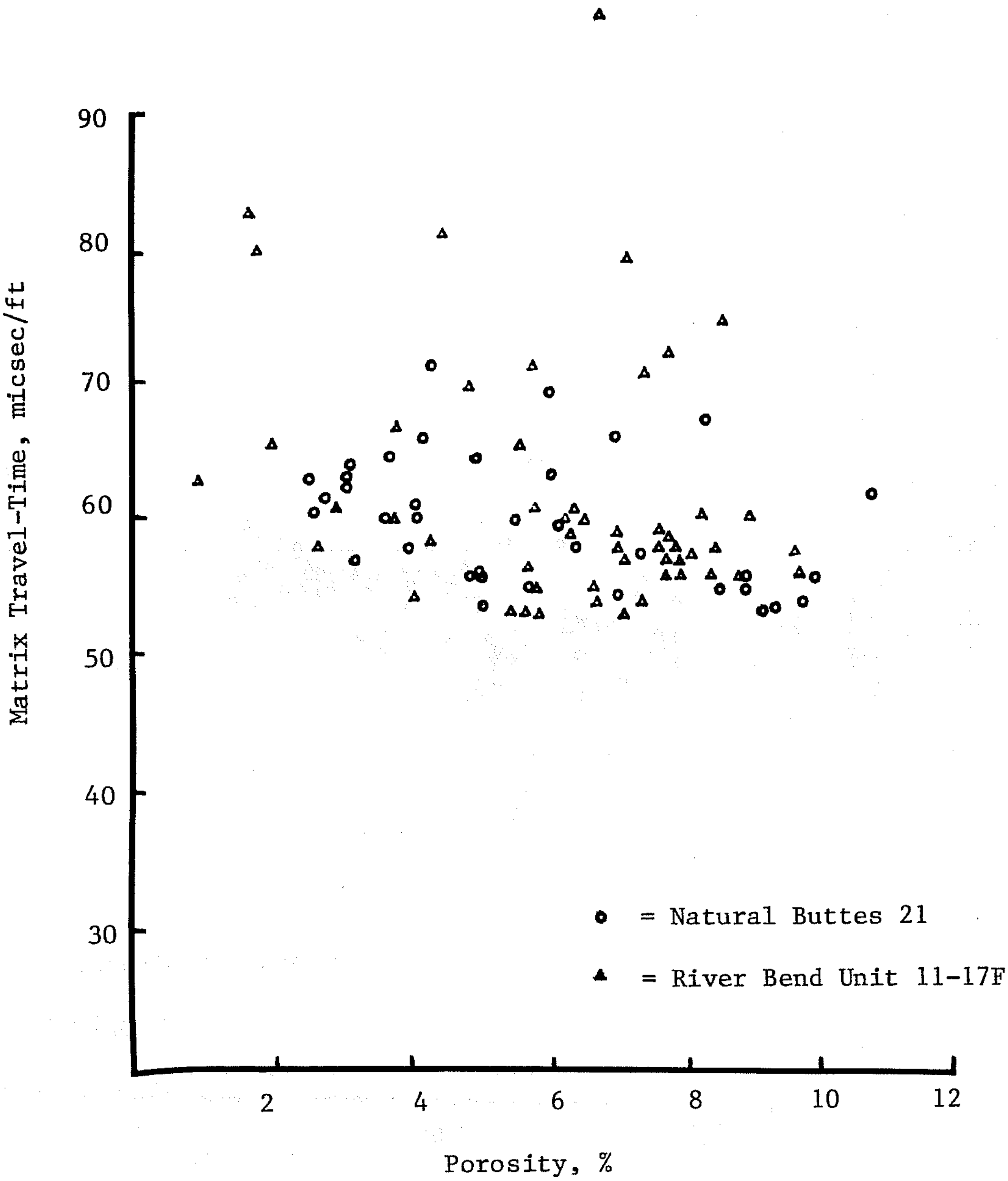


Figure 17.

Matrix Travel-Time vs
Laboratory Derived Porosity
Uinta Basin Wells

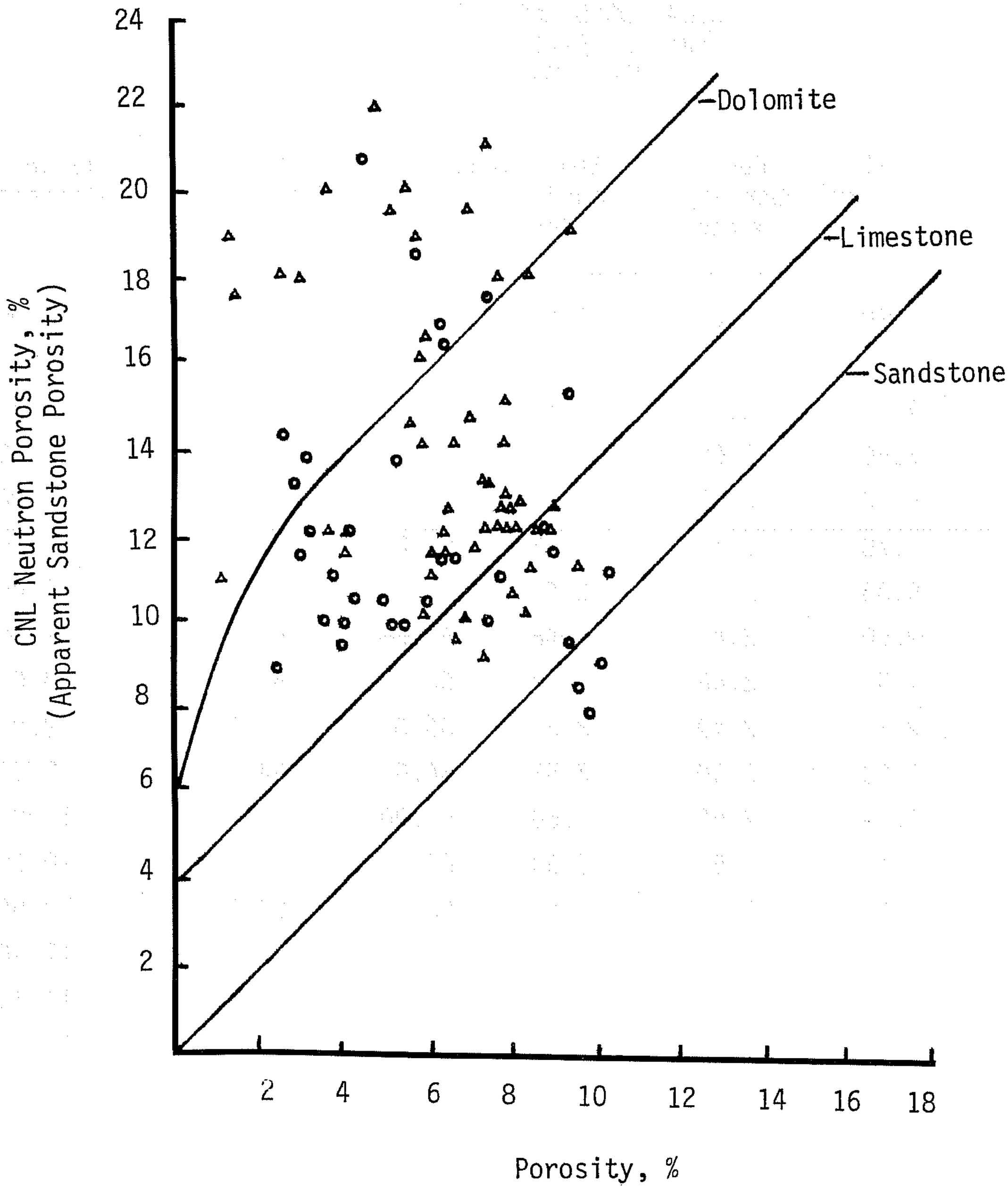


Figure 18.

Neutron Log Porosity vs
Laboratory Derived Porosity
Uinta Basin Wells

TABLE 8

CLEAN SAND ANALYSIS
Natural Buttes 21
Uinta Basin

Sample	Depth ft	Lab Porosity %	Bulk Density[1] gm/cc	Bulk Density[2] gm/cc	Log Travel-Times[3] micsec/ft	Matrix Travel-Times[4] micsec/ft	Neutron Porosity[5] %
1	7423	5.20	2.61	2.62	61.00	55.90	10.00
2	7424	5.90	2.66	2.67	63.00	55.10	10.00
3	7426	6.60	2.62	2.60	66.50	57.80	10.50
4	7427	7.50	2.59	2.54	67.00	57.10	10.50
5	8425	4.10	2.57	2.55	63.00	57.60	9.00
6	8426	3.70	2.56	2.53	65.00	60.20	10.00
7	8434	9.80	2.48	2.48	67.00	53.70	11.00
8	8436	9.00	2.48	2.48	67.00	54.90	8.00
9	8437	9.50	2.48	2.48	66.50	53.60	9.00
10	8438	9.30	2.49	2.50	66.00	53.30	9.00
11	8439	7.20	2.50	2.51	64.00	54.30	8.50
12	8483	2.60	2.62	2.60	67.00	63.70	11.00
13	8510	4.10	2.58	2.50	67.00	61.80	10.00
14	8512	4.30	2.57	2.46	66.50	60.90	10.50
15	8513	3.80	2.62	2.48	68.50	63.70	11.00
16	8514	6.40	2.57	2.46	68.50	60.20	11.50
17	8515	10.00	2.51	2.45	67.00	53.40	11.00

1 Bulk density measured in Laboratory in gm/cc.

2 Density log measured in gm/cc.

3 Sonic log measured in microseconds/ft.

4 Matrix travel-time calculated using laboratory porosity and log travel-time.

5 Neutron log reading.

TABLE 9

CLEAN SAND ANALYSIS
River Bend Unit 11 - 17 F
Uinta Basin

Sample	Depth ft	Lab Porosity %	Bulk Density[1] gm/cc	Bulk Density[2] gm/cc	Log Travel-Times[3] micsec/ft	Travel-Times[4] micsec/ft	Neutron Porosity[5] %
1	7286	7.30	2.55	2.57	64.20	54.40	13.00
2	7287	7.20	2.54	2.55	63.50	53.80	14.50
3	7288	6.70	2.56	2.57	64.20	55.20	14.00
4	8231	8.40	2.53	2.51	69.70	58.80	11.00
5	8232	7.20	2.55	2.55	67.00	57.50	9.00
6	8233	6.80	2.57	2.62	63.50	54.30	10.00
7	8238	5.50	2.57	2.59	61.00	53.60	14.50
8	8248	3.70	2.61	2.62	65.00	60.20	12.00
9	8286	7.50	1.53	2.54	68.00	58.20	12.00
10	8289	6.20	2.54	2.57	67.00	58.90	11.50
11	8291	6.10	2.56	2.55	68.00	60.10	11.50
12	8292	7.20	2.53	2.56	67.00	57.50	12.00
13	8293	7.60	2.54	2.57	68.00	58.00	12.00
14	8294	7.90	2.58	2.54	67.00	56.50	12.00
15	8395	7.70	2.53	2.54	68.00	57.90	13.00
16	8355	7.80	2.53	2.61	67.00	56.70	10.50
17	8356	5.80	2.57	2.57	68.00	60.50	10.00
18	8357	7.70	2.52	2.53	68.50	58.40	12.50
19	8359	8.70	2.52	2.53	68.00	56.50	12.00
20	8360	7.80	2.53	2.55	68.00	57.80	12.50
21	8361	6.40	2.57	2.55	68.00	59.70	12.50
22	8362	8.80	2.52	2.54	72.00	60.70	12.50
23	8363	7.70	2.54	2.55	81.00	72.00	15.00
24	8449	5.80	2.58	2.61	63.00	55.20	16.50

1 Bulk density measured in Laboratory in gm/cc.
2 Density log measured in gm/cc.
3 Sonic log measured in microseconds/ft.
4 Matrix travel-time calculated using laboratory porosity and log travel-time.
5 Neutron log reading.

DENSITY LOG CALIBRATION CURVE

The results of the core and log analyses from the Uinta Basin indicated that the formations tend to have a variable matrix density. Since the density log calculates porosity using a constant matrix density, another method is needed to correctly evaluate the density log. The bulk density versus porosity plot for the Natural Buttes 21 (Figure 19, which is the same as Figure 3 without the constant matrix density lines), has been used as a density log "calibration curve". The calibration curve is intended to convert log bulk densities to true porosities. Since the line in Figure 19 is the best fitting line through the data, use of it should provide more accurate answers than a constant matrix density.

Seven clean sands from the Natural Buttes 21 have been evaluated using the calibration curve. The porosities obtained from the calibration curve have been compared to the porosities calculated by the density, sonic, and neutron logs. These values are listed in Table 10. "Calibration curve" porosities were calculated by obtaining the average bulk density for each sand and reading the corresponding porosity from Figure 19.

Examination of Table 10 will highlight the difference between the porosities calculated in the conventional manner and porosities calculated using the calibration curve. Sonic log porosities, calculated with a matrix travel-time of 52.6 microseconds/ft, and neutron log porosities, calculated for a sandstone matrix, are considerably higher than those calculated with the calibration curve. Density log porosities are closest to those calculated with the calibration curve.

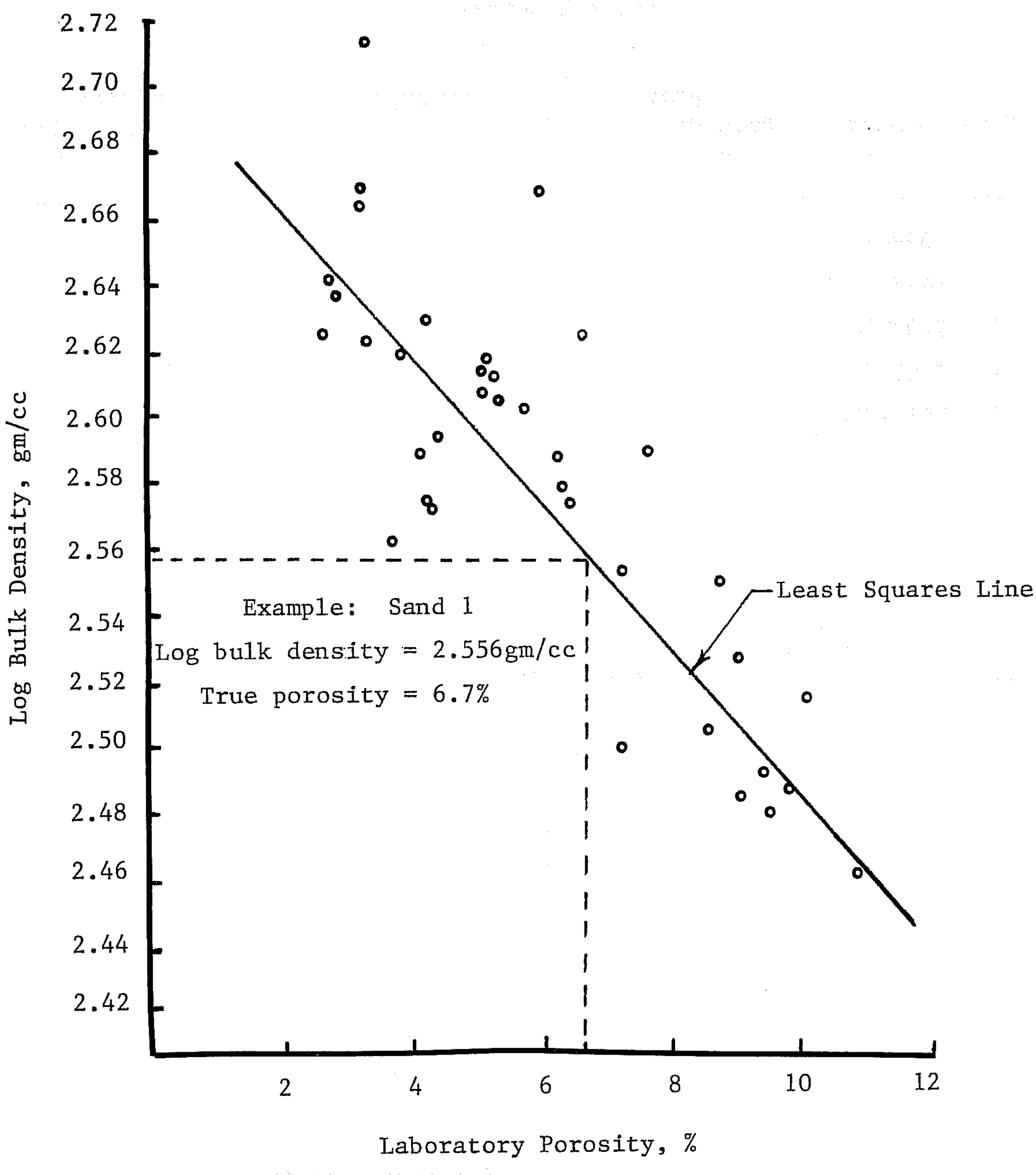


Figure 19.

Laboratory Derived Bulk Density
vs Laboratory Derived Porosity
Natural Buttes 21

TABLE 10

LOG ANALYSIS FOR CLEAN SANDS
Natural Buttes 21

Sand	Depth ft	Average Bulk Density gm/cc	Average[1] Corrected Porosity %	Average[1] Density Porosity %
1	4399-4411	2.556	6.70	7.40
2	6477-6490	2.518	8.60	9.60
3	7408-7417	2.613	4.10	3.90
4	7507-7514	2.596	4.90	5.00
5	7553-7565	2.530	7.90	8.90
6	8413-8473	2.523	8.20	9.30
7	8491-8526	2.518	8.60	9.60

Sand	Average[2] Sonic Porosity %	Average Neutron Porosity %
1	11.40	15.20
2	13.50	14.30
3	11.80	12.70
4	11.20	10.70
5	12.30	11.20
6	11.70	10.30
7	12.00	10.40

1 Calculated using the calibration cureve in Figure 1
2 Calculated using the matrix travel-time of 52.6 microseconds/ft.

CORE ANALYSIS - GREATER GREEN RIVER BASIN

Measurements have been made on the Upper Cretaceous Mesaverde from cores taken from the Rainbow Resources No. 1-3 Federal and the Pacific Transmission Supply 24-19 Federal wells located in Sweetwater County and Sublette County, Wyoming, respectively. Both cores were analyzed by Core Laboratories. Porosity, permeability, matrix density and fluid saturations have been measured.

Table 11 lists the data collected for the Rainbow Resources No.1-3 Federal. Figure 20 is a plot of permeability versus porosity. Figure 21 is a plot of calculated bulk density versus measured porosity. Although the No. 1-3 Federal is a producing gas well, water saturation was assumed to be 100% for the bulk densities calculated in Figure 21. This assumption was made so that the general trend of matrix density with porosity could be observed. As the least squares line indicates, higher porosity samples have matrix densities that approach 2.65 gm/cc.

Bulk densities have been calculated with the gas saturation taken into account. These bulk densities are plotted in Figure 22. A least squares line has been drawn through the data. These bulk densities are representative of the densities that would be measured by the density tool. The least squares line could be used as a calibration tool in the manner previously described.

Table 12 lists the data collected for the Pacific Transmission Supply 24-19 Federal. Figure 23 is a plot of permeability versus porosity. Figure 24 is a plot of calculated bulk density versus porosity. Water saturation is assumed to be 100%. A least squares line though the data indicates that the higher porosity samples tend to have matrix densities that approach 2.71 gm/cc. This is substantially different from the No.1-3 Federal well, which had matrix densities of 2.65 gm/cc for the higher porosity samples. The Mesaverde is encountered at a depth of 5100 feet in the 24-19 Federal and at 12,400 feet depth in the No. 1-3 Federal. The difference in matrix densities is probably due to pressure and temperature differences associated with these depths, which would control the solution and precipitation of the carbonate cement.

Bulk densities have also been calculated with the gas saturations taken into account. These are plotted in Figure 25.

TABLE 11

CORE DATA
Rainbow Resources, Inc.
No. 1-3 Federal
Sec. 3, T26N, R103W
Sweetwater Co., Wyoming

Sample	Depth ft	Water Saturation %	Porosity %	Matrix Density gm/cc	Permeability to air md
1	12398	41.50	11.00	2.68	3.950
2	12399	33.50	8.90	2.66	0.166
3	12400	35.70	9.60	2.67	0.102
4	12406	34.10	10.00	2.66	1.170
5	12407	41.20	10.10	2.65	4.950
6	12408	48.60	11.10	2.66	11.000
7	12409	49.20	10.00	2.66	32.000
8	12410	37.60	9.60	2.67	26.000
9	12411	19.20	9.80	2.68	0.240
10	12412	26.00	9.00	2.66	0.289
11	12413	36.40	9.00	2.65	0.272
12	12414	28.80	10.70	2.65	0.923
13	12415	24.90	10.70	2.68	0.083
14	12416	42.10	11.00	2.65	0.252
15	12417	34.90	9.60	2.65	0.452
16	12418	35.00	10.10	2.64	0.638
17	12419	44.90	9.40	2.67	0.039
18	12420	53.00	10.00	2.67	0.153
19	12421	45.10	7.90	2.59	0.128
20	12422	61.30	5.40	2.67	0.182
21	12423	54.00	8.30	2.66	0.055
22	12424	33.10	11.80	2.68	0.246
23	12425	34.20	11.30	2.64	0.087
24	12426	44.30	9.50	2.66	0.068
25	12427	35.70	9.50	2.66	0.072
26	12428	48.90	8.20	2.65	0.108
27	12429	20.50	10.60	2.66	0.365
28	12430	33.20	10.40	2.65	0.180
29	12431	56.10	6.40	2.70	0.065
30	12432	43.60	7.80	2.65	0.844
31	12433	49.90	10.60	2.65	0.055
32	12434	31.80	9.80	2.68	0.020
33	12435	46.20	8.10	2.63	0.211
34	12436	74.50	8.80	2.69	0.419
35	12440	23.50	11.40	2.68	0.683
36	12441	33.10	10.20	2.65	0.654
37	12442	40.70	9.70	2.65	0.054
38	12443	20.50	9.80	2.64	1.280

TABLE 11 (continued)

Sample	Depth ft	Water Saturation %	Porosity %	Matrix Density gm/cc	Permeability to air md
39	12444	29.60	10.00	2.67	0.878
40	12445	31.60	9.50	2.65	0.869
41	12446	50.60	9.40	2.64	1.980
42	12451	18.90	8.70	2.64	0.478
43	12452	39.40	9.30	2.69	0.071
44	12455	67.40	8.90	2.68	0.453
45	12456	35.20	10.70	2.68	5.660
46	12457	25.10	9.60	2.68	0.682
47	12458	30.00	9.60	2.67	52.000
48	12459	43.40	14.10	2.66	82.000
49	12460	56.50	11.20	2.70	108.000
50	12461	45.20	10.00	2.67	0.129
51	12462	51.50	10.60	2.69	53.000
52	12463	42.90	9.90	2.67	73.000
53	12469	66.90	4.60	2.71	16.000
54	12470	30.90	8.90	2.68	0.219
55	12471	49.30	7.00	2.68	0.071
56	12472	52.70	8.60	2.68	0.292
57	12473	34.30	9.70	2.68	0.031
58	12474	43.10	6.70	2.66	0.055
59	12475	46.00	8.70	2.66	0.232
60	12483	39.60	6.20	2.64	0.054
61	12484	41.40	8.90	2.64	0.091
62	12485	37.40	10.80	2.65	0.964
63	12486	39.40	7.90	2.73	0.071
64	12487	29.80	7.70	2.68	0.137
65	12490	28.40	8.60	2.76	0.474
66	12491	47.50	9.00	2.64	0.852
67	12492	38.60	11.60	2.64	0.796
68	12493	17.10	11.80	2.65	22.000
69	12494	39.90	11.00	2.67	0.847
70	12495	30.00	11.40	2.68	5.410
71	12496	63.10	10.40	2.76	83.000
72	12633	45.10	10.10	2.66	1.090
73	12634	43.90	10.90	2.63	0.862
74	12635	46.30	10.00	2.67	0.205
75	12636	56.30	10.20	2.66	1.170
76	12637	16.10	10.80	2.67	0.223
77	12638	47.80	10.50	2.66	0.234
78	12639	17.60	10.10	2.65	0.995
79	12640	40.00	8.50	2.66	0.906
80	12641	72.50	13.90	2.74	26.000
81	12642	25.00	6.40	2.65	0.020
82	12643	23.90	8.20	2.67	0.020
83	12644	59.80	7.40	2.62	0.055
84	12645	17.30	6.10	2.63	0.036
85	12646	35.20	8.80	2.66	0.085
86	12647	75.30	8.90	2.66	0.086

TABLE 11 (continued)

Sample	Depth ft	Water Saturation %	Porosity %	Matrix Density gm/cc	Permeability to air md
87	12648	49.20	8.70	2.68	0.080
88	12649	41.20	7.40	2.64	0.164
89	12652	37.00	8.30	2.67	0.020
90	12653	57.90	9.80	2.65	0.128
91	12654	43.60	7.50	2.63	0.025
92	12655	45.50	5.60	2.67	0.024
93	12656	48.20	4.80	2.66	0.019
94	12657	74.80	2.80	2.66	0.011
95	12658	77.80	5.30	2.71	0.012
96	12659	53.10	7.20	2.63	0.018
97	12660	55.80	9.80	2.69	0.017
98	12661	40.00	8.40	2.65	0.018
99	12662	50.40	6.30	2.63	0.072
100	12666	40.60	8.70	2.68	0.081
101	12667	31.30	10.40	2.68	0.033
102	12688	60.70	4.20	2.66	0.021
103	12689	96.30	3.90	2.66	0.023
104	12690	78.30	10.70	2.68	0.021
105	12691	66.10	5.20	2.68	0.019
106	12692	69.00	7.40	2.68	1.000
107	12693	53.90	9.60	2.68	94.000
108	12694	52.40	9.40	2.68	0.021
109	12695	65.10	8.50	2.67	0.143
110	12696	60.90	8.60	2.67	1.010
111	12697	47.00	9.30	2.68	0.376
112	12698	54.40	9.00	2.69	19.000
113	12699	45.00	10.30	2.69	0.109
114	12700	51.70	12.30	2.68	4.680
115	12701	42.00	10.70	2.68	1.490
116	12702	35.50	10.30	2.68	71.000
117	12703	26.50	17.20	2.68	1.030
118	12704	27.10	10.00	2.68	0.486
119	12705	40.60	10.30	2.68	1.530
120	12710	33.10	8.90	2.67	9.740
121	12711	36.60	9.20	2.68	0.267
122	12712	30.50	9.40	2.69	0.200
123	12713	46.10	10.90	2.67	0.817
124	12714	46.20	5.00	2.65	0.376
125	12719	15.10	0.30	2.69	0.300
126	12720	9.50	3.30	2.67	0.011
127	12721	61.20	0.50	2.75	0.021
128	12722	67.10	7.20	2.69	0.014
129	12723	67.30	4.40	2.70	0.022
130	12724	70.70	4.20	2.68	0.601
131	12725	20.10	6.10	2.69	0.022
132	12726	31.10	5.20	2.69	0.021
133	12727	23.30	5.30	2.61	0.020

TABLE 11 (continued)

Sample	Depth ft	Water Saturation %	Porosity %	Matrix Density gm/cc	Permeability to air md
134	12728	14.90	8.40	2.70	0.106
135	13419	96.40	7.10	2.77	0.033
136	13420	89.40	4.50	2.70	3.600
137	13421	88.90	5.10	2.73	0.082
138	13422	64.30	5.90	2.73	0.010
139	13423	90.90	6.60	2.73	0.010
140	13424	80.00	4.10	2.80	0.010
141	13425	79.40	9.40	2.72	0.059
142	13426	49.50	10.00	2.70	0.390
143	13427	54.30	11.00	2.71	0.206
144	13430	44.80	10.90	2.70	0.064
145	13431	44.10	11.20	2.70	4.950
146	13432	40.30	11.80	2.70	0.319
147	13433	45.00	11.90	2.71	0.972
148	13476	78.70	1.60	2.71	0.039
149	13487	89.60	3.10	2.71	0.010
150	13488	73.80	4.90	2.71	0.010

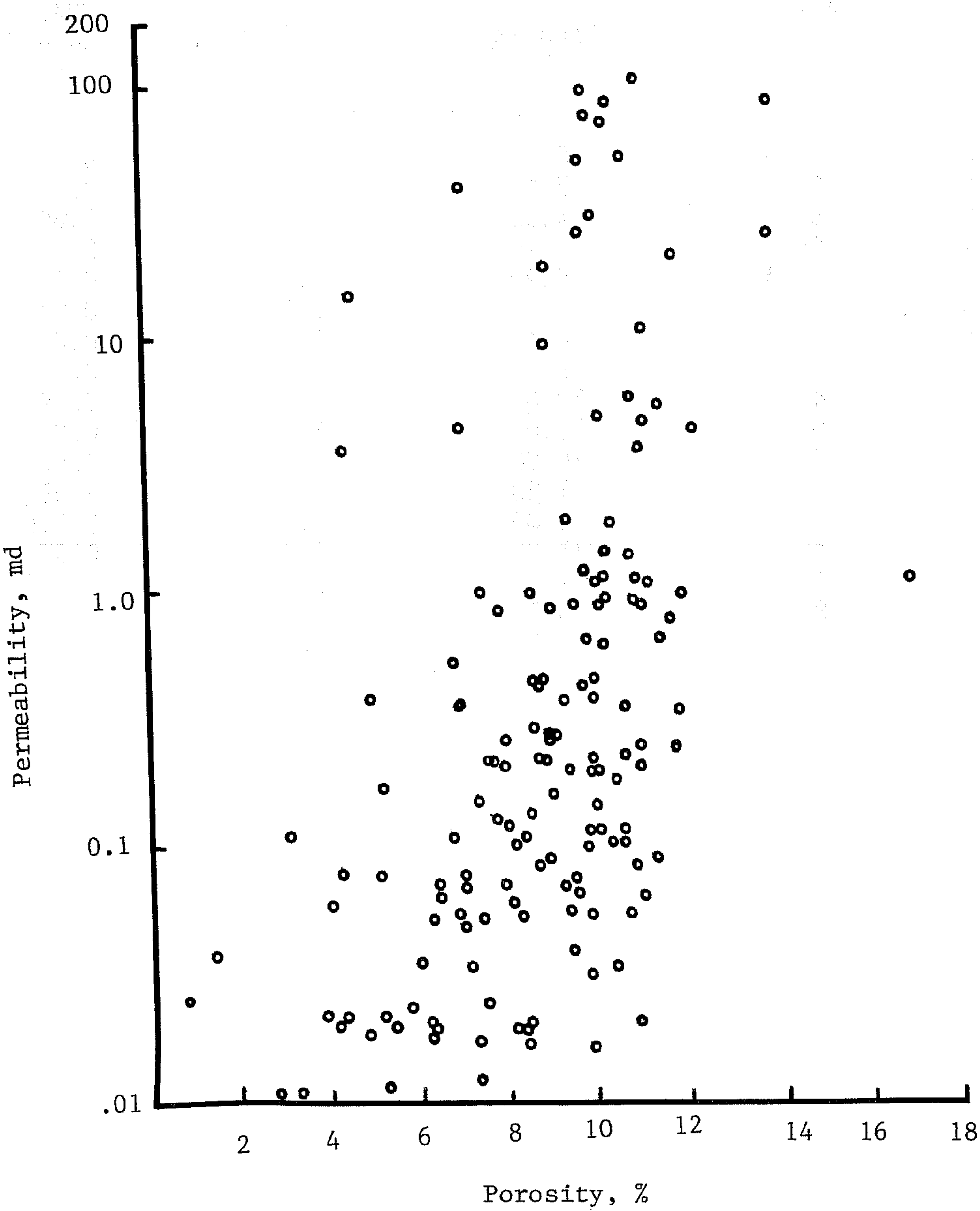


Figure 20.

Permeability vs Laboratory Derived Porosity
Rainbow Resources No. 1-3 Federal

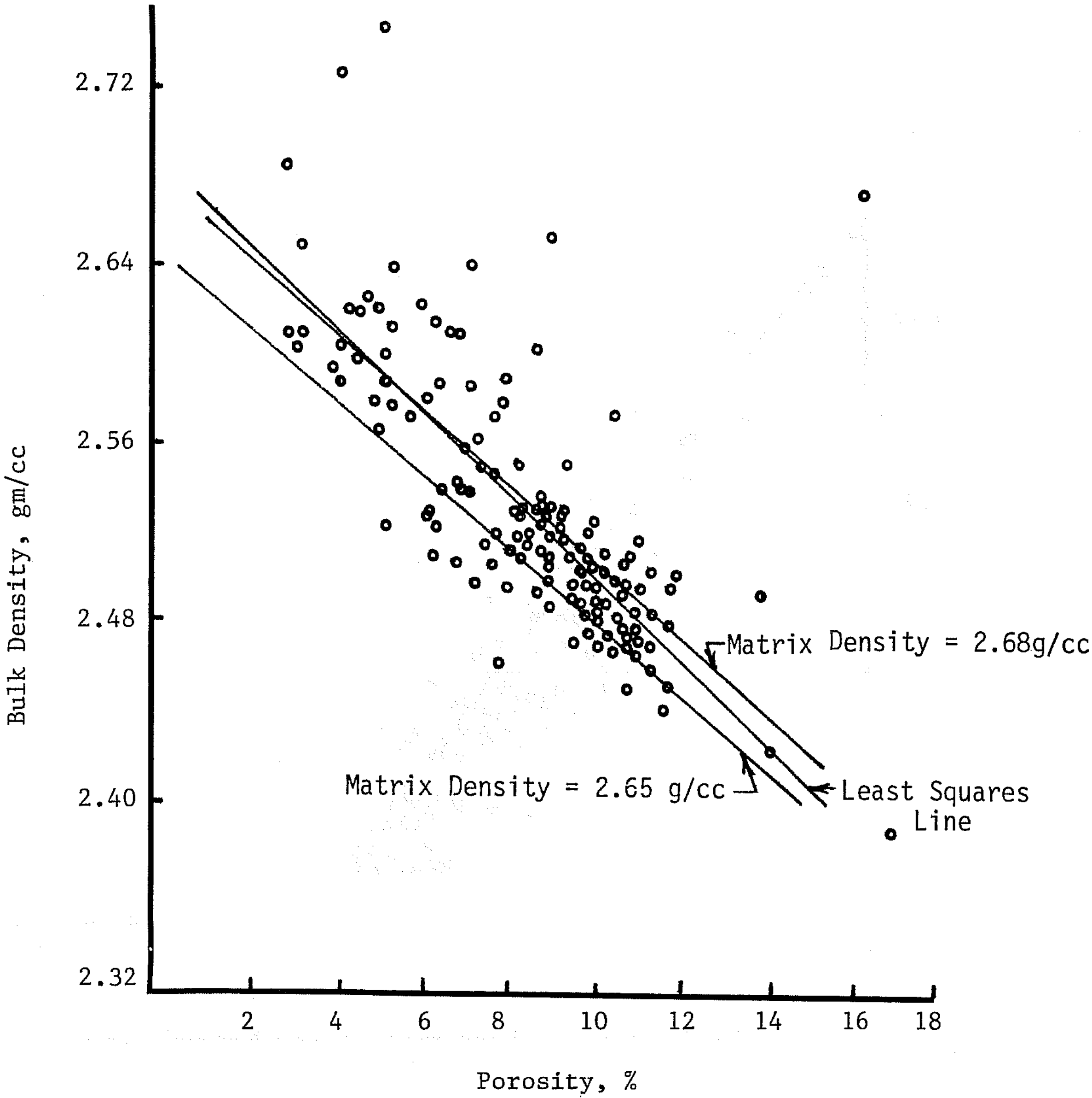


Figure 21.

Laboratory Derived Bulk Density
vs Laboratory Derived Porosity
Rainbow Resources No. 1-3 Federal
(Assumed Water Saturation = 100%)

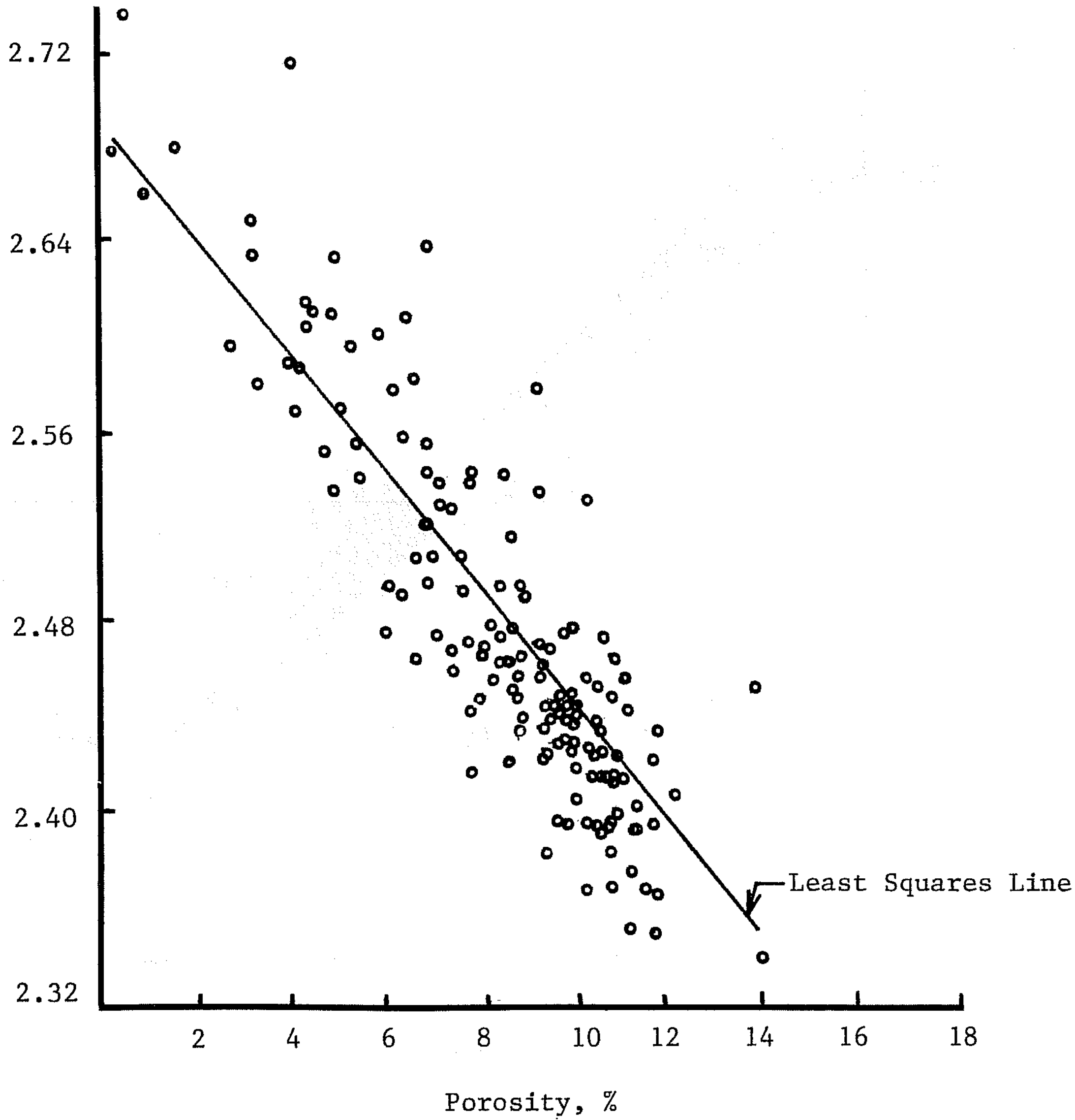


Figure 22.

Laboratory Derived Bulk Density
vs Laboratory Derived Porosity
Rainbow Resources No. 1-3 Federal
(Corrected for Gas Saturation)

TABLE 12

CORE DATA
Pacific Transmission Supply
Pts No. 24-19 Federal
Sublette Co., Wyoming

Sample	Depth ft	Water Saturation %	Porosity %	Matrix Density gm/cc	Permeability to air md
1	5116	51.30	3.70	2.63	0.05
2	6117	87.70	4.20	2.65	0.05
3	5118	85.00	3.80	2.62	0.05
4	5119	89.00	9.80	2.68	0.11
5	5120	78.20	11.60	2.68	0.08
6	5121	75.80	11.50	2.68	0.08
7	5160	74.80	4.30	2.68	0.58
8	5163	72.30	8.40	2.72	0.50
9	5166	84.00	7.80	2.70	0.33
10	5180	55.90	3.10	2.71	0.02
11	5181	51.30	5.80	2.72	0.06
12	5182	50.30	7.00	2.72	0.08
13	5192	83.60	4.70	2.65	3.90
14	5194	70.20	4.60	2.64	0.10
15	5195	75.40	6.00	2.68	0.12
16	5196	51.50	11.70	2.72	0.13
17	5197	61.20	12.70	2.71	0.19
18	5199	35.10	14.60	2.71	0.78
19	5200	55.80	13.40	2.67	0.56
20	5201	49.50	14.50	2.70	0.63
21	5202	50.70	13.40	2.71	0.27
22	5203	57.60	12.60	2.72	0.18
23	5204	47.40	12.40	2.72	0.28
24	5205	52.70	12.20	2.70	0.39
25	5206	53.20	14.30	2.70	1.10
26	5207	51.70	13.00	2.69	0.54
27	5214	57.20	13.60	2.72	0.48
28	5215	55.00	13.80	2.70	1.00
29	5216	57.60	14.30	2.71	0.96
30	5217	59.70	13.90	2.71	1.10
31	5218	59.00	14.20	2.70	1.10
32	5219	55.30	14.10	2.69	1.70
33	5220	50.40	14.70	2.70	2.20
34	5253	77.20	4.90	2.75	0.03
35	5264	66.50	3.90	2.63	0.08
36	5265	80.50	7.10	2.72	0.04
37	5266	83.20	8.20	2.71	0.05
38	5295	54.50	14.20	2.70	0.27
39	5296	51.70	13.30	2.72	0.51

TABLE 12 (continued)

Sample	Depth ft	Water Saturation %	Porosity %	Matrix Density gm/cc	Permeability to air md
40	5297	56.00	12.80	2.72	0.38
41	5298	54.20	13.00	2.70	0.35
42	5299	55.30	13.50	2.70	0.72
43	5300	48.10	13.40	2.69	1.00
44	5301	52.90	12.00	2.71	0.18
45	5302	48.50	12.00	2.69	0.18
46	5303	52.90	12.60	2.70	0.38
47	5304	52.60	13.30	2.69	1.00
48	5305	49.10	13.10	2.69	0.99
49	5306	48.70	13.30	2.70	1.40
50	5307	49.00	13.80	2.70	1.00
51	5308	51.50	13.70	2.71	0.74
52	5309	48.90	13.30	2.71	0.79
53	5310	52.60	13.50	2.71	1.10
54	5311	52.40	13.80	2.72	1.50
55	5312	54.60	13.70	2.70	1.80
56	5316	50.10	13.40	2.71	1.30
57	5317	49.40	14.10	2.71	1.30
58	5318	47.90	14.20	2.71	1.20
59	5319	55.20	14.50	2.71	1.50
60	5320	47.70	14.20	2.70	1.60
61	5321	50.30	14.20	2.71	1.50
62	5322	46.70	13.80	2.70	0.92

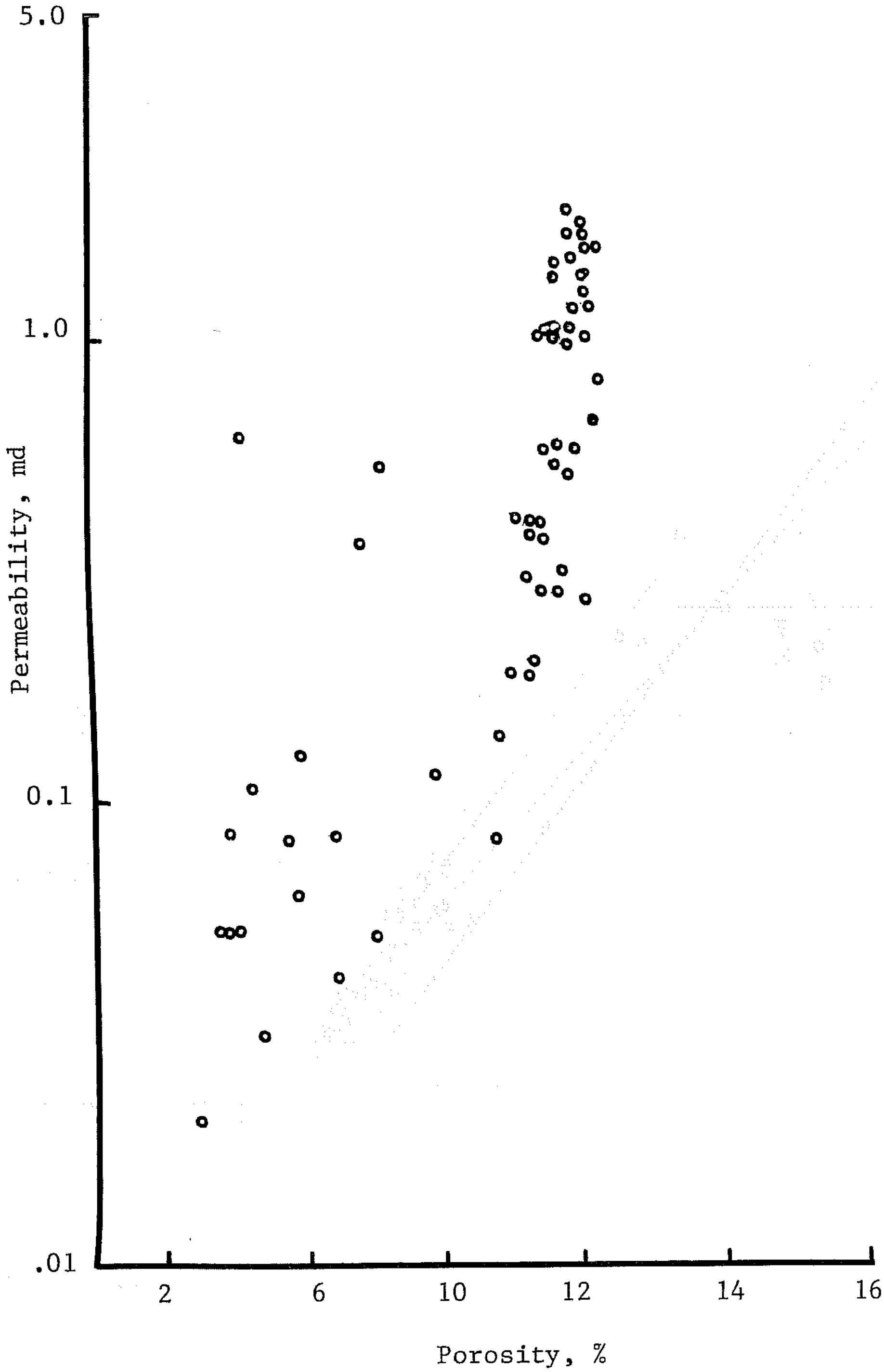


Figure 23.

Permeability vs Laboratory Derived Porosity
Pacific Transmission Supply 24-19 Federal

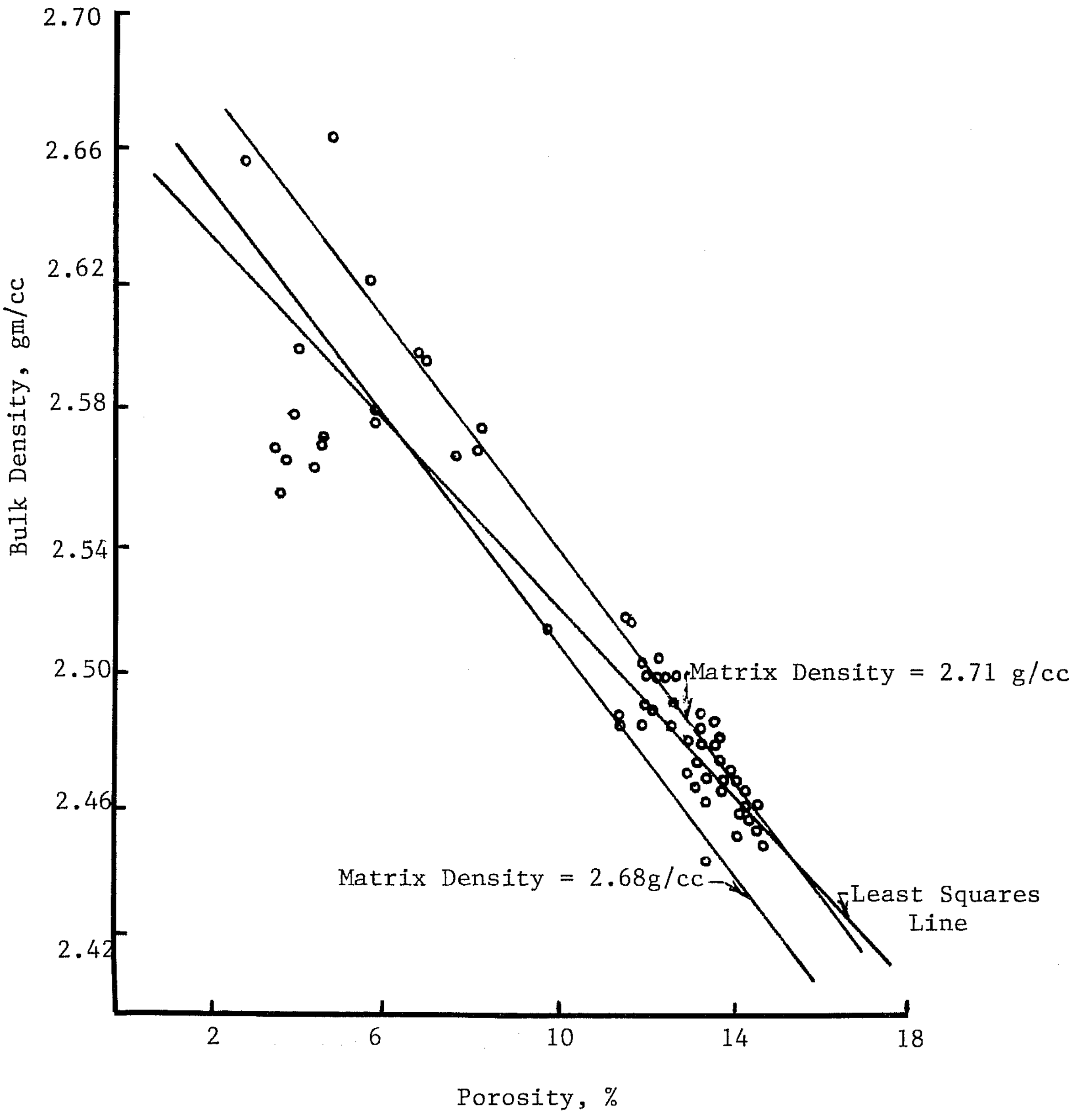


Figure 24.

Laboratory Derived Bulk Density
vs Laboratory Derived Porosity
Pacific Transmission Supply 24-19 Federal
(Assumed Water Saturation = 100%)

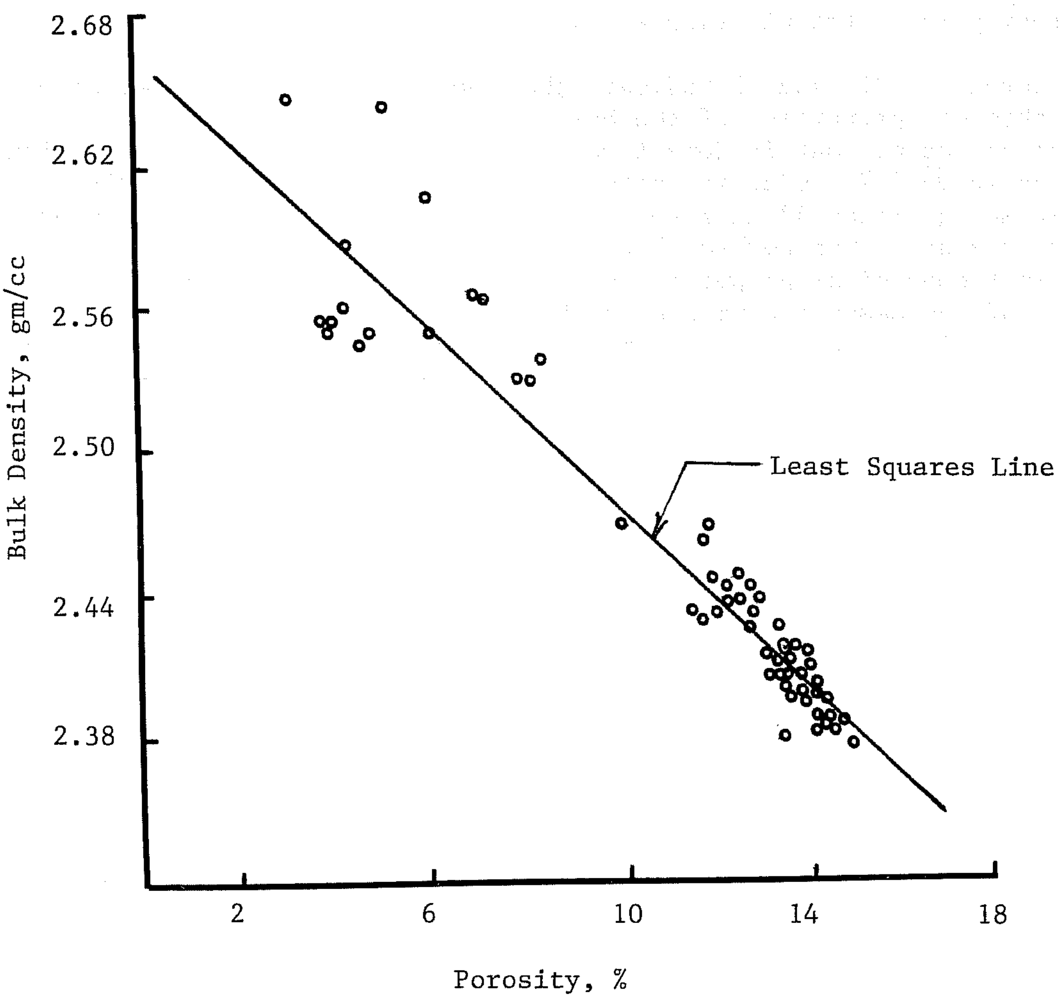


Figure 25.

Laboratory Derived Bulk Density
vs Laboratory Derived Porosity
Pacific Transmission Supply 24-19 Federal
(Corrected For Gas Saturation)

LOG ANALYSES - GREATER GREEN RIVER BASIN

Log analysis in the Greater Green River Basin has been limited to a clean sand analysis as described for the Uinta Basin. The values used in the clean sand analysis are listed in Tables 12, 13, and 14.

Bulk density and porosity for the two wells have been plotted in Figure 26. Bulk density has been corrected for gas saturation. Figure 27 is a plot of calculated matrix travel-time versus porosity. Neutron log porosity is plotted in Figure 28.

Figures 26, 27, and 28 indicate the significant changes that occur in the physical properties of the Mesaverde formation in the Greater Green River Basin. Matrix densities vary from 2.65 gm/cc in one section of the basin to 2.71 gm/cc in another section of the basin. Matrix travel-times approach 48 microseconds/ft in one area and 52 microseconds/ft in another areas. The neutron log is ineffective in both areas. The variations in the physical properties are probably related to subsurface location of the Mesaverde within the basin. Log analysis in deep, central basin wells will require log parameters that are substantially different from the parameters used in shallow Mesaverde wells.

TABLE 13

CLEAN SAND ANALYSIS
Rainbow Resources
No. 1-3 Federal
Greater Green River Basin

Sample	Depth ft	Lab Porosity %	Bulk Density[1] gm/cc	Bulk Density[2] gm/cc	Log Travel-Times[3] micsec/ft	Matrix Travel-Times[4] micsec/ft	Neutron Porosity[5] %
1	12398	11.00	2.43	2.43	65.00	49.60	10.50
2	12399	8.90	2.45	2.45	67.00	55.00	10.50
3	12400	9.60	2.44	2.44	67.00	54.00	11.00
4	12406	10.00	2.42	2.47	67.00	53.40	10.50
5	12407	10.10	2.42	2.45	68.00	54.40	10.50
6	12408	11.10	2.41	2.43	67.00	51.70	10.50
7	12409	10.00	2.44	2.43	67.00	53.40	11.00
8	12410	9.60	2.44	2.40	67.00	54.00	11.00
9	12411	9.80	2.43	2.42	68.00	54.80	11.00
10	12416	11.00	2.40	2.50	68.00	53.00	13.00
11	12417	9.60	2.42	2.51	68.00	55.10	13.50
12	12428	8.20	2.47	2.48	70.00	59.30	12.00
13	12429	10.60	2.39	2.52	70.00	55.80	12.00
14	12430	10.40	2.40	2.54	68.00	53.90	14.00
15	12431	6.40	2.56	2.50	68.00	59.70	12.00
16	12432	7.80	2.47	2.46	68.00	57.70	11.00
17	12433	10.60	2.42	2.44	68.00	53.60	10.00
18	12434	9.80	2.44	2.45	68.00	54.80	10.00
19	12435	8.10	2.45	2.43	67.00	56.20	11.00
20	12436	8.80	2.51	2.46	67.00	55.20	11.00
21	12440	11.40	2.40	2.45	67.00	51.30	11.00
22	12441	10.20	2.41	2.47	66.00	52.00	12.00
23	12442	9.70	2.43	2.49	66.00	52.70	12.00
24	12443	9.80	2.40	2.50	67.00	53.70	11.00
25	12452	9.30	2.47	2.47	68.00	55.50	11.50
26	12455	8.90	2.50	2.48	67.00	55.00	12.00
27	12461	10.00	2.44	2.57	67.00	53.40	10.00
28	12462	10.60	2.45	2.58	65.00	50.20	11.00
29	12463	9.90	2.44	2.62	66.00	52.40	15.50
30	12475	8.70	2.46	2.61	66.00	54.20	15.00
31	12483	6.20	2.50	2.50	71.00	63.20	13.50
32	12484	8.90	2.44	2.51	68.00	56.10	14.00
33	12485	10.80	2.40	2.48	66.00	51.10	15.50
34	12486	7.90	2.54	2.46	68.00	57.60	12.00
35	12487	7.70	2.49	2.43	68.00	57.90	10.00
36	12490	8.60	2.54	2.47	66.00	54.40	9.00
37	12636	10.20	2.44	2.54	66.00	52.00	12.00
38	12637	10.80	2.39	2.50	63.00	47.70	13.00
39	12638	10.50	2.43	2.46	65.00	50.40	10.00
40	12639	10.10	2.40	2.48	65.00	51.00	9.00

TABLE 13 (continued)

Sample	Depth ft	Lab Porosity %	Bulk Density[1] gm/cc	Bulk Density[2] gm/cc	Log Travel-Times[3] micsec/ft	Matrix Travel-Times[4] micsec/ft	Neutron Porosity[5] %
41	12640	8.50	2.46	2.42	65.00	53.40	10.00
42	12641	13.90	2.45	2.37	67.00	47.30	9.50
43	12642	6.40	2.49	2.42	62.00	53.30	9.00
44	12643	8.20	2.47	2.52	64.00	52.80	8.00
45	12644	7.40	2.47	2.49	63.00	52.90	10.00
46	12645	6.10	2.48	2.48	62.00	53.70	9.00
47	12652	8.30	2.47	2.53	65.00	53.70	12.00
48	12653	9.80	2.44	2.48	64.00	50.40	13.00
49	12654	7.50	2.46	2.55	65.00	54.90	11.00
50	12655	5.60	2.54	2.55	64.00	56.50	10.50
51	12657	2.80	2.60	2.54	64.00	60.30	10.00
52	12658	5.30	2.60	2.58	63.00	55.90	10.00
53	12659	7.20	2.47	2.54	64.00	54.30	10.00
54	12660	9.80	2.48	2.50	65.00	51.50	9.50
55	12661	8.40	2.46	2.58	65.00	53.60	9.00
56	12662	6.30	2.49	2.47	66.00	57.70	9.00
57	12666	8.70	2.48	2.46	65.00	53.10	9.50
58	12667	10.40	2.43	2.45	65.00	50.60	9.50
59	12688	4.20	2.57	2.55	66.00	60.60	10.00
60	12689	3.90	2.59	2.51	67.00	62.00	10.50
61	12692	7.40	2.53	2.47	68.00	58.30	11.50
62	12693	9.60	2.47	2.50	69.00	56.20	11.50
63	12694	9.40	2.47	2.50	68.00	55.40	11.00
64	12695	8.50	2.49	2.47	67.00	55.60	11.00
65	12696	8.60	2.49	2.48	67.00	55.50	11.00
66	12697	9.30	2.58	2.48	67.00	54.40	10.50
67	12698	9.00	2.49	2.44	67.00	54.90	10.50
68	12699	10.30	2.45	2.37	67.00	52.90	10.00
69	12700	12.30	2.41	2.41	67.00	49.80	10.00
70	12001	10.70	2.43	2.43	66.00	51.20	10.00
71	12704	10.00	2.43	2.52	68.00	54.50	14.00
72	12705	10.30	2.44	2.42	66.00	51.80	12.00
73	12710	8.90	2.45	2.44	68.00	56.10	13.00
74	12711	9.20	2.46	2.45	67.00	54.60	10.00
75	12401	8.00	2.46	2.43	67.00	56.30	11.00
76	12402	10.50	2.42	2.45	66.00	51.50	12.50
77	12403	10.50	2.42	2.44	65.00	50.40	12.00
78	12404	7.70	2.51	2.46	65.00	54.60	10.00
79	12405	10.80	2.42	2.49	67.00	52.20	10.00

TABLE 13 (continued)

Sample	Depth ft	Lab Porosity %	Bulk Density[1] gm/cc	Bulk Density[2] gm/cc	Log Travel-Times[3] micsec/ft	Matrix Travel-Times[4] micsec/ft	Neutron Porosity[5] %
80	12630	7.00	2.50	2.45	63.00	53.50	10.00
81	12631	7.90	2.54	2.46	65.00	54.30	9.50
82	12632	7.20	2.53	2.46	64.00	54.30	8.00
83	12663	7.10	2.51	2.50	66.00	56.50	10.00
84	12664	7.00	2.56	2.43	65.00	55.60	10.00
85	12665	7.00	2.55	2.42	65.00	55.60	9.50
86	12476	10.90	2.37	2.52	66.00	50.90	14.00
87	12477	8.40	2.35	2.50	66.00	50.10	12.00
88	12488	5.90	2.36	2.43	67.00	50.50	10.00
89	12709	7.70	2.38	2.48	66.00	53.00	11.50

1 Bulk density measured in Laboratory in gm/cc.

2 Density log measured in gm/cc.

3 Sonic log measured in microseconds/ft.

4 Matrix travel-time calculated using laboratory porosity and log travel-time.

5 Neutron log reading.

TABLE 14

CLEAN SAND ANALYSIS
Pts 24-19 Federal
Greater Green River Basin

Sample	Depth ft	Lab Porosity %	Bulk Density[1] gm/cc	Bulk Density[2] gm/cc	Log Travel-Times[3] micsec/ft	Matrix Travel-Times[4] micsec/ft	Neutron Porosity[5] %
1	5207	13.00	2.47	2.45	78.00	61.40	17.00
2	5214	13.60	2.48	2.47	77.00	59.30	18.00
3	5215	13.80	2.46	2.48	77.00	59.00	18.00
4	5216	14.30	2.46	2.48	76.00	57.10	18.00
5	5217	13.90	2.47	2.475	76.00	57.70	15.50
6	5218	14.20	2.45	2.46	75.00	56.10	16.00
7	5219	14.10	2.45	2.46	75.00	56.20	16.00
8	5220	14.70	2.45	2.49	75.00	55.30	15.00
9	5304	13.30	2.46	2.45	77.00	59.80	15.00
10	5305	13.10	2.46	2.47	81.00	64.70	14.00
11	5306	13.30	2.47	2.46	80.00	63.20	14.00
12	5307	13.80	2.46	2.45	76.00	57.90	15.00
13	5308	13.70	2.47	2.45	76.00	58.00	14.00
14	5309	13.30	2.48	2.475	78.00	60.90	15.00
15	5310	13.50	2.47	2.49	78.00	60.60	15.00
16	5311	13.80	2.48	2.51	76.00	57.90	15.00
17	5312	13.70	2.46	2.48	75.00	56.90	16.00
18	5316	13.40	2.48	2.43	78.00	60.80	15.00
19	5317	14.10	2.46	2.42	75.00	56.20	17.00
20	5318	14.20	2.46	2.47	75.00	56.10	16.00
21	5319	14.50	2.46	2.48	74.00	54.40	14.00
22	5320	14.20	2.45	2.47	75.00	56.10	13.00
23	5321	14.20	2.46	2.45	77.00	58.40	14.00
24	5322	13.80	2.46	2.43	77.00	59.00	14.00

1 Bulk density measured in Laboratory in gm/cc.

2 Density log measured in gm/cc.

3 Sonic log measured in microseconds/ft.

4 Matrix travel-time calculated using laboratory porosity and log travel-time.

5 Neutron log reading.

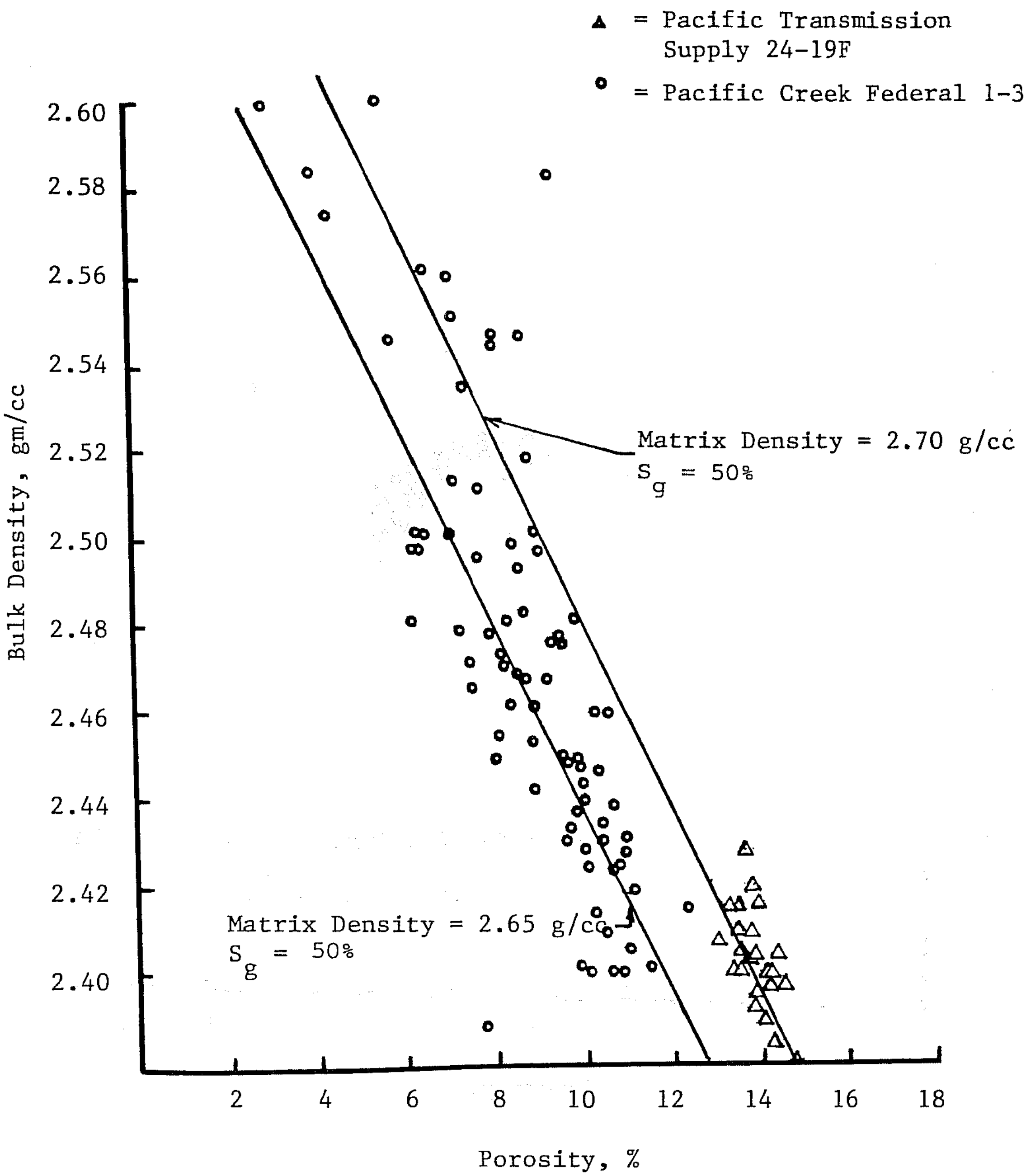


Figure 26.

Laboratory Derived Bulk Denisty
vs Laboratory Derived Porosity
Green River Basin Wells

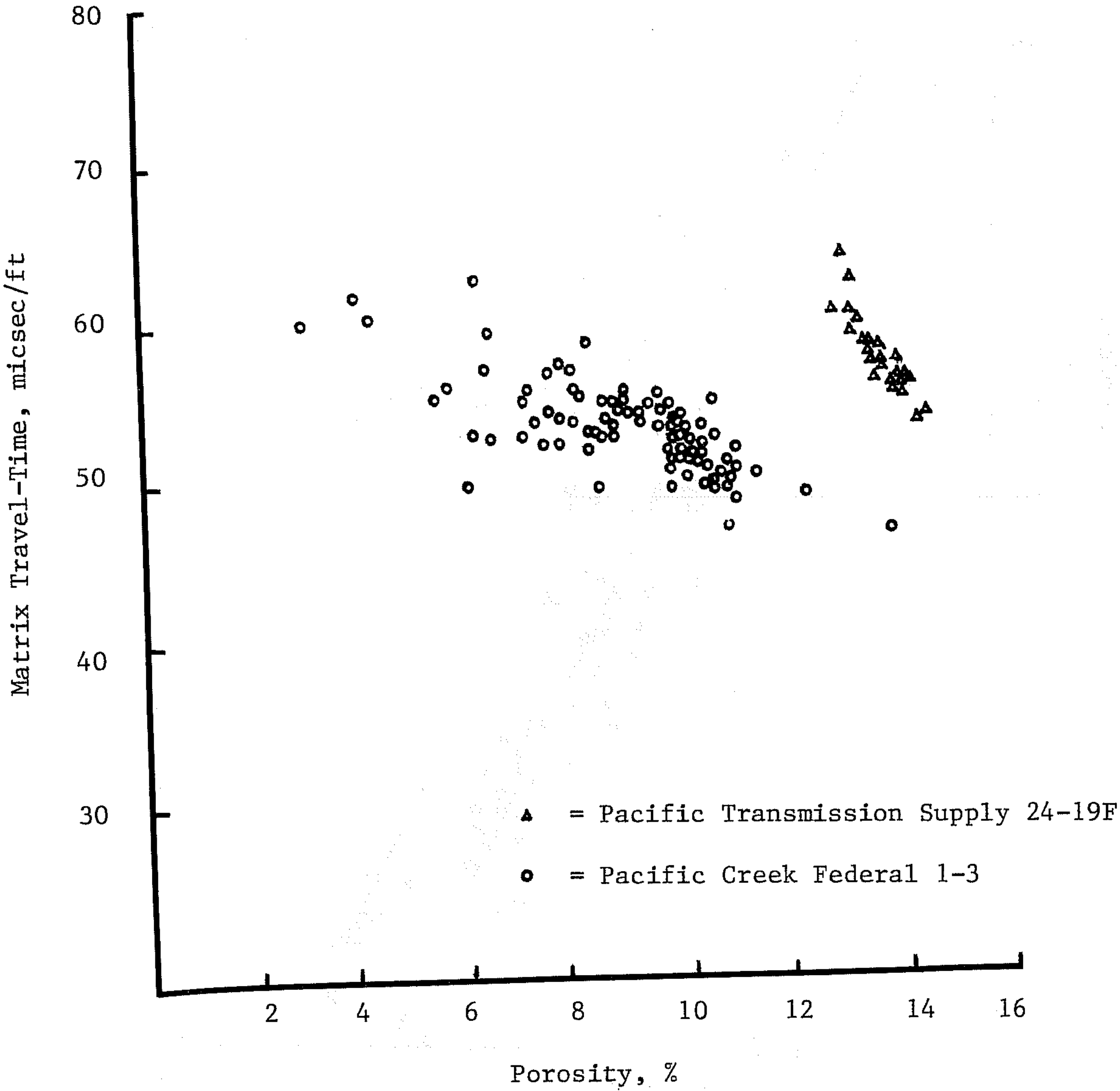


Figure 27.

Matrix Travel-Time vs
Laboratory Derived Porosity
Green River Basin Wells

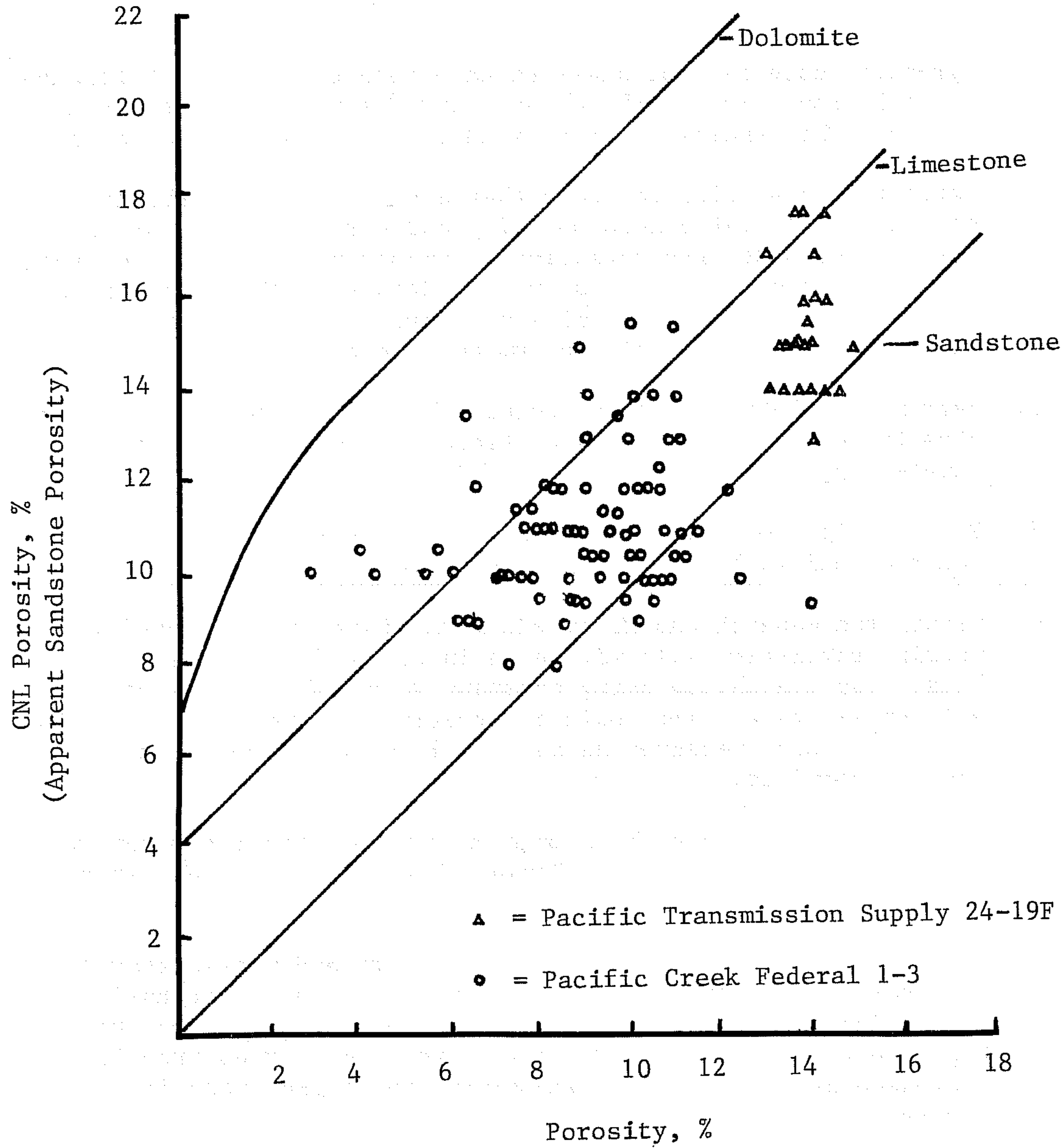


Figure 28.

Neutron Porosity vs
Laboratory Derived Porosity
Green River Basin Wells

CONCLUSIONS

Petrographic, core and log analyses have been combined to determine certain physical properties of the Wasatch and Mesaverde formations in the Uinta Basin. The results of these studies can be stated as follows:

1. Petrographic studies indicate that a high density carbonate cement greatly influences porosity and matrix density of the Wasatch and Mesaverde formations. Higher porosity samples tend to have less cementation and matrix densities that approach 2.65 gm/cc. Lower porosity samples are more heavily cemented and have matrix densities of 2.68 gm/cc or more.

2. Matrix travel-times are not reduced by the presence of the high density cement. Matrix travel-times for the high porosity samples approach 55.6 microseconds/ft.

3. Even in high porosity intervals, no single calibration of the neutron tool will provide accurate values of porosity.

4. Within the Wasatch and Mesaverde formations, matrix density and matrix travel-time will vary even in clean, high porosity intervals. Log evaluation using constant values for matrix density and matrix travel-time could be greatly in error. A calibration curve has been presented as an example of the type of analysis that is required.

Core and log studies have been made on samples from the Mesaverde formation in the Greater Green River Basin. The following conclusions can be made:

1. Physical properties such as matrix density and matrix travel-time vary considerably within the Greater Green River Basin. Matrix density varies from 2.65 gm/cc to 2.71 gm/cc for the higher porosity samples. Matrix travel-time varies from 48 microseconds/ft to 52 microseconds/ft for higher porosity samples.

2. The variation in physical properties is probably due to the different structure position of the Mesaverde, with attendant differences of pressure and temperature, within the Greater Green River Basin.

3. No single calibration of the neutron tool will provide accurate values of porosity.

A final, general conclusion can be made: Effective evaluation of low permeability gas sands will require combined core, petrographic and log analyses.

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