DISCUSSION OF RESEARCH

The purpose of this study is to determine whether the reservoir water resistivity, reservoir permeability, and other rock properties of the Bryan Field can be determined from well logs alone-- without special core analyses.

Fifty-two core samples have been obtained from three wells located in different parts of the field. The well logs for each of these wells were also obtained.

Using the core analysis equipment in the Petroleum Engineering Department, I will determine the following rock properties:

1) Effective porosity
2) Absolute permeability
3) Relative permeability
4) Capillary pressure
5) Core resistivity as a function of
   a) formation water resistivity, and
   b) water saturation

Since porosity and core resistivity can also be obtained from well logs, the values obtained from the core analysis can be used to determine appropriate correction factors to be applied to the well logs of any well in the field.

Although rock permeability is not measured by well logs, a relatinship does exist between porosity and permeability in some homogeneous reservoirs. This relationship varies from field to field. By plotting measured values of porosity versus permeability, I will determine if a substantial correlation exists between porosity and permeability for the Bryan Field.

By saturating the core samples with water of known resistivity and then measuring the saturated core resistivity, I will attempt to develop a resistivity versus depth curve which matches the resistivity curve from the well log. If a good match is obtained, then I believe the formation water resistivity is the same as the water resistivity used in the lab.

I will also determine the cementation factor, and shale fraction for the field as well as make some qualitative observations about the reservoir homogeneity.

LABORATORY STUDY TO DETERMINE PERMEABILITY FROM WELL LOGS IN THE BRYAN FIELD

by

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Approved by:

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ABSTRACT

The purpose of this research was to determine if a substantial, consistent correlation exists between log derived porosity and formation permeability in the Bryan Field. Porosity and permeability measurements were performed on samples from three wells in the Bryan Field. The measured porosities were then plotted versus their corresponding permeabilities for each well. Two of the three wells exhibited porosity-permeability relationships that were consistent enough to be expressed in mathematical form. However, the two equations are dissimilar, therefore there is no field wide correlation according to this data.

PURPOSE

The purpose of this research is to determine whether there exists a substantial, consistent correlation between log derived porosity and formation permeability in the Bryan Field. When the Schlumburger brothers invented the first down-hole electric log, they thought they were measuring permeability. Decades later, there is still no logging tool which measures formation permeability directly, though some computerized logs do attempt to show a permeability track, based on the information received about other rock properties. Since logging is relatively inexpensive, a "permeability log" would keep the operator from having to spend a lot of money coring the well and having the sample analyzed.

One alternative approach to inventing a new logging tool is the porosity-permeability cross-plot. This technique involves plotting porosity versus permeability for several core samples, observing any trends in the data, and expressing the trends mathematically. Mathematical expressions have already been developed to calculate permeability from log porosity in many west Texas fields. Some correlations apply only to one well, but the really useful correlations apply field wide.

If a mathematical expression relating porosity and permeability can be developed for the Bryan Field, the need for many coring operations would be eliminated.

GEOLOGY

The Bryan Field is a north to south trending, thin, stratigraphic reservoir. The field dimensions are approximately 9 miles long by 2 to 4 miles wide (Figure 1).

The field produces from the Woodbine sand. The sand was probably deposited in a high energy, deep water, marine environment. The sand may have washed in from the north, cutting gouches into the Eagleford Shale of varying depth. This caused variations in the sand thickness.

The porosity and permeability in the Bryan Field are relativily high. Porosity values range from 10 to 20% while permeabilities range from 26 to over 5,000 md. A table of reservoir properties is included in the appendix of this report.

DATA ACQUISITION

In order to develop a field wide correlation of porosity versus permeability, data on several wells was sought. However, complete information was available on only three wells. Fifty-three core samples were obtained along with the neutron and density logs

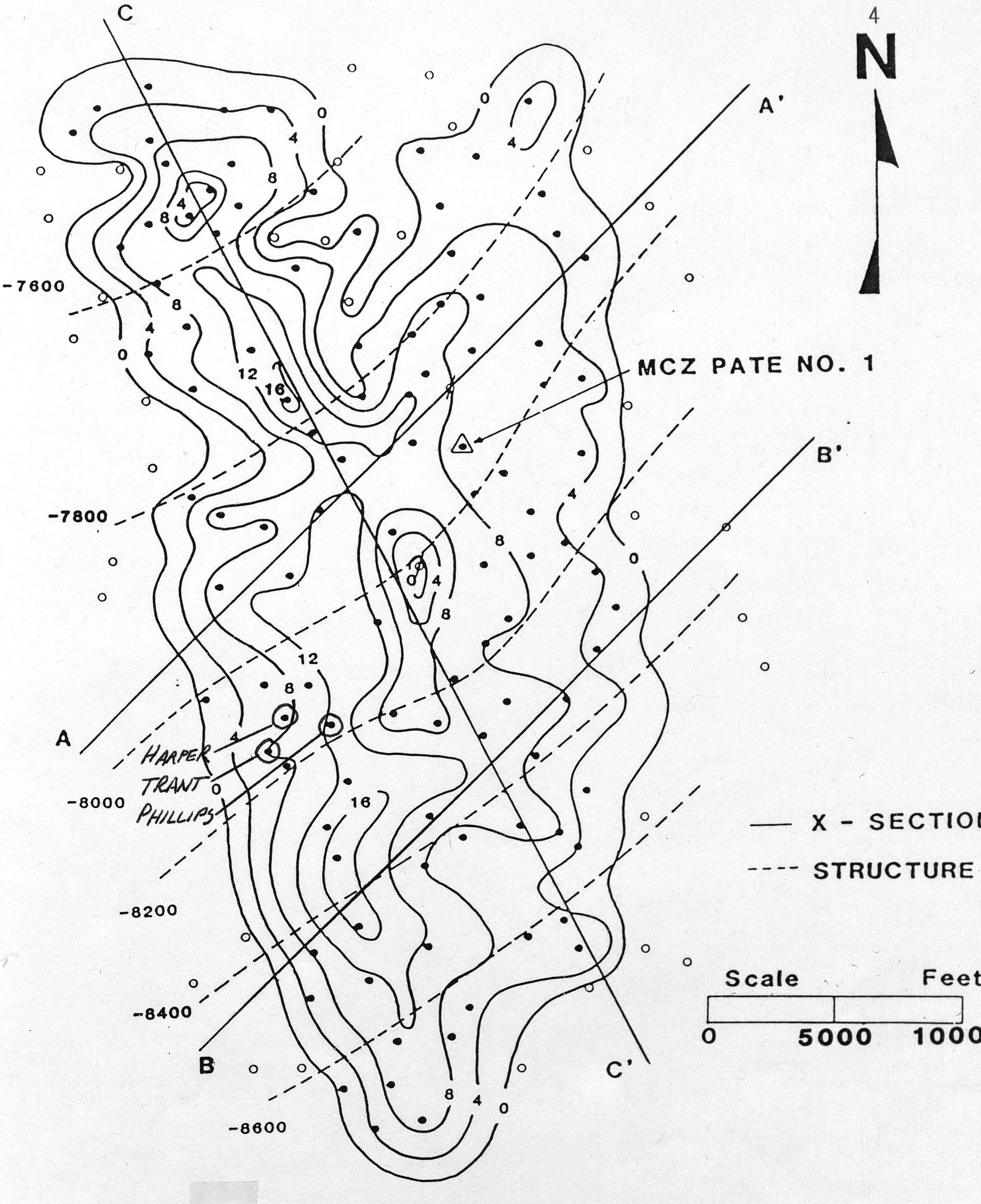

FIGURE 1 - NET SAND ISOPACHOUS AND STRUCTURE MAP

from the Trant No. 1, Phillips No. 1, and Harper No. 1. The locations of these wells are shown in Figure 1.

PROCEDURE

In order to formulate a log porosity versus permeability correlation, a detailed lab procedure had to be written which would produce all of the desired data with accuracy. The original lab procedure was as follows:

1) Clean the core samples using the USBM extraction apparatus, and dry the extracted samples in the core oven.

2) Measure and weigh all samples.

3) Measure the pore and matrix volume of all samples using the helium porosimeter*.

4) Measure the air permeability of all samples using the air permeameter.

5) Measure the liquid permeability of all samples by flowing brine through the sample with a constametric pump and recording the pressure drop across the core.

However, data could not be obtained from the constametric pump. Because the cores are so highly permeable (100-5600 md), a large flowrate was required in order to

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* A complete description of the equipment used in the laboratory is included in the appendix.

produce a pressure drop which could be accurately recorded with the available pressure gauge. A liquid flow rate of 100 cc/minute was required for a few of the more permeable samples. Since the maximum output of the constametric pump is 9 cc/minute, pressure drops across the core could not be read accurately.

LOG ANALYSIS

Once the remainder of the laboratory work was accomplished, the well logs were analyzed. A cross-plot of porosity readings from the neutron and the density logs was used to find the true porosity (corrected for shale in the rock). These porosities were then plotted versus depth, along with the lab determined porosities, to determine if an additional correction factor was necessary. The results of this correlation are discussed in the results section on this report.

PERMEABILITY CALCULATION

Since the use of the constametric pump for measuring liquid permeabilities was impractical, permeability values were derived from the air permeability data based on the method developed by Klinkenberg. Klinkenberg found that the air permeability of a core sample varied linearly with the reciprocal of the mean pressure at which the reading was made. This effect occurred as the diameters of the capillary openings in the rock approach the mean free path of the gas used in the measurement. In order to obtain the desired liquid permeability valueds, a computer program was written which calculates the air permeabilities at three different mean pressures from the flowrates and pressure differentials measured in the lab. The program then calculates the equivalent liquid permeability from a least squares fit of a permeability versus reciprocal mean pressure plot. The program outputs are included in the results section of this report.

RESULTS

COMPARISON OF LOG DERIVED POROSITIES WITH LABORATORY MEASUREMENTS

TABLE 1--TRANT NO. 1

Core Depth	ϕ_{Logs}	ϕ_{Lab}
8610.5-11.0	.107	.113
8611.0-11.5	.154	.153
8611.5-12.0	.163	.166
8612.0-12.5	.177	.180
8612.5-13.0	.180	.182
8613.0-13.5	.176	.161
8613.5-14.0	.160	.160
8614.0-14.5	.154	.158
8614.5-15.0	.145	.142
8615.0-15.5	.144	.164
8615.5-16.0	.140	.143
8616.0-16.5	.158	.161
8616.5-17.0	.138	.148
8617.0-17.5	.138	.120

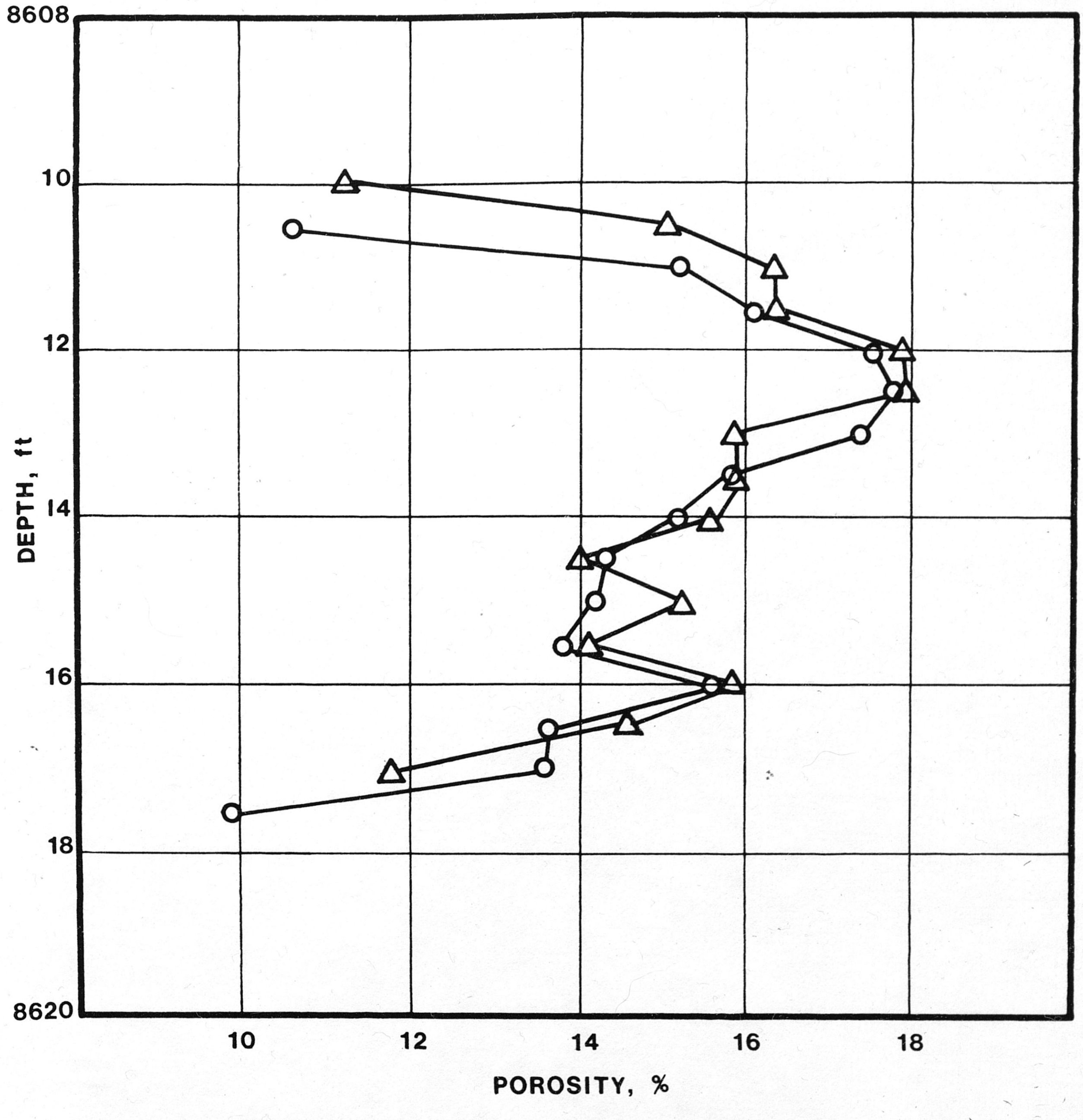


Fig. 2--Comparison of log derived porosity versus laboratory measurements for Trant No. 1 (○ = log, △ = lab)

COMPARISON OF LOG DERIVED POROSITIES WITH LABORATORY MEASUREMENTS

TABLE 2--PHILLIPS NO. 1

Core Depth	ϕ_{Logs}	ϕ_{Lab}
8964.5-65.0	.143	.144
8965.0-65.5	.166	.193
8965.5-66.0	.184	.185
8966.0-66.5	.195	.180
8966.5-67.0	.197	.192
8967.0-67.5	.195	.204
8967.5-68.0	.194	.199
8968.0-68.5	.193	.196
8968.5-69.0	.199	.196
8969.0-69.5	.207	.194
8969.5-70.0	.211	.205
8970.0-70.5	.214	.209
8970.5-71.0	.214	.210
8971.0-71.5	.218	.211
8971.5-72.0	.222	.220
8972.0-72.5	.221	.207
8972.5-73.0	.189	.200
8973.0-73.5	.162	.178
8973.5-74.0	.147	.172
8974.0-74.5	.162	.203

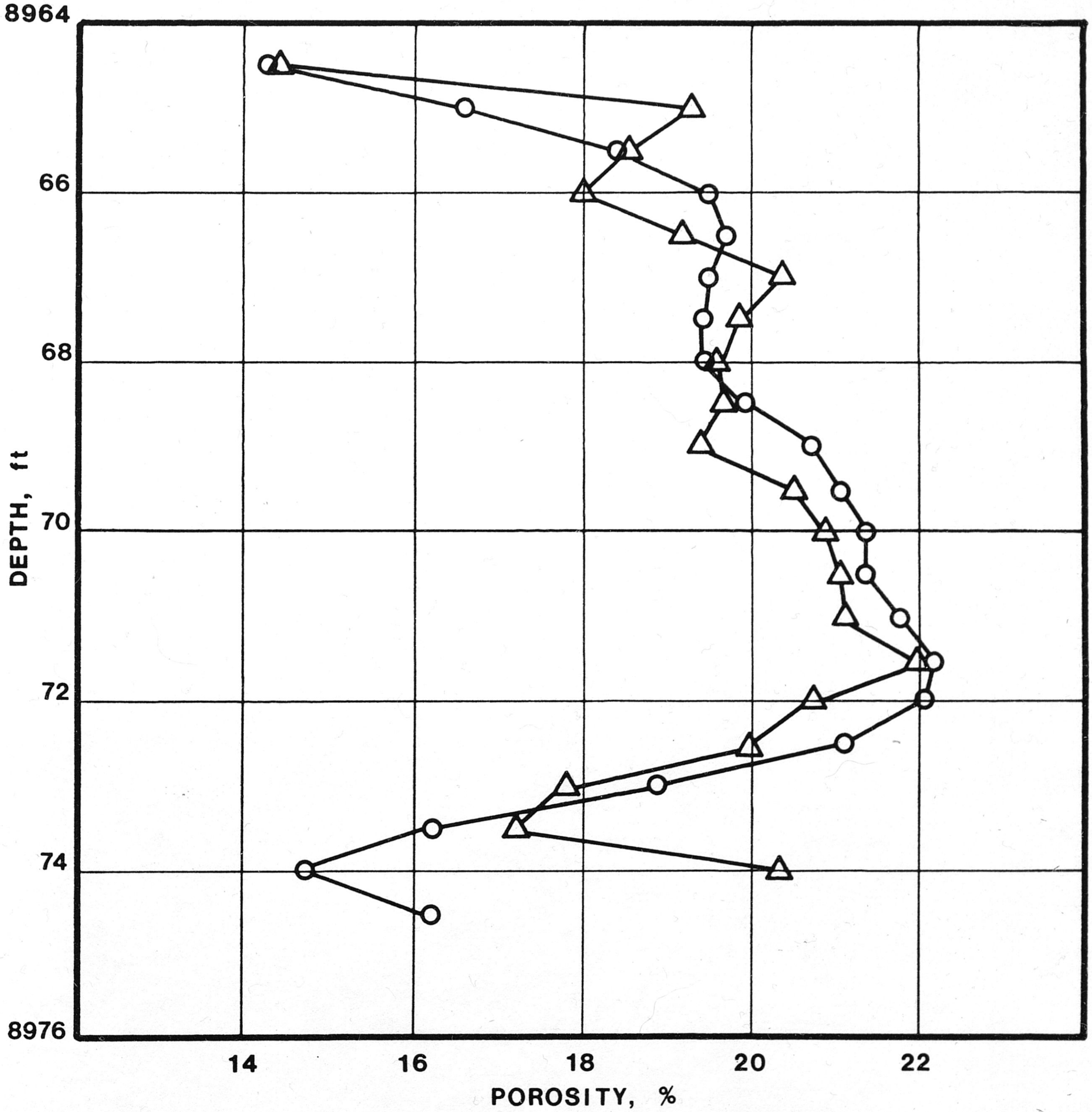


Fig. 3--Comparison of log derived porosity versus laboratory measurements for Phillips No. 1 (O = log, △ = lab)

COMPARISON OF LOG DERIVED POROSITIES WITH LABORATORY MEASUREMENTS

TABLE 3--HARPER NO. 1

Core Depth	ϕ_{Logs}	ϕ_{Lab}
8657.0-57.5	.117	.152
8657.5-58.0	.144	.160
8658.0-58.5	.178	.160
8658.5-59.0	.184	.176
8659.0-59.5	.190	.196
8659.5-60.0	.191	.200
8660.0-60.5	.192	.198
8660.5-61.0	.191	.188
8661.0-61.5	.188	.169
8661.5-62.0	.190	.186
8662.0-62.5	.192	.188
8662.5-63.0	.180	.184
8663.0-63.5	.159	.175

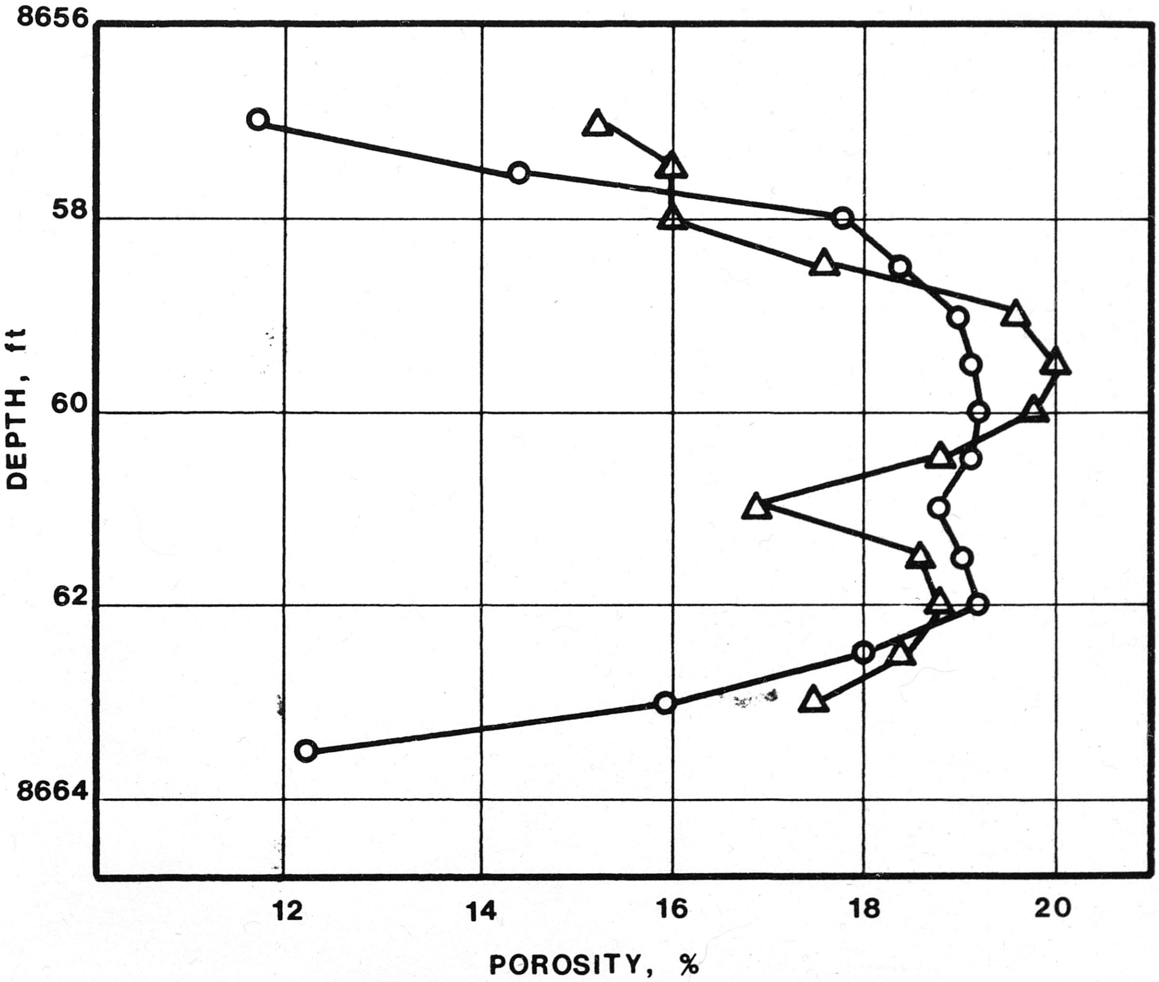


Fig. 4--Comparison of log derived porosity versus laboratory measurements for Harper No. 1 (○ = log, △ = lab)

AIR PERMEAMETER DATA

Table 4 -- Trant No. 1

SAMPLE 2.
L=2.833
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	54.89106409
10 PSI	109.7820959
20 PSI	219.5642725
MEAN P=20 PSI	
5 PSI	53.20457986
10 PSI	106.4091284
20 PSI	212.8183351
MEAN P=30 PSI	
5 PSI	52.64241881
10 PSI	105.2848067
20 PSI	210.5696907

K=1.582

SAMPLE 3.
L=3.244
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	71.00226065
10 PSI	142.0044796
20 PSI	284.0090635
MEAN P=20 PSI	
5 PSI	69.7989382
10 PSI	139.5978354
20 PSI	279.1957733
MEAN P=30 PSI	
5 PSI	69.39783094
10 PSI	138.7956211
20 PSI	277.5913442

K=2.412

SAMPLE 4.
L=3.48
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	51.00461387
10 PSI	102.0091978
20 PSI	204.0184705
MEAN P=20 PSI	
5 PSI	48.16892658
10 PSI	96.33782485
20 PSI	192.6757205
MEAN P=30 PSI	
5 PSI	47.22369812
10 PSI	94.44736848
20 PSI	188.8948064

K=1.71

SAMPLE 5.
L=2.855
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	78.4215626
10 PSI	156.8430791
20 PSI	313.6862734
MEAN P=20 PSI	
5 PSI	74.53023176
10 PSI	149.0604197
20 PSI	298.1209489
MEAN P=30 PSI	
5 PSI	73.23312238
10 PSI	146.4662017
20 PSI	292.932511

K=2.186

SAMPLE 6.
L=2.984
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	37.86344166
10 PSI	75.72686107
20 PSI	151.4537777
MEAN P=20 PSI	
5 PSI	35.16328468
10 PSI	70.32654869
20 PSI	140.653149
MEAN P=30 PSI	
5 PSI	34.26323297
10 PSI	68.5264458
20 PSI	137.0529419

K=1.05

SAMPLE 7.
L=4.759
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	4.424395576
10 PSI	8.848788552
20 PSI	17.69758361
MEAN P=20 PSI	
5 PSI	2.822850565
10 PSI	5.645699471
20 PSI	11.29140309
MEAN P=30 PSI	
5 PSI	2.289002594
10 PSI	4.578003842
20 PSI	9.156011049

K=0.063

SAMPLE 8.
L=2.716
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	32.29831952
10 PSI	64.59662007
20 PSI	129.1932876
MEAN P=20 PSI	
5 PSI	27.90209058
10 PSI	55.80416476
20 PSI	111.6083705
MEAN P=30 PSI	
5 PSI	26.43668194
10 PSI	52.87334834
20 PSI	105.7467355

K=0.692

SAMPLE 9.
L=3.442
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	22.40472644
10 PSI	44.8094397
20 PSI	89.61891233
MEAN P=20 PSI	
5 PSI	21.25361818
10 PSI	42.50722387
20 PSI	85.01447897
MEAN P=30 PSI	
5 PSI	20.8699157
10 PSI	41.73981912
20 PSI	83.47966892

K=0.75

SAMPLE 10.
L=4;636
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	23.34260054
10 PSI	46.68518736
20 PSI	93.37040905
MEAN P=20 PSI	
5 PSI	20.4273678
10 PSI	40.85472359
20 PSI	81.70947721
MEAN P=30 PSI	
5 PSI	19.45562422
10 PSI	38.911237
20 PSI	77.82250262

K=0.88

SAMPLE 11.
L=3.211
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	18.63006433
10 PSI	37.2601177
20 PSI	74.52026281
MEAN P=20 PSI	
5 PSI	17.41733899
10 PSI	34.83466772
20 PSI	69.66936107
MEAN P=30 PSI	
5 PSI	17.01309748
10 PSI	34.02618495
20 PSI	68.05239494

K=0.564

SAMPLE 12.
L=4.521
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	25.64427147
10 PSI	51.28852785
20 PSI	102.5770934
MEAN P=20 PSI	
5 PSI	24.04562941
10 PSI	48.09124468
20 PSI	96.18252473
MEAN P=30 PSI	
5 PSI	23.51274909
10 PSI	47.02548435
20 PSI	94.05100328

K=1.1

SAMPLE 13.
L=2.994
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	17.08719711
10 PSI	34.17438417
20 PSI	68.34879347
MEAN P=20 PSI	
5 PSI	12.96540637
10 PSI	25.93080511
20 PSI	51.86162928
MEAN P=30 PSI	
5 PSI	11.59147706
10 PSI	23.18294731
20 PSI	46.36591166

K=0.287

SAMPLE 14.
L=3.915
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	8.181210385
10 PSI	16.36241596
20 PSI	32.72484395
MEAN P=20 PSI	
5 PSI	6.788801503
10 PSI	13.57759902
20 PSI	27.15520801
MEAN P=30 PSI	
5 PSI	6.32466553
10 PSI	12.64932734
20 PSI	25.29866398

K=0.229

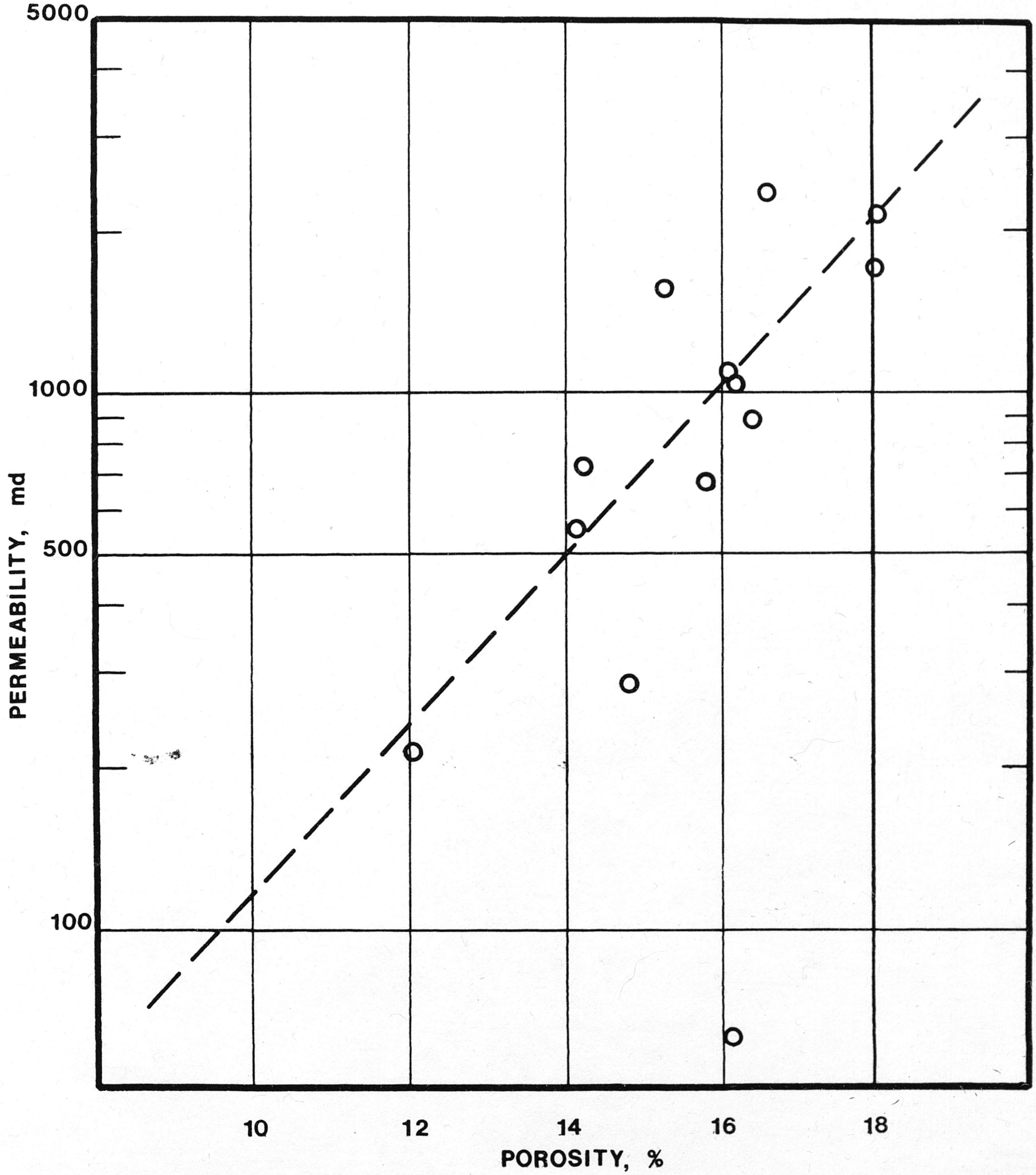


Fig. 5--Porosity-Permeability Correlation for Trant No. 1.

$$k = 10^{(15.6209\phi + .5096)}$$

AIR PERMEAMETER DATA

Table 5 -- Phillips No. 1

SAMPLE 1.
L=3.995
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	24.55813868
10 PSI	49.11626292
20 PSI	98.23256195
MEAN P=20 PSI	
5 PSI	21.1930229
10 PSI	42.38603334
20 PSI	84.77209784
MEAN P=30 PSI	
5 PSI	20.07131841
10 PSI	40.14262502
20 PSI	80.28527954

K=0.772

SAMPLE 2.
L=3.96
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	55.4288829
10 PSI	110.8577332
20 PSI	221.7155479
MEAN P=20 PSI	
5 PSI	54.38979602
10 PSI	108.7795601
20 PSI	217.5592001
MEAN P=30 PSI	
5 PSI	54.04343395
10 PSI	108.0868361
20 PSI	216.1737517

K=2.29

SAMPLE 3.
L=4.987
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	11.07421908
10 PSI	22.14843164
20 PSI	44.29687955
MEAN P=20 PSI	
5 PSI	9.25551306
10 PSI	18.51102068
20 PSI	37.02205495
MEAN P=30 PSI	
5 PSI	8.649278137
10 PSI	17.29855119
20 PSI	34.59711508

K=0.402

SAMPLE 4.
L=4.125
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	9.063981553
10 PSI	18.12795778
20 PSI	36.25592887
MEAN P=20 PSI	
5 PSI	7.461852753
10 PSI	14.92370112
20 PSI	29.8474132
MEAN P=30 PSI	
5 PSI	6.927810185
10 PSI	13.8556163
20 PSI	27.71124277

K=0.262

SAMPLE 5.
L=4.986
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	26.43780145
10 PSI	52.87558736
20 PSI	105.7512136
MEAN P=20 PSI	
5 PSI	24.274582
10 PSI	48.54914973
20 PSI	97.09833514
MEAN P=30 PSI	
5 PSI	23.55350936
10 PSI	47.10700488
20 PSI	94.21404436

K=1.195

SAMPLE 6.
L=2.544
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	10.20444287
10 PSI	20.40887975
20 PSI	40.81777449
MEAN P=20 PSI	
5 PSI	7.622609651
10 PSI	15.24521482
20 PSI	30.49044084
MEAN P=30 PSI	
5 PSI	6.761999171
10 PSI	13.52399437
20 PSI	27.04799867

K=0.139

SAMPLE 7.
L=3.044
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	36.95689052
10 PSI	73.91375935
20 PSI	147.8275729
MEAN P=20 PSI	
5 PSI	34.99622769
10 PSI	69.99243484
20 PSI	139.9849211
MEAN P=30 PSI	
5 PSI	34.34267387
10 PSI	68.68532757
20 PSI	137.3707056

K=1.09

SAMPLE 8.
L=4.266
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	41.65518303
10 PSI	83.31034158
20 PSI	166.6207444
MEAN P=20 PSI	
5 PSI	38.92867158
10 PSI	77.85732027
20 PSI	155.7146978
MEAN P=30 PSI	
5 PSI	38.01983505
10 PSI	76.03964774
20 PSI	152.0793514

K=1.674

SAMPLE 9.
L=2.728
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	23.71794602
10 PSI	47.43587809
20 PSI	94.87179106
MEAN P=20 PSI	
5 PSI	22.34273646
10 PSI	44.68545978
20 PSI	89.37095241
MEAN P=30 PSI	
5 PSI	21.88433359
10 PSI	43.7686543
20 PSI	87.53734079

K=0.62

SAMPLE 10.
L=3.432
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	17.06814385
10 PSI	34.13627766
20 PSI	68.27258041
MEAN P=20 PSI	
5 PSI	13.76251196
10 PSI	27.52501584
20 PSI	55.0500519
MEAN P=30 PSI	
5 PSI	12.66063543
10 PSI	25.32126341
20 PSI	50.64254543

K=0.389

SAMPLE 11.
L=3.99
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	55.64759736
10 PSI	111.295162
20 PSI	222.5904059
MEAN P=20 PSI	
5 PSI	53.25809233
10 PSI	106.5161534
20 PSI	213.032385
MEAN P=30 PSI	
5 PSI	52.46159116
10 PSI	104.9231515
20 PSI	209.8463801

K=2.2

SAMPLE 12.
L=4.18
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	35.35734189
10 PSI	70.71466299
20 PSI	141.429378
MEAN P=20 PSI	
5 PSI	32.56561474
10 PSI	65.13121033
20 PSI	130.2624685
MEAN P=30 PSI	
5 PSI	31.63503965
10 PSI	63.2700607
20 PSI	126.5401679

K=1.349

SAMPLE 13.
L=3.545
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	33.39573996
10 PSI	66.79146029
20 PSI	133.5829697
MEAN P=20 PSI	
5 PSI	29.77521821
10 PSI	59.55041893
20 PSI	119.1008816
MEAN P=30 PSI	
5 PSI	28.56837846
10 PSI	57.13674013
20 PSI	114.2735222

K=1.005

SAMPLE 14.
L=3.335
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	98.12893178
10 PSI	196.2578058
20 PSI	392.5157559
MEAN P=20 PSI	
5 PSI	96.54852864
10 PSI	193.0970005
20 PSI	386.1941429
MEAN P=30 PSI	
5 PSI	96.021728
10 PSI	192.0433995
20 PSI	384.0869402

K=3.433

SAMPLE 15.
L=3.013
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	80.07489764
10 PSI	160.1497482
20 PSI	320.2996141
MEAN P=20 PSI	
5 PSI	78.00586234
10 PSI	156.0116788
20 PSI	312.0234723
MEAN P=30 PSI	
5 PSI	77.31618441
10 PSI	154.6323234
20 PSI	309.2647604

K=2.48

SAMPLE 16.
L=2.92
A=5.016
MEAN P=10 PSI

DEL P	Q
5 PSI	63.80103814
10 PSI	127.6020388
20 PSI	255.2041713

MEAN P=20 PSI

5 PSI	60.47810948
10 PSI	120.9561834
20 PSI	241.9124557

MEAN P=30 PSI

5 PSI	59.37046736
10 PSI	118.7408998
20 PSI	237.4818869

K=1.809

SAMPLE 17.
L=3.309
A=5.016
MEAN P=10 PSI

DEL P	Q
5 PSI	42.17882437
10 PSI	84.35762396
20 PSI	168.7153098

MEAN P=20 PSI

5 PSI	39.2118438
10 PSI	78.42366457
20 PSI	156.8473867

MEAN P=30 PSI

5 PSI	38.22285096
10 PSI	76.44567947
20 PSI	152.891415

K=1.3

SAMPLE 18.
L=3.378
A=5.016
MEAN P=10 PSI

DEL P	Q
5 PSI	16.45400851
10 PSI	32.90800733
20 PSI	65.81603885

MEAN P=20 PSI

5 PSI	15.39618525
10 PSI	30.79236145
20 PSI	61.58474553

MEAN P=30 PSI

5 PSI	15.04357774
10 PSI	30.08714663
20 PSI	60.17431538

K=0.525

SAMPLE 19.
L=4.42
A=5.016
MEAN P=10 PSI

DEL P	Q
5 PSI	14.42798448
10 PSI	28.85596049
20 PSI	57.71194219

MEAN P=20 PSI

5 PSI	13.37142426
10 PSI	26.74284066
20 PSI	53.48570098

MEAN P=30 PSI

5 PSI	13.01923775
10 PSI	26.03846786
20 PSI	52.07695486

K=0.59

SAMPLE 20.
L=4.568
A=5.016
MEAN P=10 PSI

DEL P	Q
5 PSI	55.07307738
10 PSI	110.1461224
20 PSI	220.2923257

MEAN P=20 PSI

5 PSI	52.84261821
10 PSI	105.6852054
20 PSI	211.3704884

MEAN P=30 PSI

5 PSI	52.09913228
10 PSI	104.1962339
20 PSI	208.3965444

K=2.506

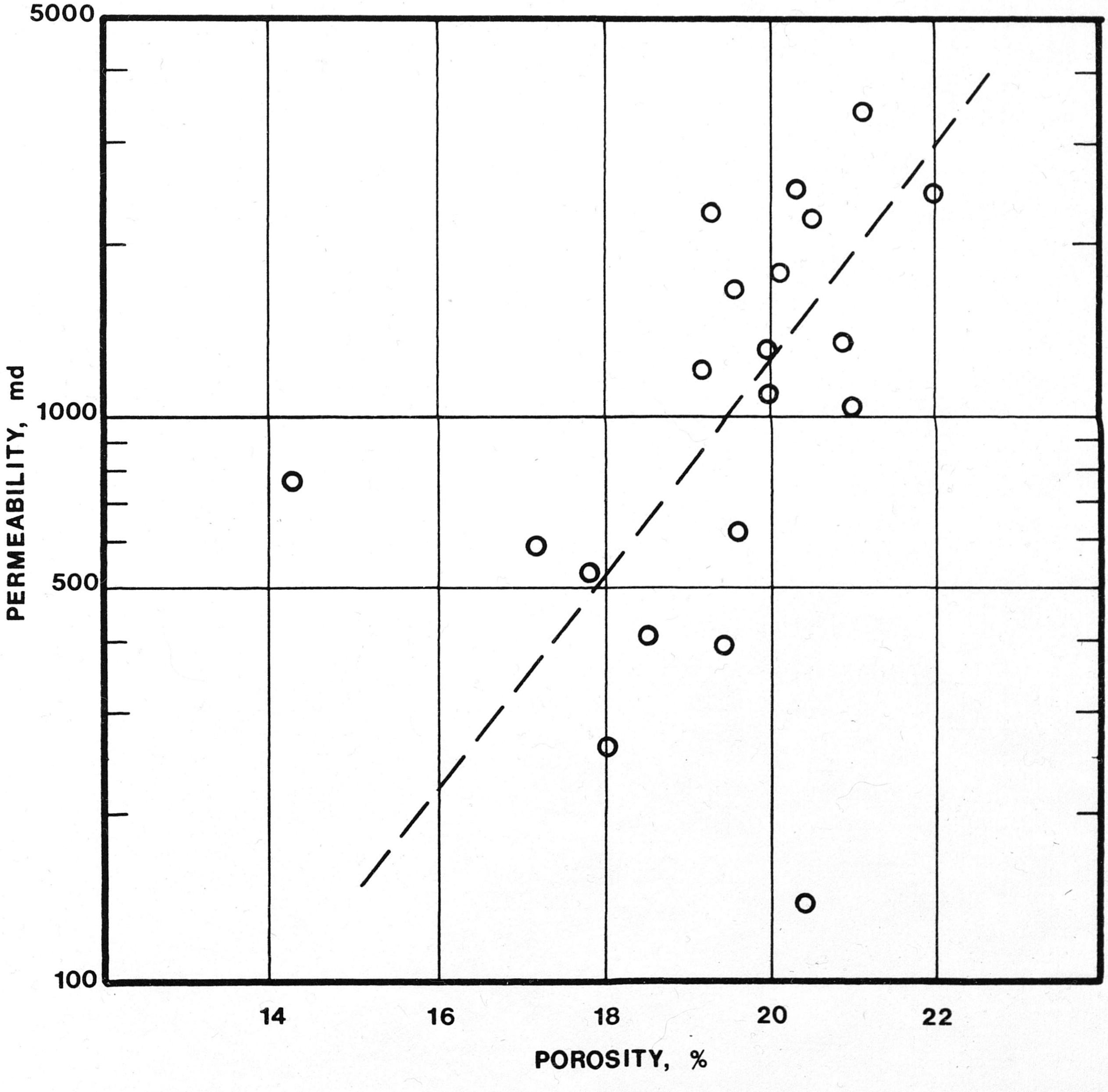


Fig. 6--Porosity-Permeability Correlation for Phillips No. 1

$k = 10^{(18.8\phi - 1.667)}$

AIR PERMEAMETER DATA
Table 6 -- Harper No. 1

SAMPLE 1.
L=3.131
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	122.3868555
10 PSI	244.7736391
20 PSI	489.547458
MEAN P=20 PSI	
5 PSI	119.5649886
10 PSI	239.129907
20 PSI	478.2599896
MEAN P=30 PSI	
5 PSI	118.6243669
10 PSI	237.2486642
20 PSI	474.4975026

K=3.962

SAMPLE 3.
L=4.878
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	33.94830292
10 PSI	67.8965859
20 PSI	135.7932216
MEAN P=20 PSI	
5 PSI	33.04065908
10 PSI	66.08129874
20 PSI	132.162646
MEAN P=30 PSI	
5 PSI	32.73811134
10 PSI	65.47620344
20 PSI	130.952455

K=1.699

SAMPLE 4.
L=4.743
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	43.72907599
10 PSI	87.45812629
20 PSI	174.9163169
MEAN P=20 PSI	
5 PSI	41.41301033
10 PSI	82.82599632
20 PSI	165.6520535
MEAN P=30 PSI	
5 PSI	40.640989
10 PSI	81.28195412
20 PSI	162.563968

K=2.01

SAMPLE 5.
L=3.026
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	74.81547441
10 PSI	149.6309048
20 PSI	299.2619196
MEAN P=20 PSI	
5 PSI	70.62456824
10 PSI	141.249095
20 PSI	282.4982937
MEAN P=30 PSI	
5 PSI	69.22760046
10 PSI	138.4551602
20 PSI	276.9104222

K=2.179

SAMPLE 7.
L=4.097
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	134.1581694
10 PSI	268.3162599
20 PSI	536.6327168
MEAN P=20 PSI	
5 PSI	130.9857749
10 PSI	261.9714728
20 PSI	523.943138
MEAN P=30 PSI	
5 PSI	129.9283108
10 PSI	259.8565452
20 PSI	519.7132814

K=5.676

SAMPLE 8.
L=2.71
A=5.016

MEAN P=10 PSI	
DEL P	Q
5 PSI	174.7383035
10 PSI	349.4765041
20 PSI	698.9532651
MEAN P=20 PSI	
5 PSI	172.3410248
10 PSI	344.6819482
20 PSI	689.3641499
MEAN P=30 PSI	
5 PSI	171.5419325
10 PSI	343.0837641
20 PSI	686.1677804

K=4.992

SAMPLE 9.
L=4.021
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	67.69166713
10 PSI	135.3832945
20 PSI	270.7666883
MEAN P=20 PSI	
5 PSI	64.70527793
10 PSI	129.4105178
20 PSI	258.8211307
MEAN P=30 PSI	
5 PSI	63.70981555
10 PSI	127.4195936
20 PSI	254.8392809

K=2.69

SAMPLE 11.
L=3.909
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	69.97463042
10 PSI	139.9492197
20 PSI	279.8985422
MEAN P=20 PSI	
5 PSI	68.92585222
10 PSI	137.8516639
20 PSI	275.7034291
MEAN P=30 PSI	
5 PSI	68.57625971
10 PSI	137.1524791
20 PSI	274.3050589

K=2.876

SAMPLE 12.
L=3.715
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	90.77769634
10 PSI	181.5553393
20 PSI	363.110812
MEAN P=20 PSI	
5 PSI	88.10277749
10 PSI	176.2055032
20 PSI	352.4111359
MEAN P=30 PSI	
5 PSI	87.21113853
10 PSI	174.4222258
20 PSI	348.8445798

K=3.44

SAMPLE 13.
L=3.093
A=5.016

DEL P	Q
MEAN P=10 PSI	
5 PSI	131.0136484
10 PSI	262.0272196
20 PSI	524.054632
MEAN P=20 PSI	
5 PSI	126.9071742
10 PSI	253.8142737
20 PSI	507.6287341
MEAN P=30 PSI	
5 PSI	125.5383504
10 PSI	251.0766269
20 PSI	502.1534386

K=4.117

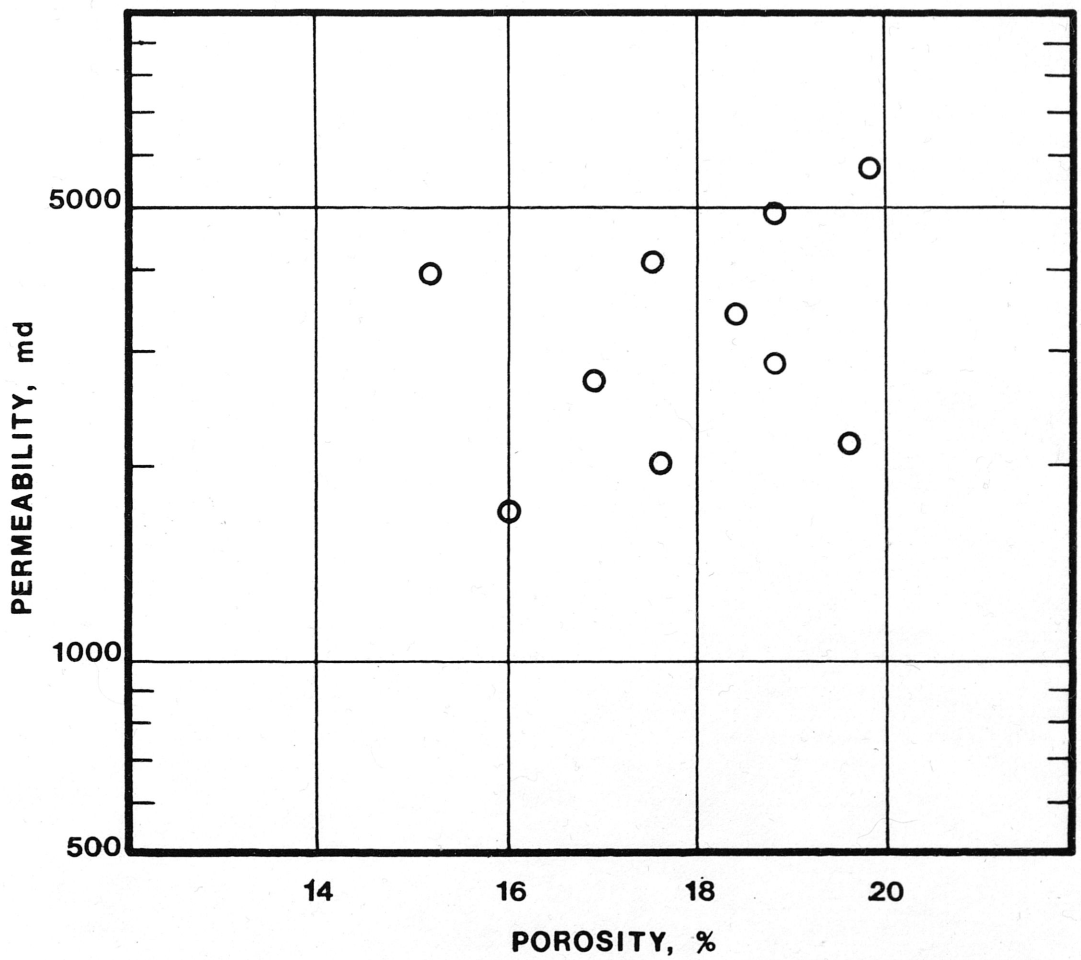


Fig. 7--Porosity-Permeability Correlation for
Harper No. 1

DISCUSSION OF RESULTS

Before any attempt to correlate log derived porosity and formation permeability can be made, the relationship between the log porosity values and the actual formation porosity must be examined. Comparisons of the two sets of porosity values are shown in Figures 2, 3, and 4 for each well studied. The data for the Trant and the Phillips wells is in excellent agreement while the Harper log data is acceptable. All three wells fail to exhibit any consistent shift or deviation of the log values from the actual measured porosities. Instead, the discrepancies appear to be the result of non-representative samples and, in a few cases, some laboratory error. Many of the samples tested were quite small (less than 1 inch in length), thus decreasing the likelihood that they would be truly representative of the formation. Nevertheless, the porosities derived from both sources of data appear to be in good agreement and so no attempt well be made to derive a method to correct the log readings, other than the standard neutron-density cross-plot.

After verifying the log derived porosities with the helium porosimeter data, the actual porosity versus permeability plots were drawn. Based on past experience with similar studies in other fields, the porosities were plotted versus the log of permeability. These plots are shown in Figures 5, 6, and 7. The Trant well exhibited the most significant correlation. By discarding one of the data points, a least squares fit of the remaining data resulted in a correlation coefficient, r = .82. This indicates a high, positive correlation between porosity and the logarithm of permeability which is described by the expression

$$k = 10^{(15.6209\phi + .5096)}$$

The results for the Phillips well also show a significant trend (Figure 6). Discarding two inconsistent data points, a correlation coefficient of .73 was obtained. However, the mathematical expression for this well,

$$k = 10^{(18.8\phi - .667)}$$

is quite different from the equation developed for the Trant well.

The results from the Harper well are shown in Figure 7. No significant correlation exists between porosity and permeability for this well according to the data obtained. There are several possible explanations for this anomaly:

1) The grain size distribution in the Harper well changes significantly with depth.

2) Too few data points were obtained to define a "trend".

3) Permeabilities determined for these samples were in error, due to the small size of the Harper well samples.

Any of these factors could have accounted for the poor correlation, with the grain size distribution theory being the most likely.

CONCLUSIONS

The following conclusions have been derived from this research:

1) Substantial correlations exist relating derived porosity to formation permeability in two of the three wells studied.

2) Mathematical expressions for these correlations are unique to the individual well (ie. No field wide equation relating porosity and permeability could be determined from this data).

3) Data from the Harper well indicates a vertical variation of grain size distribution in the well, causing a poor porosity-permeability correlation.

REFERENCES

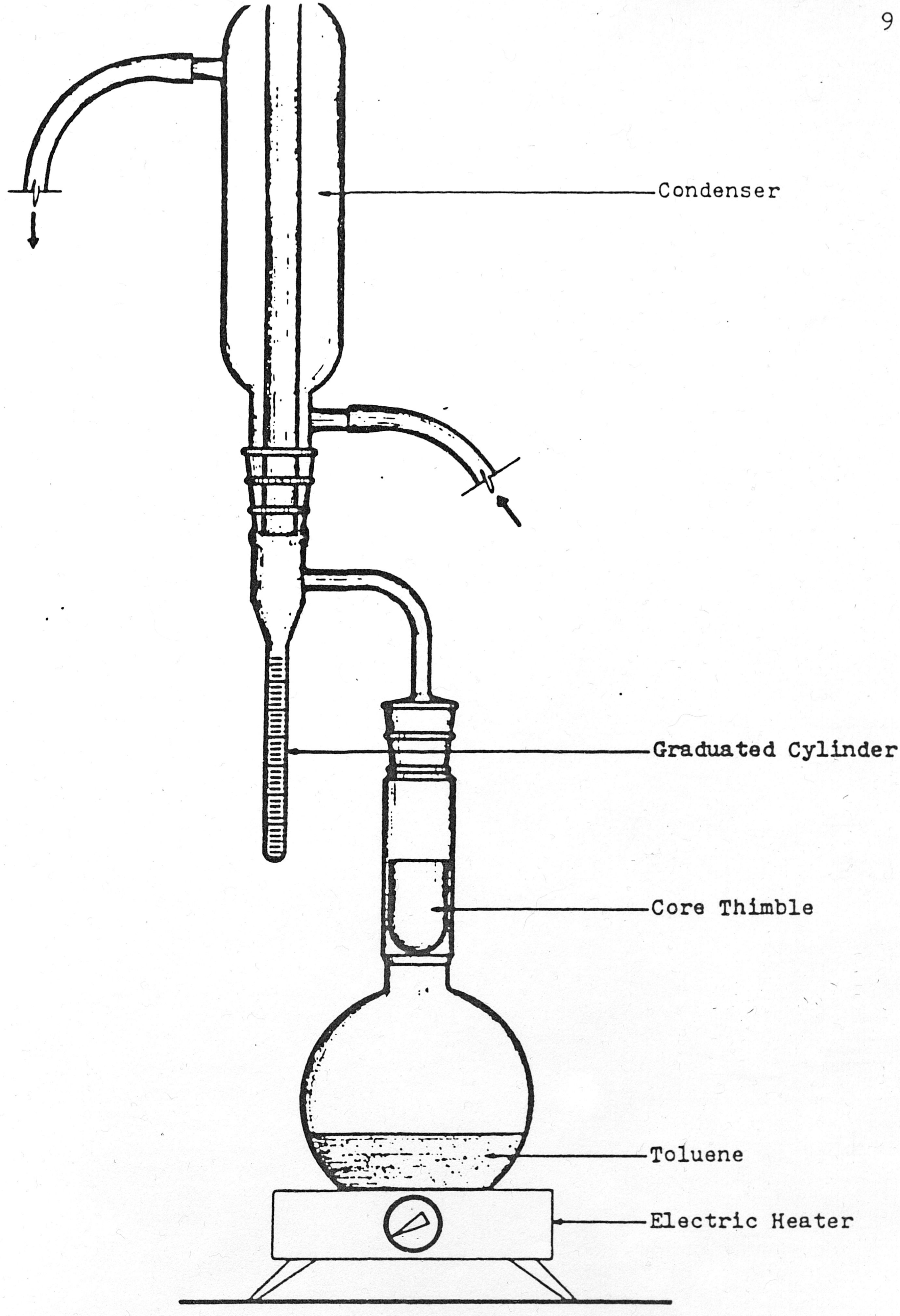
Givens, James W., "Reservoir Management of the Bryan (Woodbine) Field", Society of Petroleum Engineers, No. 13267, 1984.

Von Gonten, W.D., Laboratory Manual for Petroleum Engineering 309, Department of Petroleum Engineering, Texas A&M University, College Station, Texas, 1985.

APPENDIX

USBM EXTRACTION APPARATUS

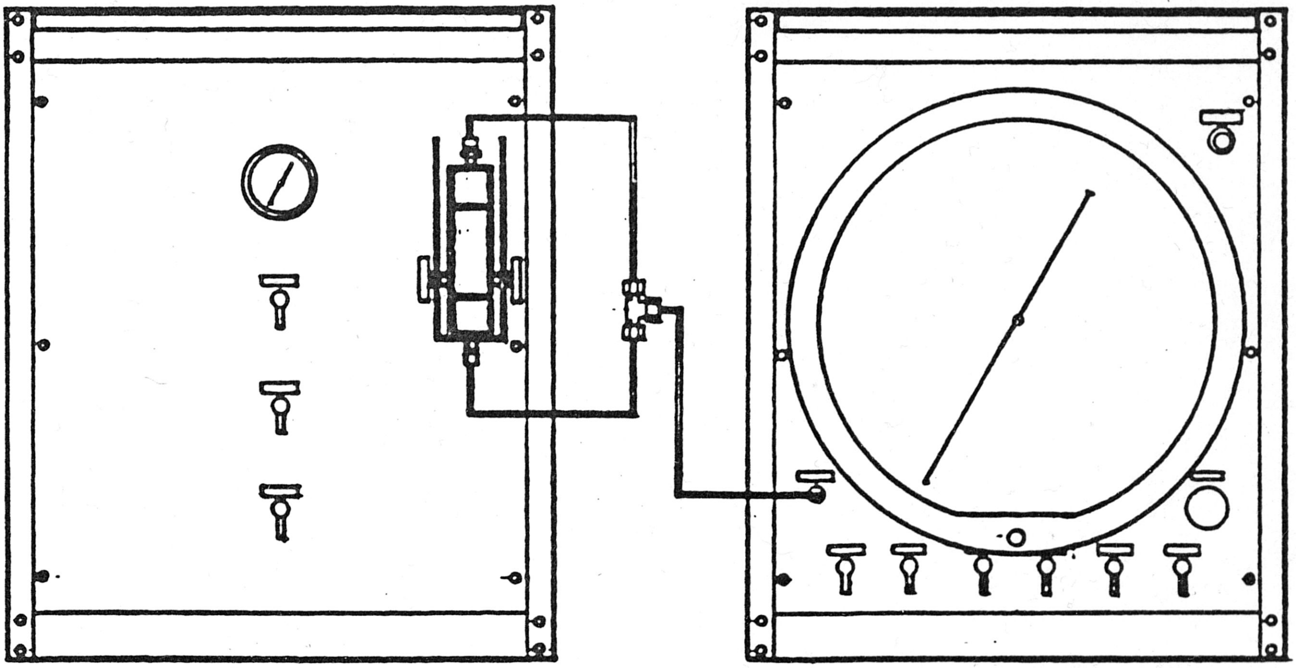
The USBM extraction apparatus is used in determining the fluid content of a core sample. A sample 50 to 100 grams in weight is sized to fit into the extraction thinble. With the core in place, toluene is added to the flask and the apparatus is assembled. When heat is applied, water and oil are "leached" from the core by the toluene. The water condenses in the graduated tube while the oil is carried into the flask. When all of the water has been extracted from the core, the trap is cooled and the volume of water is read directly. The oil volume must be determined indirectly.



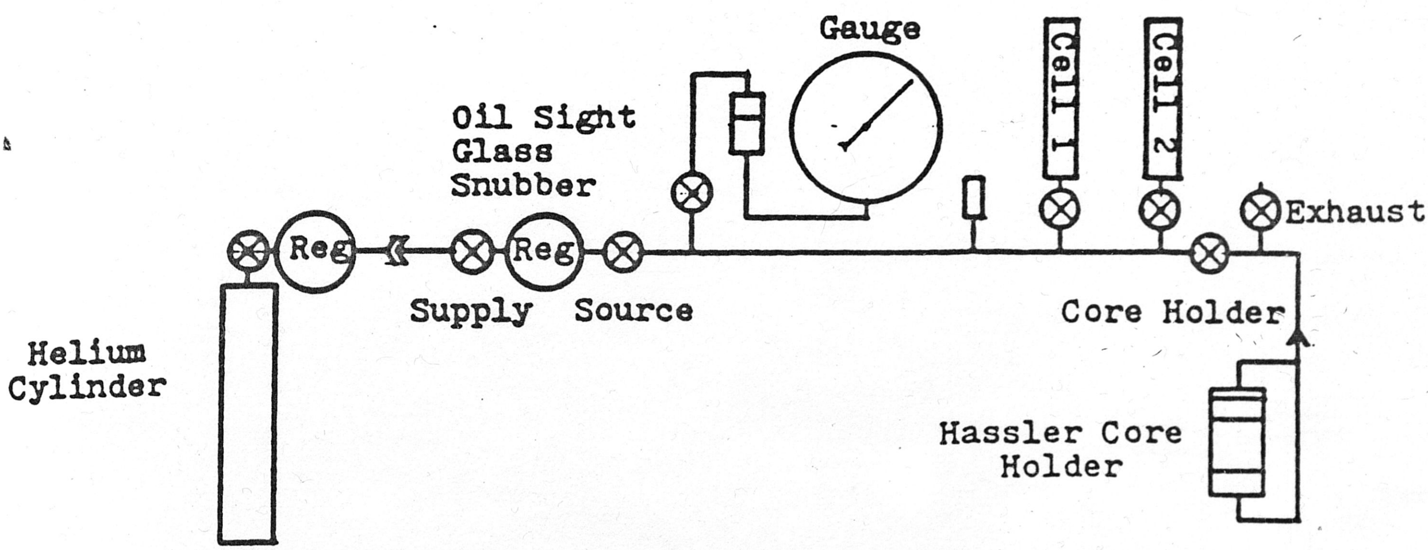
USBM EXTRACTION APPARATUS

HELIUM POROSIMETER

The helium porosimeter is used to determine the pore and matrix volume of a core sample. The system between the source and core holder is pressurized to a standard reference pressure, usually 100 psig. By opening the core holder valve, the helium is allowed to expand into the core chamber. The equilibrium pressure is proportional to the volume of the chamber by Boyle's Law. By repeating the process with the core in place, the matrix volume is obtained. The pore volume is obtained by placing the core in a Hassler sleeve so that helium passes through the interconnected pore space and not around the outside of the core. From the pressure data at equillibrium, the pore volume is obtained. This particular He porosimeter is calibrated so that pore and matrix volume can be read directly.



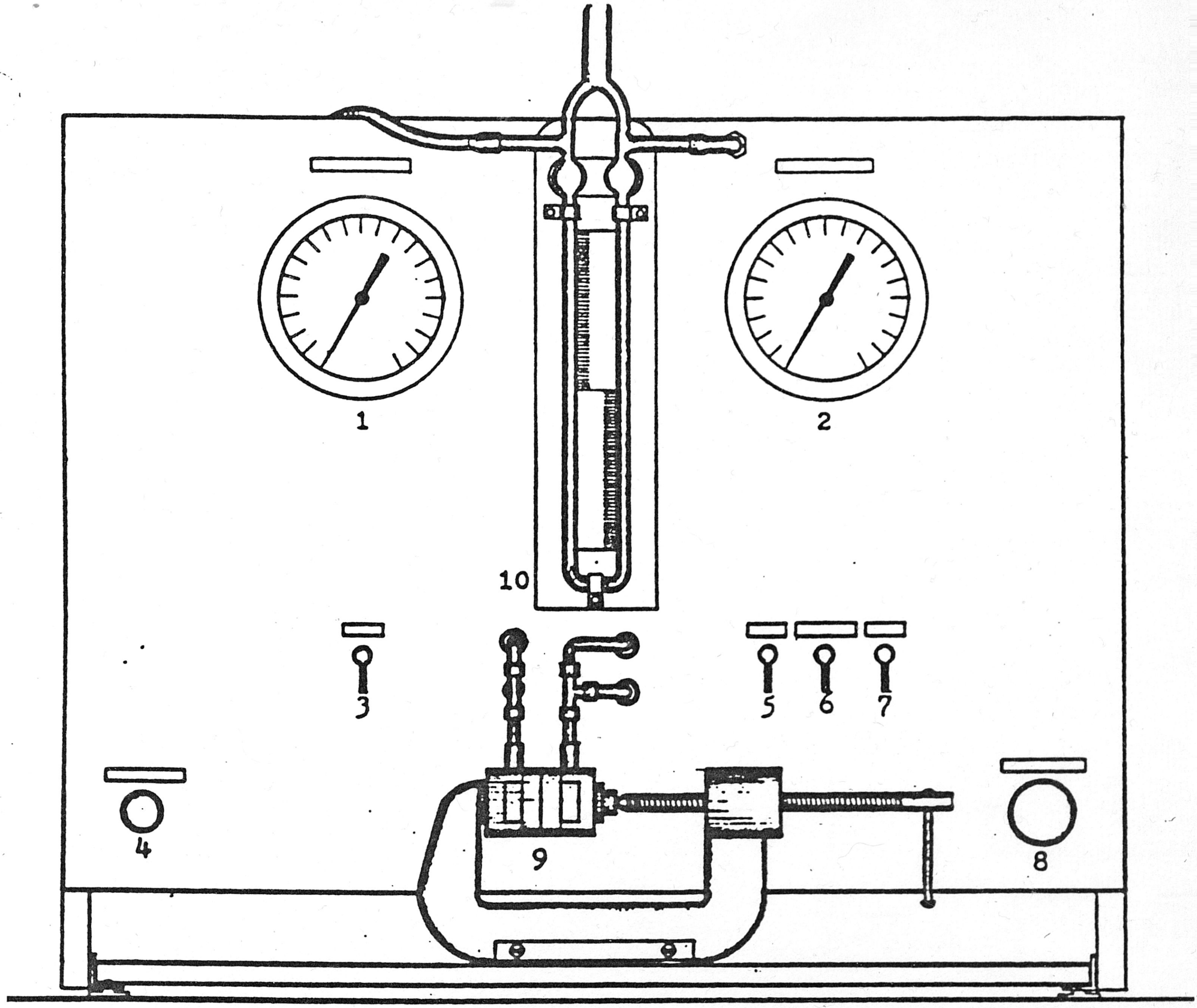
HELIUM POROSIMETER



HELIUM POROSIMETER DIAGRAM

AIR PERMEAMETER

The air permeameter is used to determine the permeability of a core sample when air is the fluid flowing through the core. First, the sample to be tested is placed in the Hassler sleeve of the air permeameter. Dry air flows through the core and out the flowmeter. When the flow has stabilized, the upstream and downstream pressures are read from the pressure gauges. The flow rate is calculated using the flowmeter reading and empirically determined curves for each exit orifice size. This procedure is repeated for several different flow rates to obtain a curve from which permeability can be calculated.



1. Downstream Pressure
2. Upstream Pressure
3. Gauge Valve
4. Metering Valve
5. Gauge Valve
6. Atmosphere Valve
7. Air Valve
8. Pressure Regulator
9. Hassler Sleeve
10. Flowmeter

AIR PERMEAMETER