DB-550

POROSITY DETERMINED FROM NEUTRON, DENSITY AND SONIC LOGS IN WESTERN TIGHT GAS SANDS

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Research Conducted for
United States Department of Energy

ABSTRACT

The tight gas sands of the Rocky Mountain Region contain large volumes of gas; yet, to date there is very little production from this region. One of the reasons for the lack of exploitation of this valuable reserve may be the inability to accurately evaluate the reserve. The most practical way to evaluate this resource is with wire-line logs. Therefore, research is being conducted in order to determine the best methods of evaluating this reserve. Specifically, the research is being directed toward evaluating the ability of the neutron, the density and the sonic log to predict the porosity of the subsurface formations.

Laboratory techniques designed to measure the porosity of reservoir rock are being evaluated to determine the most reliable method for determining the porosity of the tight western gas sands.

The initial results of calculating the porosity from wire-line logs indicates that the porosities calculated from the density log are in closer agreement with the porosities determined on core samples than the porosities calculated from the sonic log or the neutron log. The matrix density used in calculating the porosity from the density log was found to be higher for the tight shaley sands than for the cleaner, more porous sands.

INTRODUCTION

Tight gas sands of the western part of the United States including Utah, Colorado, Wyoming, Montana and New Mexico are being scrutinized for possible development.[1]

Tight gas sands of the western United States have not been fully exploited for several reasons;one may be the lack of description and understanding of the physical features of these sands. In an attempt to bring this gas to market, research was conducted to study the logging methods that are available to evaluate this resource. Specifically, in this study the ability of the density, neutron, and sonic logs to accurately predict the porosity is being evaluated by comparing the predictions of these logs with actual measurements of porosity of core samples. In addition, several methods of determining the porosity in the laboratory are being investigated to determine if the usual techniques employed in determining the porosity of the more permeable sands can be used in the determination of porosity of these very tight western gas sands.

The tight western gas sandstones have shown a marked decrease in permeability with increasing overburden pressure in the laboratory results that have been reported to date. By contrast, the reports indicate that the porosities when subjected to increased overburden pressure may decrease only slightly.[2,3] It is the purpose of this research to determine the best method of determining the porosity in the laboratory that is representative of the porosity that exists in the reservoir.

Laboratory results will be compared with the readings of wire-line logs so that techniques may be developed to predict the porosity of subsurface formation.

LABORATORY MEASUREMENT AND CALCULATION

Sections of core from the Natural Buttes 21 in Unita County, Utah, (See Figure I) has been received in our laboratory. Plugs 1-1/2 inch in diameter have been cut from this core and properties of these samples are being measured at this time. Ten representative samples were selected from the core, and have been analyzed petrographically in great detail. Table 1 shows the depth of the plugs that have been analyzed petrographically. The analysis included percentages of quartz, feldspar, plagioclase, carbonate, mica and the relative amounts cement free. Porosity and matrix density of each of the samples are also shown in this figure. In addition, sieve analysis for each of the ten samples has been completed and histograms for each of the samples were constructed. The properties of the subsurface formation based on the analysis of the core samples will be related to the density, to the sonic travel time, and to the porosity from the neutron log using regression analysis techniques as outlined by Von Gonten[4] in an effort to develop an accurate technique for determining the porosity of these western gas sands.

Porosity of the samples cut from the cores are being measured in the laboratory using three basic techniques. The porosity is being determined by measurement of the matrix volume using a gas (helium) expansion technique. The bulk volume is determined by measurement of dimensions of the core sample and by immersion of the core sample into mercury. The porosity is then calculated.

The porosity is also being determined by direct measurement of the pore volume using gas expansion. The porosity is calculated using this direct measurement of pore volume with the previously measured bulk volume.

The third method used to determine the porosity is the saturation method. The sample is dryed in an oven at 99°C and then the weight obtained. The sample is then evacuated and saturated with kerosene. The weight of the sample is then determined together with the density of the kerosene. The porosity is calculated using the previously determined bulk volume.

All three of these methods are used by various laboratories to determine the porosity of conventional cores. By comparing the measurements of porosity by the three methods, it will be determined which of the methods is the most reliable.

Once the most reliable method for measuring the porosity of the tight gas sands has been found, laboratory measurements will be made at increasingly higher confining pressures. An analysis of this data will provide an insight into how laboratory measurements must be conducted in order to accurately represent the porosity of the formations as they exist in the subsurface.

To date, the porosities that have been determined in the laboratory involve the direct measurement of the matrix volume of the sand. The porosimeter that has been used for the measurement of the pore volume of usual core samples was not adequate for measuring porosity of these very tight samples. Therefore, steps are being taken to modify the porosimeter in order to complete the measurements of the pore volume of the tight western gas sands.

To date the major effort to determine porosities using wire-line logs has been with the density log. Initially, the matrix of the rock was assumed to be sandstone. However, the laboratory measurements of the matrix density was higher than 2.65 gm/cc for the tight samples. One of the objects of the laboratory research will be to determine a method for predicting a matrix density to be used in the calculation of porosity from the density log using values obtained by conventional wire-line logs.

Table 2 presents a number of the samples taken from the core cut from the Natural Buttes 21 Well and the log depths from which the samples were taken. The core has been broken up into Zones A, B, C, through K to indicate intervals on the log from which log readings were obtained. Also presented in Table 3 are the actual porosities determined from samples in these intervals. For example, in Zone A the lowest gamma ray reading in this interval was found to be 70. The highest gamma ray reading was 80. The lowest porosity calculated from the density log from this interval was around 2.6% and the highest porosity in this interval is about 2.7% . The porosity of core samples measured in the laboratory from this interval showed that the lowest porosity was about 2.6% and the highest porosity was around 2.68%. As yet the gamma ray readings have not been incorporated in the calculations of porosity. However, it is hoped that the relative gamma ray readings may be used to indicate the shaleness of the sample and therefore, add a correction to the determination of the porosity as calculated from the various logs to better represent the actual porosity of the formations.

PRELIMINARY FINDINGS

Most of the log interpretation to date has been concentrated on the density log. In these initial calculations, the porosity determined from the density log appears to be in better agreement with porosity measured in the laboratory than do the other logs. The preliminary investigations indicate that the density log is very sensitive to the conditions of the hole. The density log does not approximate the porosity in intervals that are washed out. Therefore, it appears that to utilize the density log, the caliper log must be considered to make sure that the hole is not enlarged in intervals for which the porosity is being calculated.

The laboratory measurements of the matrix density of samples taken from the Natural Buttes 21 Well indicate that the density is usually higher than the average value of 2.65 gr/cc for sandstones. Figure 2 presents the matrix density of a number of samples from Natural Buttes 21 Well as a function of the porosity as determined in the laboratory. The samples were broken up into three groups according to their appearance. The tightest samples tended to have the highest matrix density actually above 2.7 gm/cc. The matrix density of the high porosity samples appears to be in the range of 2.65 gm/cc.

The sieve analysis of the samples indicates that the lower porosity samples tend to have a higher percentage of fines than do the higher porosity samples. This is probably not unusual since most researchers would expect a reduction in porosity and a reduction in permeability with an increase in fines. However, it appears that the matrix density of the low porosity rock which contains a high concentration of fines, tends to be higher than the matrix density of the rocks having higher porosity is rather unusual compared with normal log analysis. In general, the fines are associated with shales and, therefore, tend to have a density which is usually lower than the density of the sand grains themselves. It is hoped that the detailed analysis of the samples will enable a method to be developed which can accurately calculate the porosity.

The plot of the porosity determined with the density log as compared with the porosity from laboratory measurements is displayed in Figure 3. In this figure, the porosity was calculated from the density log using a strandard sandstone matrix density. In the figure the maximum value calculated for each interval is presented as a large dot and the minimum value calculated from log is indicated as the small dot. In addition, the number opposite each interval inaicated the gamma ray reading for this interval.

One of the first efforts in order to correct the density log values will involve the use of the gamma ray log to determine the fraction of the rock that may contain shales. The properties of the shales in this area appear to be different than the properties found in the rest of the United States.

Preliminary observations indicate that the porosities determined from the sonic logs tend to be somewhat higher than the porosities determined from the density log. It appears that the variation of the sonic travel time in the matrix may behave differently than normally expected in reservoir rock. Both the sonic travel time and matrix density are being correlated with the gamma ray log which is being used as a shale indicator. Again, the results are sketchy, but it appears that the influence of shale on the sonic log and the density log could be quite different from that normally expected inusual oil and gas fields in the rest of the United States.

Attempts to use neutron logs to determine the porosities have met with very little success to date. This can be attributed in most cases to the fact that very little care has been taken in calibrating the old neutron logs. In fact, a large number of runs actually were made simply to correlate and there was no attempt to calibrate the logs to determine porosity. However, as more cores become available and calibrated neutron logs are made available a technique will be developed for obtaining porosity from the neutron log.

CONCLUSIONS

Based on the analysis of one core obtained from the Natural Buttes 21 Well, it appears that the density log provides closest agreement with the actual porosities determined in the laboratory. The matrix density of the western gas sands appears to be higher than 2.65 and the matrix density appears to be a function of porosity. That is, the lower porosity formations tend to have a higher matrix density.

The sonic log based on preliminary examination indicated that the porosity calculated from the log tends to be higher than the porosity obtained from the density log.

The neutron log has not been very accurate in predicting the porosity of subsurface formations apparently primarily due to the fact that very little care has been spent in calibrating the log to measure the porosity.

REFERENCES

1. Haun, John D., Geologic History of Rocky Mountain Region. Bulletin of the American Association of Petroleum Geologist (1965) p. 1781-1786.

2. Short, J. A., Massive Frac. Treatments Tapping Tight Gas Sands in Uinta Basin. Oil and Gas Journal (1978).

3. Rex, D. Thomas, Effects of Overburden Pressure and Water Saturation on Gas Permeability of Tight Sandstone Cores, Petroleum Trans., SPE-AIME (June 1971) p. 50.

4. Von Gonten, W. D. and Whiting, R. L., Correlation of Physical Properties of Porous Media. SPE paper 1720 (Feb. 1967) p. 266.

TABLE 1

NATURAL BUTTES #21

SAMPLES STUDIED PETROGRAPHICALLY

Sample Number	Log Depth	Porosity(%) Porosimeter	Density (gr/cc)
5	4457'	2.82	2.68-2.685
7	4459'1"	5.15	2.69-2.697
16	4465'10"	4.17	2.70-2.703
12	6472'1"	8.48	2.64-2.645
13	6472'9"	5.52	2.67-2.674
30	7425'6"	6.47	2.72-2.724
25	7476'8"	2.47	2.750-2.751
32	7481'	5.61	2.699-2.70
38	8435'4"	10.09	2.65-2.657
43	8483'	2.64	2.67-2.669

TABLE 2

CODING OF SAMPLES FROM NATURAL BUTTES 21

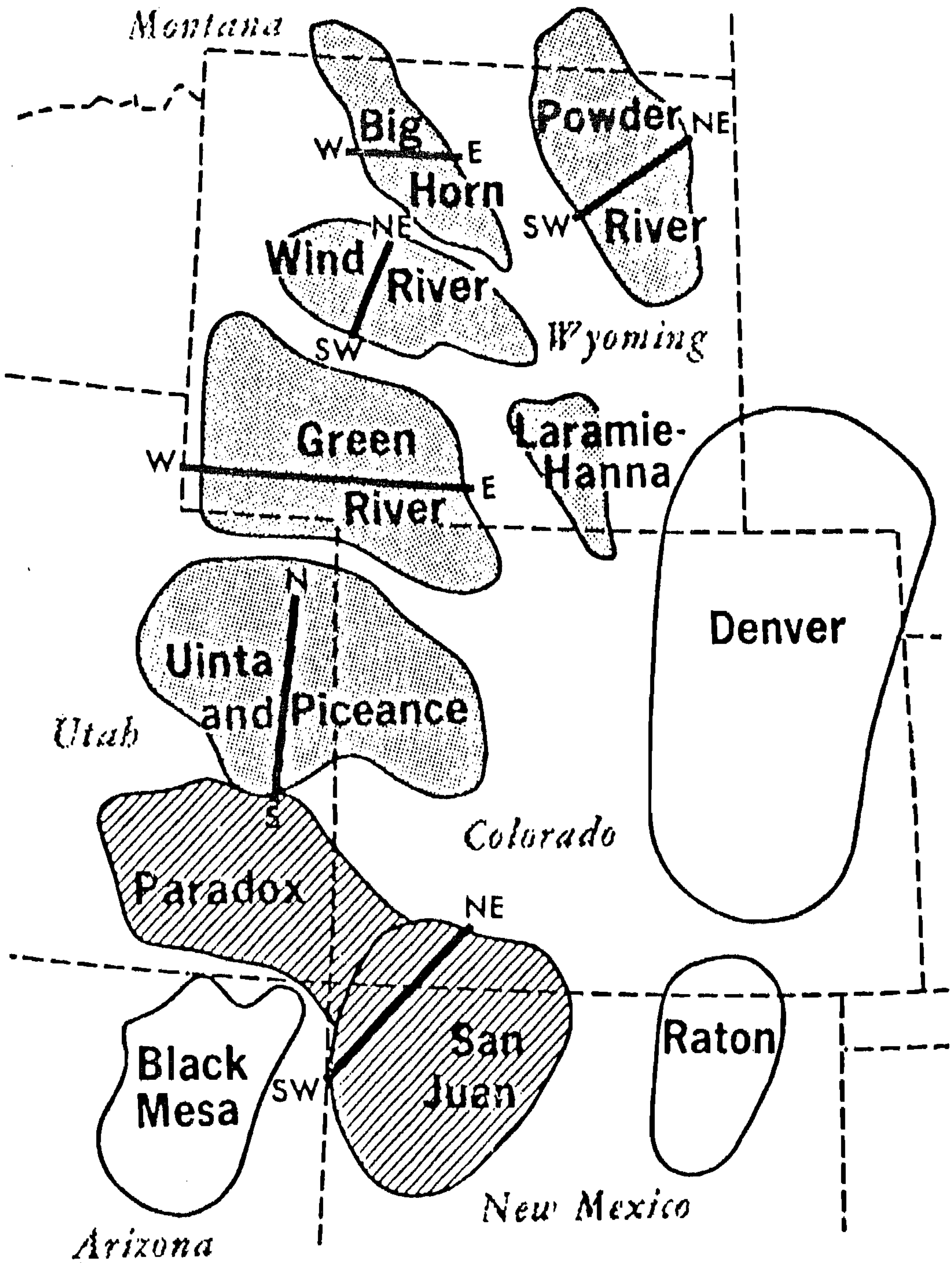
Plug #	Log Depth in Feet	Zone
2	4441'4½"	A
1	4441'6½"	
3	4441'9½"	
4	4442'	
5	4457'	B
9	4457'6"	
8	4458'10"	
7	4459'1"	
6	4460'6"	
10	4463'8"	
11	4463'11"	
16	4465'10"	
17	6405'	C
18	6405'10"	
19	6406'	
	6423'8"	D
12	6472'1"	E
13	6472'9"	
14	6473'1"	
15	6473'10"	
28	7423'	F
29	7424'	
30	7425'6"	
21	7426'	
22	7426'11"	
23	7429'	
24	7430'	
25	7476'8"	G
26	7478'1"	
27	7479'3"	
31	7479'6"	
32	7481'	
33	7482'	
34	7482'1"	
35	8425'	H
36	8425'11"	
37	8434'6"	I
38	8435'4"	
39	8436'1"	
40	8437'	
41	8438'2"	
42	8439'	
43	8483'	J
44	8510'	K
45	8512'3"	
46	8513'	
47	8514'	
48	8515'3"	

TABLE 3

NATURAL BUTTES # 21 - LABORATORY MEASURED POROSITY, GAMMA RAY & DENSITY LOG VALUES

	From Log				From Porosimeter	
Zone	Lowest Gr	Highest Gr	Lowest ϕ	Highest ϕ	Lowest ϕ	Highest ϕ
A	70	80	2.6	2.7	2.6	2.68
B	67	78	0	2.5	2.8	5.2
C	70	90	2.5	13	4.2	4.2
D	70	85	2	5	1.5	6.4
E	60	100	5	10	5.5	10.8
F	40	90	5	7.8	5.1	9.0
G	50	100	2.5	15	2.5	6.2
H	30	35	5	10	3.8	4.1
I	25	34	6	12.5	7.2	10.1
J	25	30	9	15	2.6	2.6
K	25	33	7.5	12.5	3.8	10.

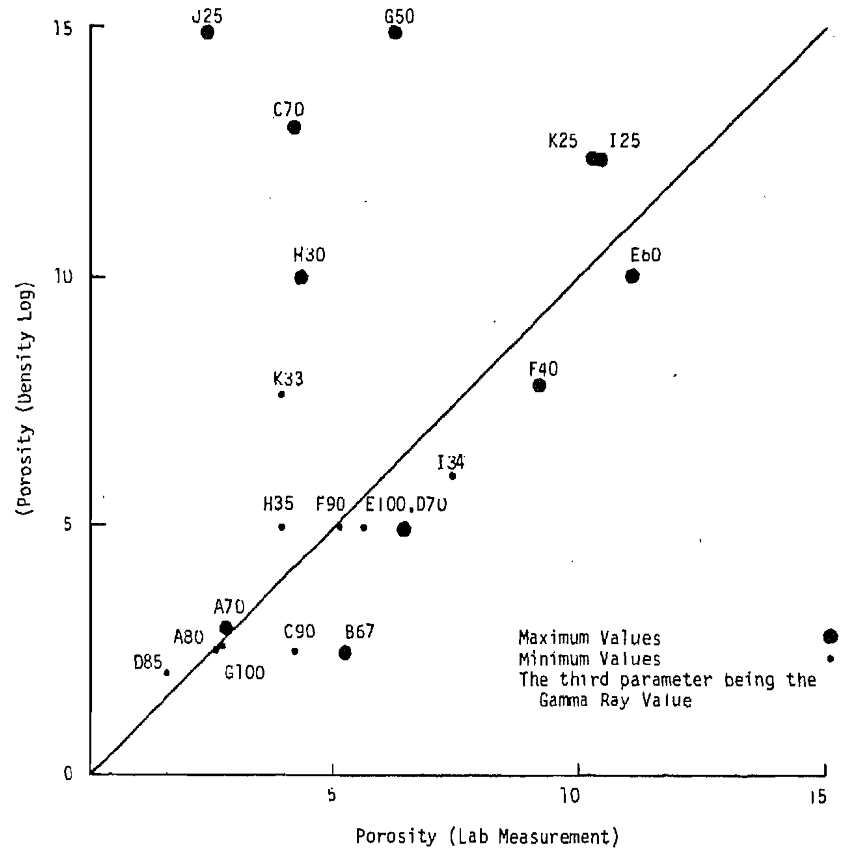
Figure 1



(From Barlow, James A., Rocky Mtn. Asso. of Geol., 1968)

Figure 3

POROSITY FROM DENSITY LOG AND CORE ANALYSIS
Natural Buttes # 21



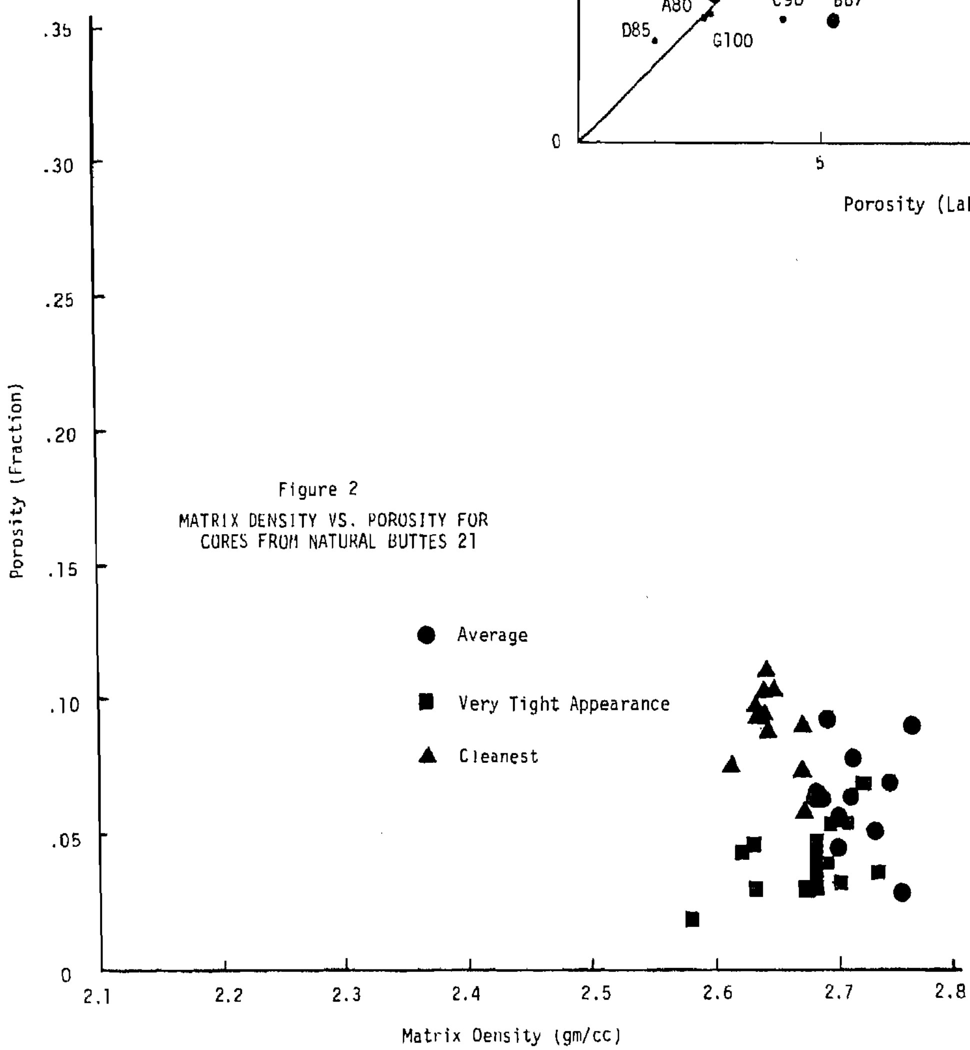


Figure 2

MATRIX DENSITY VS. POROSITY FOR CORES FROM NATURAL BUTTES 21