SPE 26060

Permeability Evaluation in Heterogeneous Formations Using Geophysical Well Logs and Geological Interpretations

S. Ameri, D. Molnar, S. Mohaghegh, K. Aminian
West Virginia University
SPE Members

This paper was prepared for presentation at the SPE Western Regional Meeting held in Anchorage, Alaska, 26-28 May 1993.

ABSTRACT

Permeability is the key parameter for reservoir characterization. The permeability of the formation is usually evaluated from the cores and/or well tests. It should be noted that cores and well test data are often only available from few wells in a reservoir while the well logs are available from the majority of the wells. Therefore, the evaluation of permeability from well log data represents a significant technical as well as economic advantage.

The evaluation of permeability in heterogenous formation from well log data however represents a difficult and complex problem. Generally, a simple correlation between permeability and porosity cannot be developed in heterogenous formation. The goal of this study has been to develop a generalized methodology to determine the permeability of a heterogeneous formation utilizing geophysical well logs as well as other geological information.

Granny Creek Field in West Virginia has been selected as the study area in this paper. This field has produced oil from Big Injun Formation since early 1900's. The waterflooding operation was initiated in 1970's and currently is in progress. Well log data are available on substantial number of wells. Core samples are also available from a few wells. Core samples and the well logs were analyzed to determine permeability, porosity and water saturation. The results of core and log analysis were complemented by geological interpretations to develop a correlation between permeability and well log responses. The results presented in this paper could serve as a guideline for correlating permeability with well logs responses in heterogeneous formations. A systematic and synergetic approach which integrating data from various well logs as well as depositional, lithological and sedimentological interpretations has been developed to evaluate the permeability.

INTRODUCTION

Reservoir characterization play a critical role in appraising the economic success of reservoir management and development methods. The prediction of permeability distribution is the most critical aspect of reservoir characterization. Nearly all reservoirs show some degree of heterogeneity due to the contrasting lithologies, digenesis, or sedimentological complexity. Characterization of heterogeneous reservoirs is a complex problem. The problem stems from the fact that sufficient data to accurately predict permeability distribution is not usually available. The permeability of the formation is usually evaluated from the cores and/or pressure transient tests. Cores and well test data however, are available only from few wells in a reservoir. At the same time, the geophysical logs from the majority, if not all, of the wells in the reservoir are usually available. Consequently, the evaluation of permeability from well log data represents a significant technical as well as economic advantage.

Prediction of permeability from porosity begins with the relationship between core porosity and core permeability, which is then generalized by calibration of well logs so that permeability can be prrJicted from log porosity throughout the reservoir. The attempts to predict permeability from well log data has generally been in the form empirical correlations between permeability, porosity, and water saturation (1). This technique has been used with some success in sandstone (2) and carbonate reservoirs (3,4). However, the exiting correlation are mainly for homogeneous formations that have fairly constant porosity and grain size.

The objective of this study is to investigate the feasibility of evaluating permeability distribution for a heterogenous reservoirs utilizing geophysical well logs as well as geological interpretations. Granny Creek field in West Virginia has been selected as the study area. The producing horizon in the Granny Creek field is the upper Pocono Big Injun sand of Lower Mississippian age that is characterized by sever heterogeneity.

BACKGROUND

The Granny Creek oil field is located approximately 25 miles northeast of Charleston, West Virginia (see Figure 1). The field is located structurally on the northwest flank of a syncline which strikes N 15-20 degrees east to S 15-20 degrees west.The oil accumulation was partially controlled by porosity and permeability variations as well as structure. The producing horizon in the Granny Creek field is the upper Pocono Big Injun sand of Lower Mississippian age. The Pocono Big Injun sandstone has been subdivided into three informal members (see Figure 2) that correspond to grain-size distribution and bulk density variations(5,6):

(1) A member: the upper coarse-grained sandstone and conglomerate (low densit) of the channel facies with generally good porosity and permeability.

(2) B member: the underlying coarse-grained sandstone and conglomerate (high density) with poor porosity and permeability.

(3) C member: the basal fine-grained sandstone (low density).

Laterally, the C member consists of prograding tongues, numbered from oldest to youngest, respectively, as Cl, C2, and C3 within Granny Creek field. The C member and its tongues represent a facies deposited in a deltaic river-mouth bar environment and the subfacies are the distal and proximal parts of the bar, further distinguished by whether dominated by marine or fluvial processes (see Figure 2). The best porosity and permeability in Granny Creek field occur more consistently in the proximal mouth-bar facies of the Big Injun(6).

The digenesis played an especially important role in contributing to the heterogeneity of the Big Injun reservoir in Granny Creek field, particularly in terms of porosity and permeability. The initial porosity and permeability of the A and B members probably, was high, but cementation of the B member during burial produced a digenetic facies. The main factor in porosity preservation in the proximal mouth-bar interval was the development of well-formed chlorite coatings that restricted quartz cementation. A combination of these factors came into play to lower porosity of distal mouth-bar facies to some extent and drastically reduce permeability (6).

The field was developed over a period of nearly 30 years beginning in 1916. Production has continued throughout most of the field until the present day.The field is roughly five miles long, has a maximum width of a little over two miles, and has a total productive area of about 3,000 acres . The crude oil in Granny Creek field is a paraffin base, Pennsylvania Grade oil. It has a viscosity of 3.14 cp at atmospheric pressure and 75°F., and a liquid gravity of 45.4°API at 60°F. Total oil production is estimated to be between 6,500,000 and 6,750,000 barrels.

The waterflooding operations in Granny Creek Field were initiate during the 1970's and early 1980's. The waterflood has been moderately successful. However, the waterflood areal and vertical sweep efficiencies have been poor due to the heterogeneous nature of the formation. A tertiary recovery CO_2 pilot project was conducted beginning in 1976. Because of the extremely heterogeneous nature of the reservoir formation, less that 4 percent of the injected CO_2 entered the pattern. Even this small amount was responsible for the production of over 4000 barrels of oil from within the pattern. This recovery was considered very good under the circumstances. A minitest CO_2 project was conducted in a part of the same pattern several years later. A small amount of additional oil was produced. The CO_2 flood has not been expanded because of poor economics.

METHODOLOGY

The objective of this study is to predict permeability of Big Injun Formation in Granny Creek Field from well log data. Due heterogeneous nature of the Big Injun Formation, it was necessary to divide the formation into practical subunits (or zones) that internally show a trend in permeability variation and homogeneity with respect to facies content. Subsequently, the permeability variations in each zones will be studied as function well log data to investigate the existence of a correlation between permeability and log data.

The results of the whole (or full diameter) core analysis on 7 centrally located wells in the Granny Creek field were available (see Figure 1). Gamma Ray, Induction, and Density Logs were collected for all these wells. The zones were identified and delineate based on geological interpretations (see Figure 2). The results of the whole core and logs analysis for various zones (based on stratigraphy, lithofacie, and depositional environments) were studied to develop correlations between permeability, porosity, water saturation, depositional environment,and pore type. However, satisfactory correlations could not be developed. The inability in finding a correlation between permeability and log data was contributed to insufficient accuracy of the whole core analysis. This is not to say that the physical measurements are inaccurate. However, the full diameter core analysis results represent the average rock properties over the interval of study. As a result, the whole core analysis has a tendency to ignore the rapid changes in rock properties that are common to heterogenous formations.

In order to alleviate the averaging problem with whole core analysis , two wells, were selected for detailed plug (or conventional) core analysis. The two investigation wells, as shown in Figure 1, are located on the most easterly (well 15-1110) and the most westerly (well 15-1134) sides of the field. Figures 3 and 4 illustrate the stratigraphic/lithologic interpretations for the two investigation wells. It is apparent that the stratigraphic/lithologic interpretations are not similar. For example, zone C3 in the 15-1110 well corresponds to the three bar depositional environments. In the 15-1134 well, zone C3 is absent and zones C2 and C1 correspond to these same deposits.

Core plug were taken at approximately 6-inch intervals throughout the length of the core in both investigation wells. The permeability and porosity values of the core plugs were measured in the laboratory. The comparison of the measured porosity values for core plugs and the porosity values evaluated from well logs indicated the need for some adjustments to overcome the inherent inadequacies in coring and core handling techniques. In other words, the core was moved up or down to provide a good match between porosity values determined from the core and log analysis. Figure 5 shows the comparison of core and log determined porosity values for well 15-1110.

The measured permeability values for the primary investigation wells and the log response values of bulk density, resistivity, and gamma ray are illustrated in Figures 6 and 7. Actual log response values were selected in order to minimize any assumptions that are needed for determining porosity and water saturation from well logs. The permeability values as function well log responses were studied for previously defined stratigraphic/lithologic zones. Although, the results of data evaluation indicated a general trend might exist between permeability and bulk density but, the scatter in data points was significant enough to preclude possibility of developing a correlation. This failure to develop correlations can be mainly contributed to qualitative nature of geological interpretations relative to depositional environments, grain-size, stratigraphy, and lithology. In other words, the boundaries of the various zones are approximately defined. Therefore, it is necessary to integrate the geological descriptions of the various zones, geophysical well log responses and the trend of the permeability variations in order to define the zones quantitatively.

The comparison of log responses and permeability values on the two investigation wells indicated similarities on permeability variation and the responses in density, induction, and gamma ray logs from well to well. As a result, several zones were delineated in terms of log responses and annotated as Gamma Ray-Induction-Density (G.I.D.) zones 1, Transition, and 2. Zones 1 and 2 were further subdivided into 1A ,1B, 2A and 2B. As illustrated in Figures 6 and 7, zone 1A begins with the first cross over of induction and gamma ray log responses and terminates when they cross over again. Zone 1B initiates at this second cross over and terminates at the next cross over of induction and gamma ray responses. The transition zone starts at the last cross over and continues as density and induction log responses follow a decreasing trend while gamma ray response increases and then decreases. Zone 2A is characterized by relatively constant induction and gamma ray log responses. When the induction and gamma ray log responses begin to diverge zone 2B begins and continues to the end of the core. Figures 3 and 4, compare the

G.I.D zones, as defined in this study, for the two investigation wells with other geological interpretations.

RESULTS AND DISCUSSION

Figures 8,9, and 10 illustrate the permeability values for the two investigation wells that are plotted versus bulk density for G.I.D. zone 1, transition, and zone 2. Although there are few data points in zone 1, a trend can be postulated. The data in the transition zone, as expected, demonstrates lack of permeability - bulk density correlation. The existence of a well defined relationship between permeability and bulk density for zone 2 is apparent in Figure 10.

The data available from the 7 wells with whole core analysis, that are located between the two investigation wells, were utilized to evaluate the applicability of the correlations developed in the previous section. The G.I.D. zones were first delineated utilizing the log responses on each well. Figure 11 illustrates the log responses for one of these wells (15-1107). As it can be seen, the established trends of the log responses are present in this well (and all other wells). Therefore, the various G.I.D. zones can be readily delineated for each well. Figure 12 and 13 compare the results for zones 1 and 2 with the established correlation from the two investigation wells. Figure 12 indicates that the whole core analysis data have the same general trend (slope) as compare to the correlation for zone 1 but the data points are shifted toward higher permeability values. Several factors contribute to this situation. First, the correlation for zone1 is developed from limited data and is therefore unreliable at this point. Second, the permeability values determined from whole core analysis tend to be somewhat optimistic. It should be further noted that zone 1 is the less productive and/or unproductive part of the formation so it is of less interest. Figure 13, however, illustrate a fairly good agreement between the data points and the correlation. Considering the nature of whole core analysis data, the close agreement can substantiate the reliability of this correlation.

CONCLUSIONS

The followings conclusions were reached in this study:

1. It is plausible to develop a correlation for predicting the permeability from well log responses in heterogeneous reservoirs.

2. Whole core analysis is not sufficiently accurate for developing correlations in heterogenous formations.

3. It is necessary to use detailed conventional core (plug) analysis in heterogeneous formations.

4. It is necessary to integrate the geological interpretations, geophysical well log responses and the trend of the permeability variations in order to divide the formation into the zones for correlation purposes.

REFERENCES

1. Timur, A.: "An investigation of Permeability, Porosity, and Water Saturation Relationship for Sandstone Reservoirs," The Log Analyst, Vol.9, No.4, 1968.

2. Weber, K.J., and VanGeuns,L.C.: "Framework for Constructing Clastic Reservoir Simulation model, " JPT, Vol. 42, No.10, 1990.

3. Lucia,F.J. : "Petrophysical Parameter Estimated from Visual Description of Carbonate Rock : A Field Classification of Carbonate Pore Space,"JPT, Vol. 35, No. 3, 1983.

4. Licia, F.J., and Fogg, G.E.: "Geologic/Stochastic mapping of heterogeneity in a carbonate reservoir," JPT, Vol. 42, No. 10, 1990.

5. Donaldson, A., et al.: Measuring and Predicting Reservoir Heterogeneity in Complex Deposystems, Annual Report, DOE/BC/14657-7, August 1992.

6. Donaldson, A., et al.: Measuring and Predicting Reservoir Heterogeneity in Complex Deposystems, Annual Report, DOE/BC/14657, August 1993 (In print).

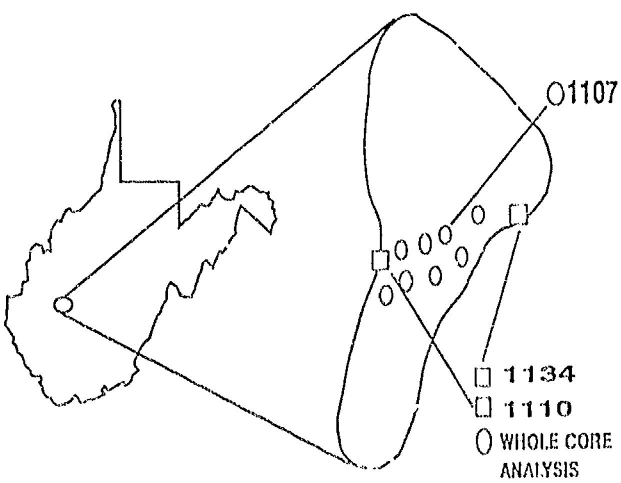

Figure 1. Granny Creek Field, West Virginia

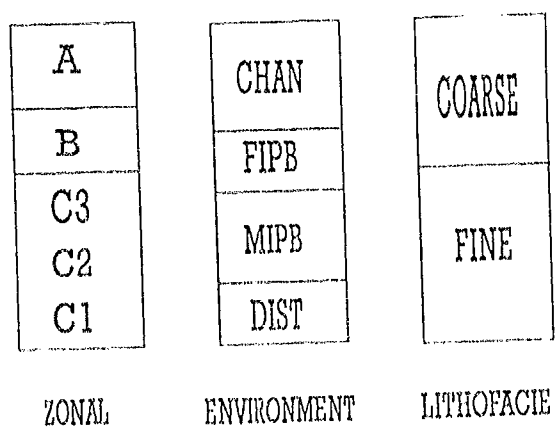

Figure 2. Various Geological Interpretations in Granny Creek Field

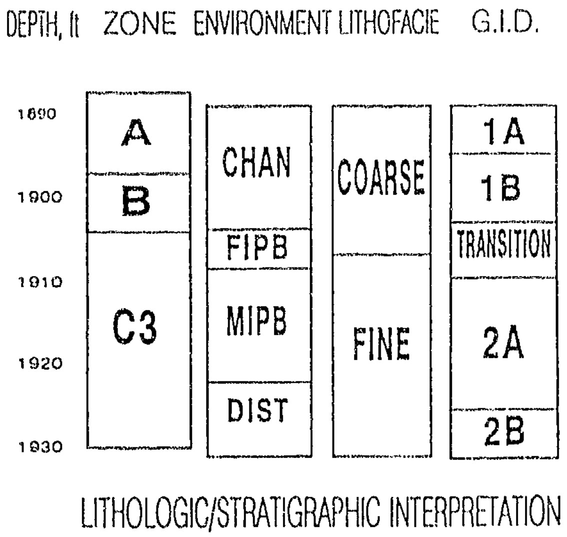

Figure 3. Geological Interpretations for Well 15-1110

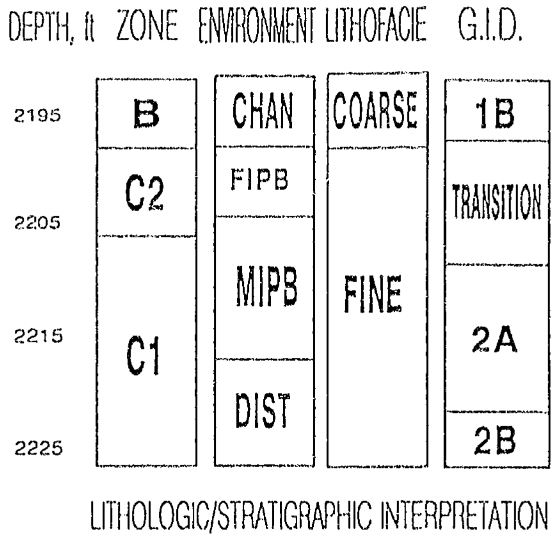

Figure 4. Geological Interpretations for Well 15-1134

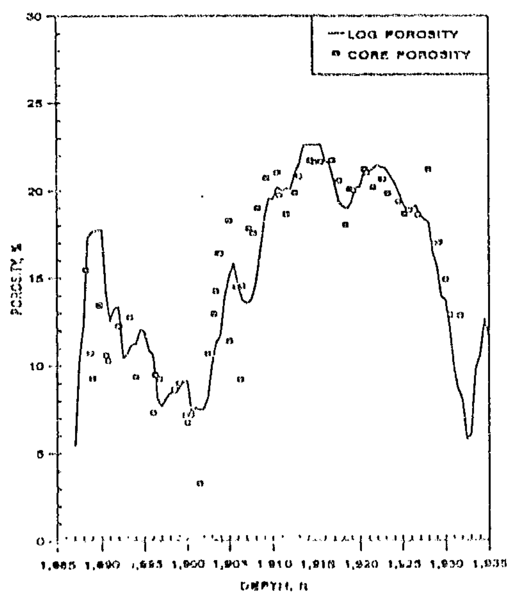

Figure 5. Core Porosity vs. Log Porosity for Well 15-1110

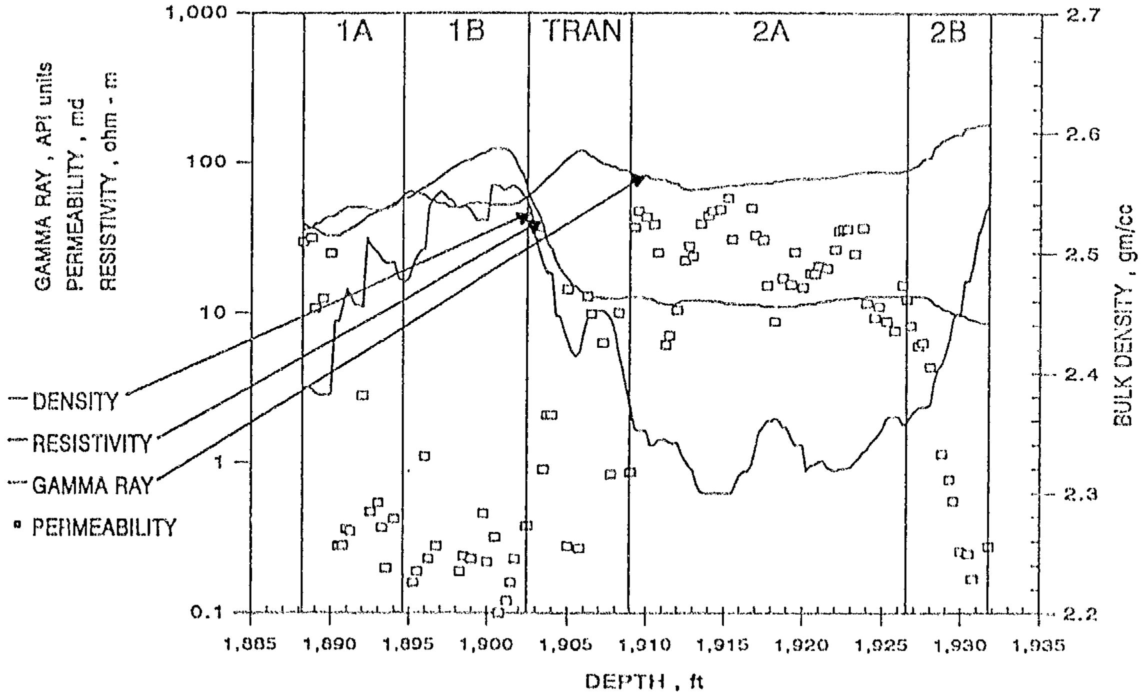

Figure 6. Core Plug Permeability and Log Responses for Well 15-1110

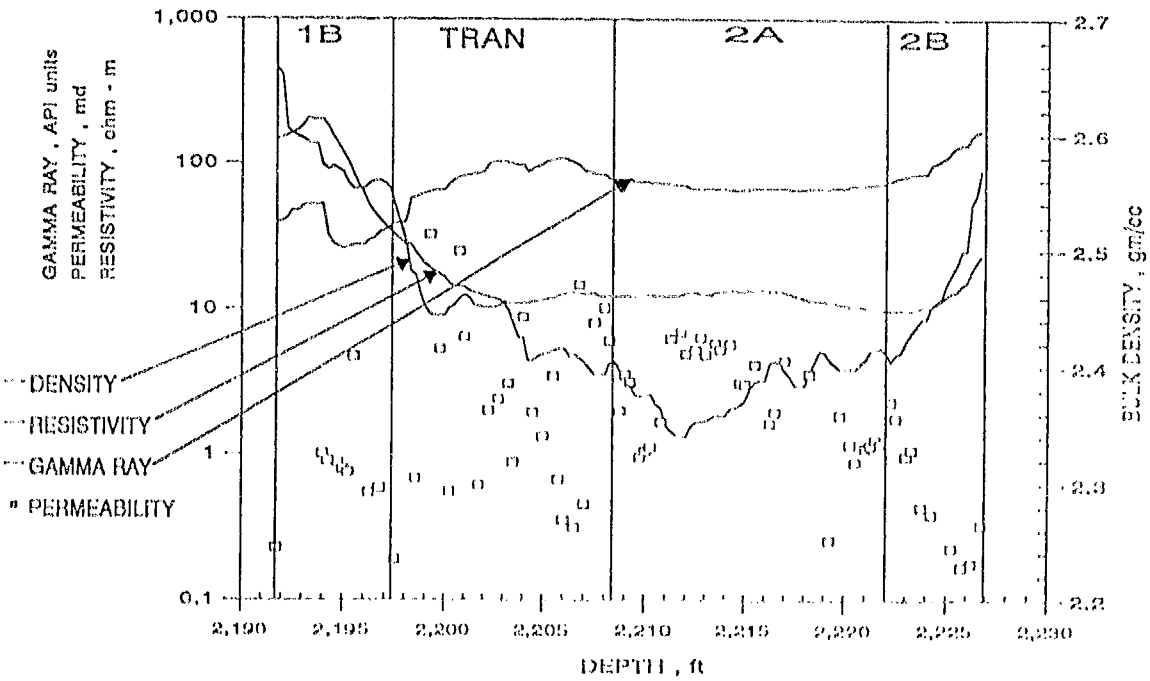

Figure 7. Core Plug Permeability and Log Responses for Well 15-1134

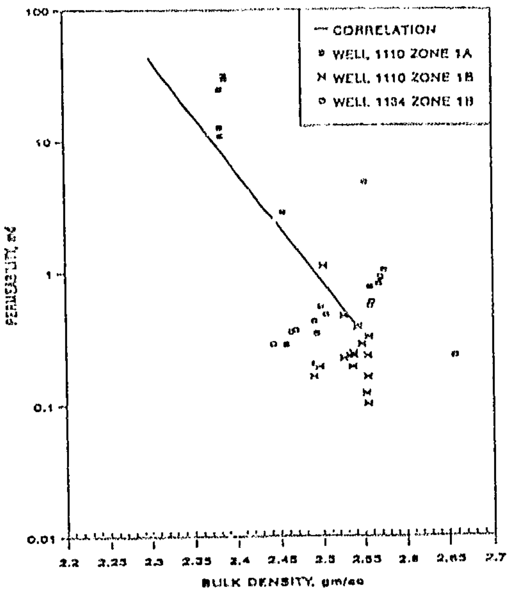

Figure 8. Permeability vs. Bulk Density for Zone 1

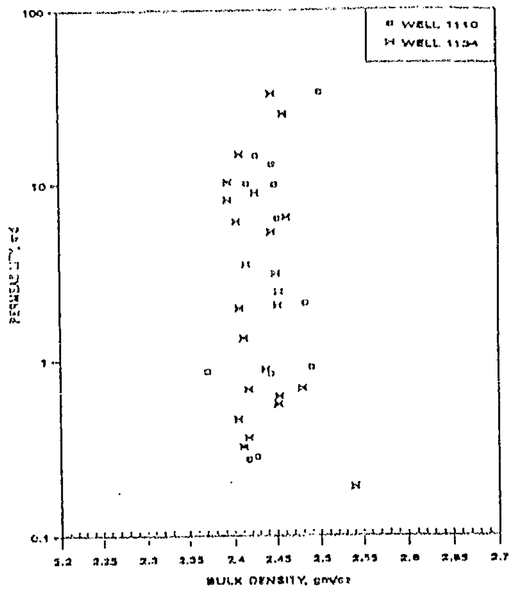

Figure 9. Permeability vs. Bulk Density for Transition Zone

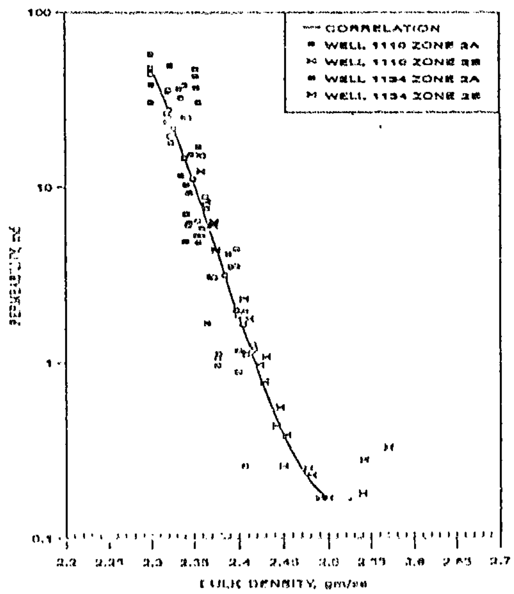

Figure 10. Permeability vs. Bulk Density for Zone 2

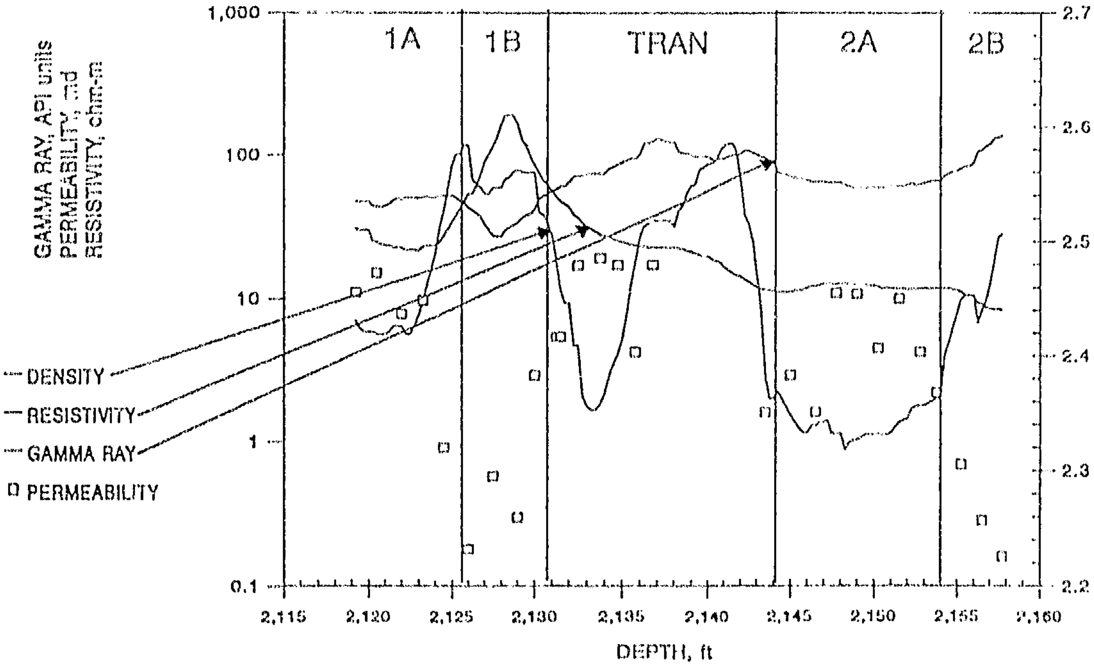

Figure 11. Whole Core Permeability and Log Responses for Well 15-1107

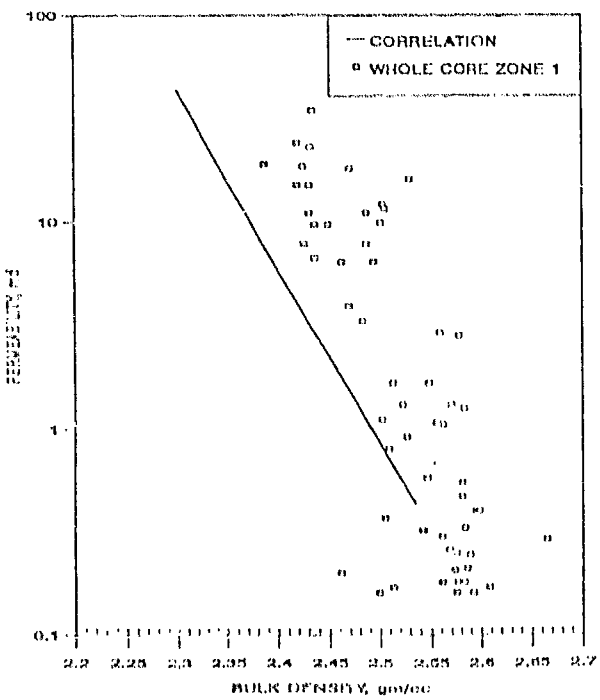

Figure 12. Whole Core Permeability vs. Bulk Density for Zone 1

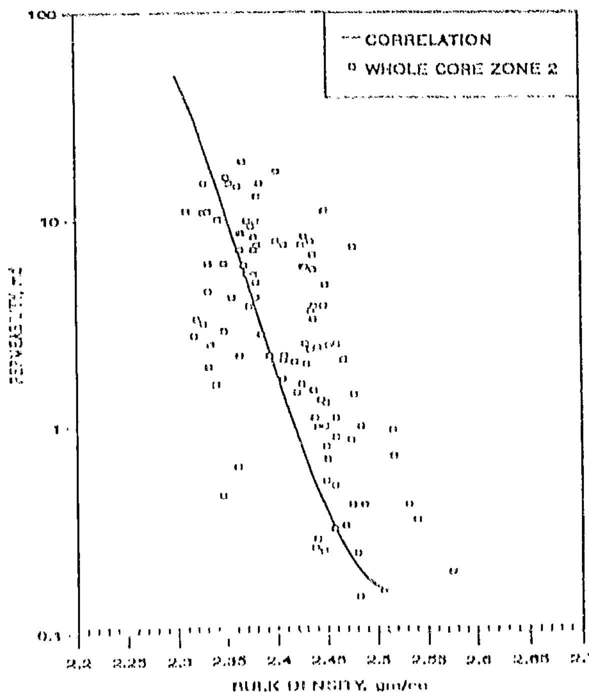

Figure 13. Whole Core Permeability vs. Bulk Density for Zone 2