FEASIBILITY OF ESTIMATING WATER QUALITY IN SHALLOW SANDSTONE AQUIFERS BY MEANS OF OUTCROP SAMPLING AND WELL-LOG ANALYSIS

By

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CHAPTER I

INTRODUCTION

Several formations of shale in Payne County contain thick strata of permeable sandstone. For some distance down-dip from the outcrops, these sandstones are saturated with potable water. In some areas of rural Payne County, many people rely on these local aquifers as sources of water for drinking, for household uses and for irrigation. Payne County has supported an active petroleum industry. Numerous oil wells in Payne County have fewer than 200 feet of surface casing and therefore some were logged through zones containing potable water. Resistivities recorded on wireline logs in these "fresh water" zones can be used to estimate general quality of water in the local aquifers. Samples from the outcrops of sandstones can be tested in the laboratory for amounts of permeability, porosity and resistivity. Information gathered in laboratory tests can be used to refine estimates of water quality made from wireline logs.

Purpose

The purpose of this research was to assess the feasibility of estimating the quality of water in a shallow sandstone aquifer in T. 18 N., R. 3 E., and T. 19 N., R. 4 E., Payne County, Oklahoma, by analysis of wireline logs. A secondary but directly related endeavor was to determine the feasibility of measuring petrophysical characteristics of the sandstone and using these measurements to refine estimates of water quality.
The purpose of this investigation can be described by four questions:

1) Can the outcrop of the sandstone be mapped adequately? 2) If the sandstone can be mapped adequately, can it be sampled to an extent sufficient to characterize its lithology and basic petrophysical properties? 3) If the outcrop can be sampled sufficiently, can data gained by testing the samples in the laboratory be summarized usefully? 4) Can the data from the analyses be used in conjunction with well logs to obtain reliable estimates of general water quality within the aquifer?

Overview of Procedure

A "formation" of sandstone in the Eskridge Shale was selected for this study. The sandstone is extensive at the surface and in the subsurface and is penetrated by domestic water wells. Boundaries of the study area were defined and the sandstone was mapped at the surface (Plate 1). A log-signature map (Plate 2) and four cross sections (Plates 3, 4, 5 and 6) were used to depict the sandstone in the subsurface. Samples were collected from outcrops and core plugs were extracted. Permeabilities of core plugs were measured and porosities were calculated. The plugs were charged selectively with water from the aquifer. Conductivity of the water was measured and converted to resistivity. Resistances of the water-filled core plugs were measured and converted to resistivities. Measurements of resistivity were used to calculate a range of "formation factors" of the sandstone. Formation factors and measurements of resisitivities from well logs were combined for estimations of general water quality in the aquifer.

CHAPTER II

GEOLOGIC SETTING

Geology of Payne County

Payne County is in north-central Oklahoma (Figure 1), on the Central Oklahoma Platform (Figure 2). At the surface, Upper Pennsylvanian and Lower Permian sedimentary rocks are overlain locally by Quaternary sediments (Figure 3). The Pennsylvanian System is represented by approximately 1400 ft. of strata of the Vamoosa and Ada Groups of the Virgilian Series and the Vanoss and Oscar Groups of the Gearyan Series. The Permian System is represented by about 800 ft. of the Wellington Formation of the Cimarron Series. The Quaternary System is recorded by alluvial terraces and by alluvium, mainly with the Cimarron River and some large creeks (Shelton, et al. 1985, p. 4-19). The Oklahoma Geological Survey has classified rocks of the Admire, Council Grove, and Chase Groups, Wolfcampian Series, Permian System, as the Vanoss and Oscar Groups, Gearyan Series, Pennsylvanian System (Shelton, et al. 1985, p. 4). Payne County is within the Prairie Plains Homocline, which dips westward from the Ozark Uplift. In Payne County, dip is westward at about 50 feet per mile. Locally, dip is as much as 200 feet per mile, in the vicinities of some structural noses, anticlines and synclines (Shelton et al. 1985, p. 36-38).

Geology of Study Area

The area of the combined geologic and subsurface maps is approximately 78 square miles. The study area extends from the Cimarron River near Ripley, northward to State Highway 51 and approximately 3 miles east and 7 miles west of State Highway 108 (Figure 3). Surface geology in the study area includes the Neva Limestone, Eskridge Shale, Garrison Shale and Doyle Shale of the Oscar Group.

The mapped area (Plate 1) is underlain primarily by the Neva Limestone and Eskridge Shale. The lowermost sandstone of the Garrison Shale is present in the southern one-third of the area.

Neva Limestone. The Neva Limestone is approximately 20 feet thick (Figure 4). The formation mostly is reddish brown shale, but interbedded with shale are three thin strata of limestone. The lowest bed is red, sandy, fossiliferous, limestone about one foot thick (Figure 5). The middle and upper beds of carbonate rock are red, sandy, dolomitic limestone. Each generally is less than one foot thick, and surfaces of both beds show tracks, trails and burrows (Ross 1970, p. 16).

Eskridge Shale. The Eskridge Shale is next above the Neva; it is approximately 80 feet thick (Figure 4). The Eskridge is bounded above by the Cottonwood Limestone. In terrain underlain by the Eskridge, exposures chiefly are sandstone; shale and siltstone are expressed poorly at the surface. Two thick, extensive strata of sandstone are near the base of the Eskridge. These were given the ad-hoc names "Pe-20" and "Pe-40" (Ross 1970, p. 19) and later "Pes-20" and "Pes-40" (Shelton et al. 1985, p. 10); their stratigraphic positions are approximately 20 and 40 feet above the base of the Neva, respectively (Ross 1970, p. 19). Position-in-sequence of these sandstones above the Neva is the main criterion in identifying them at the surface and in the subsurface, by means of wireline logs.

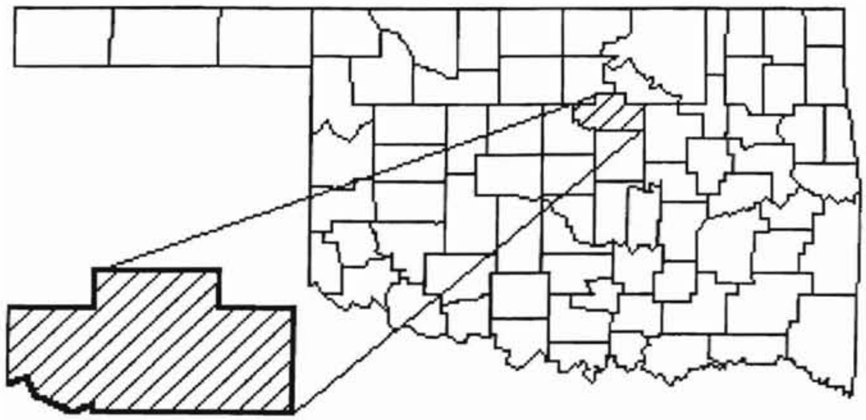

Figure 1. Location of Payne County, Oklahoma.

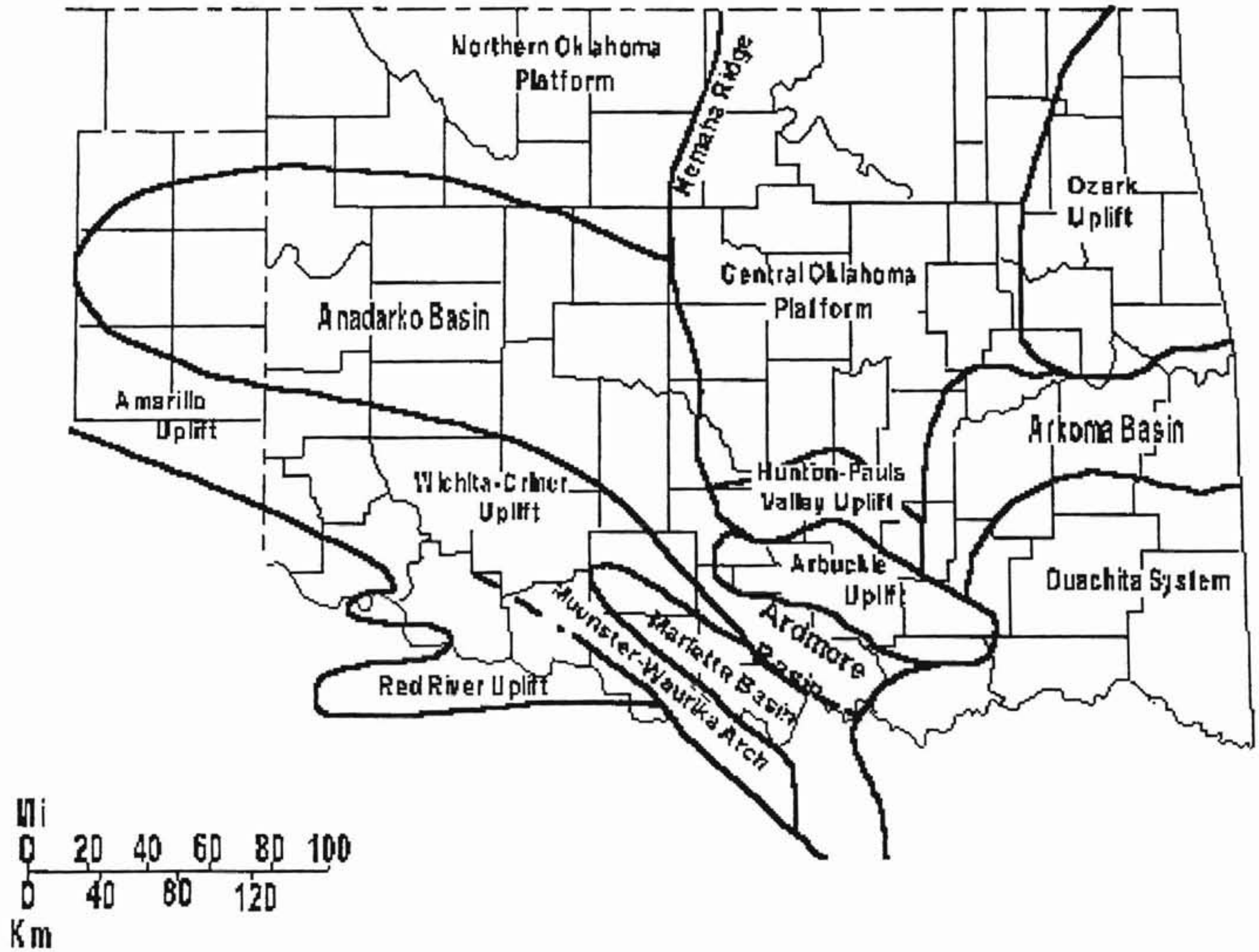

Figure 2. Geologic provinces of Oklahoma.

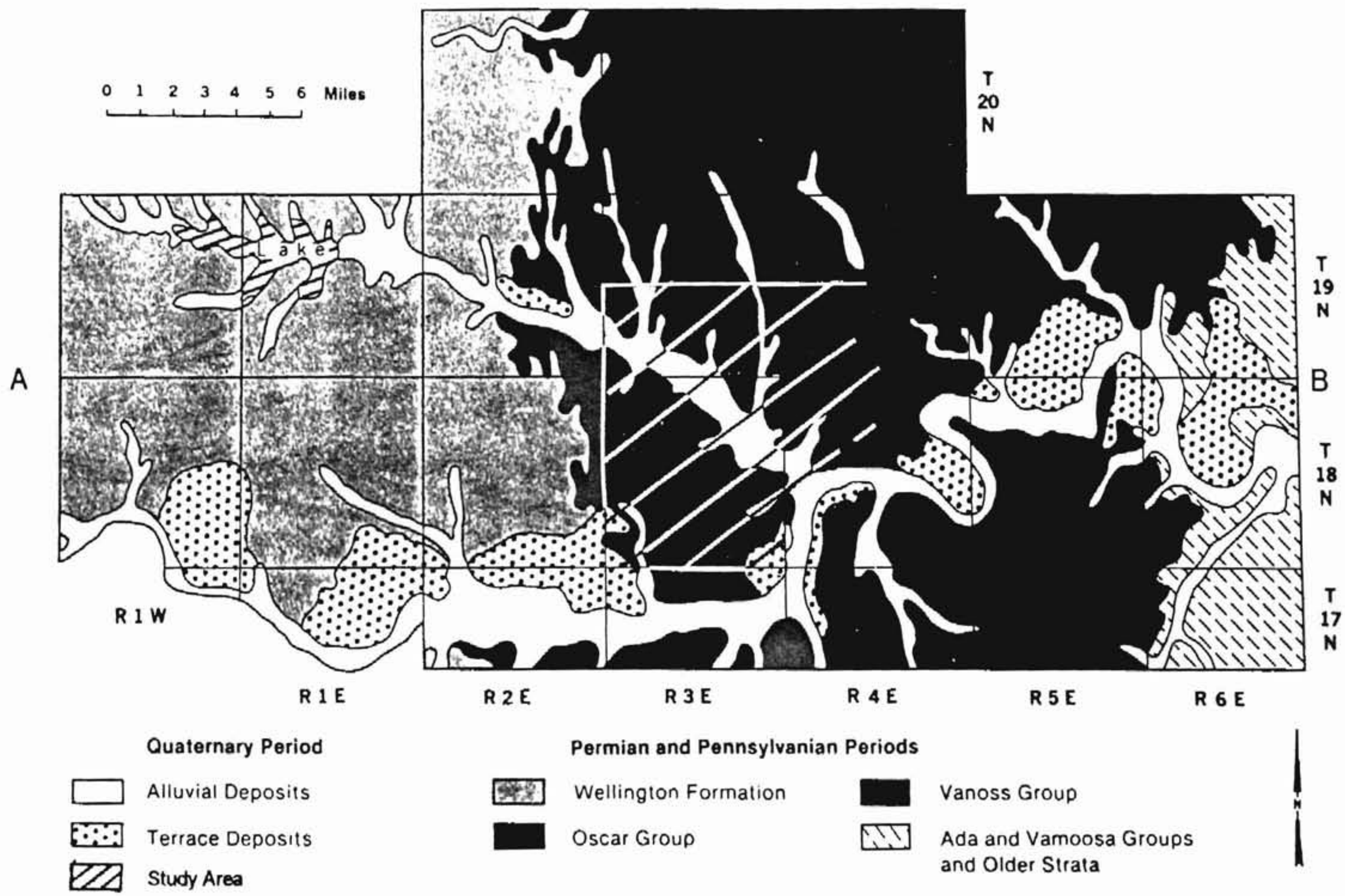

Figure 3. General Geology of Payne County, Oklahoma. Modified from Henley et al. (1987).

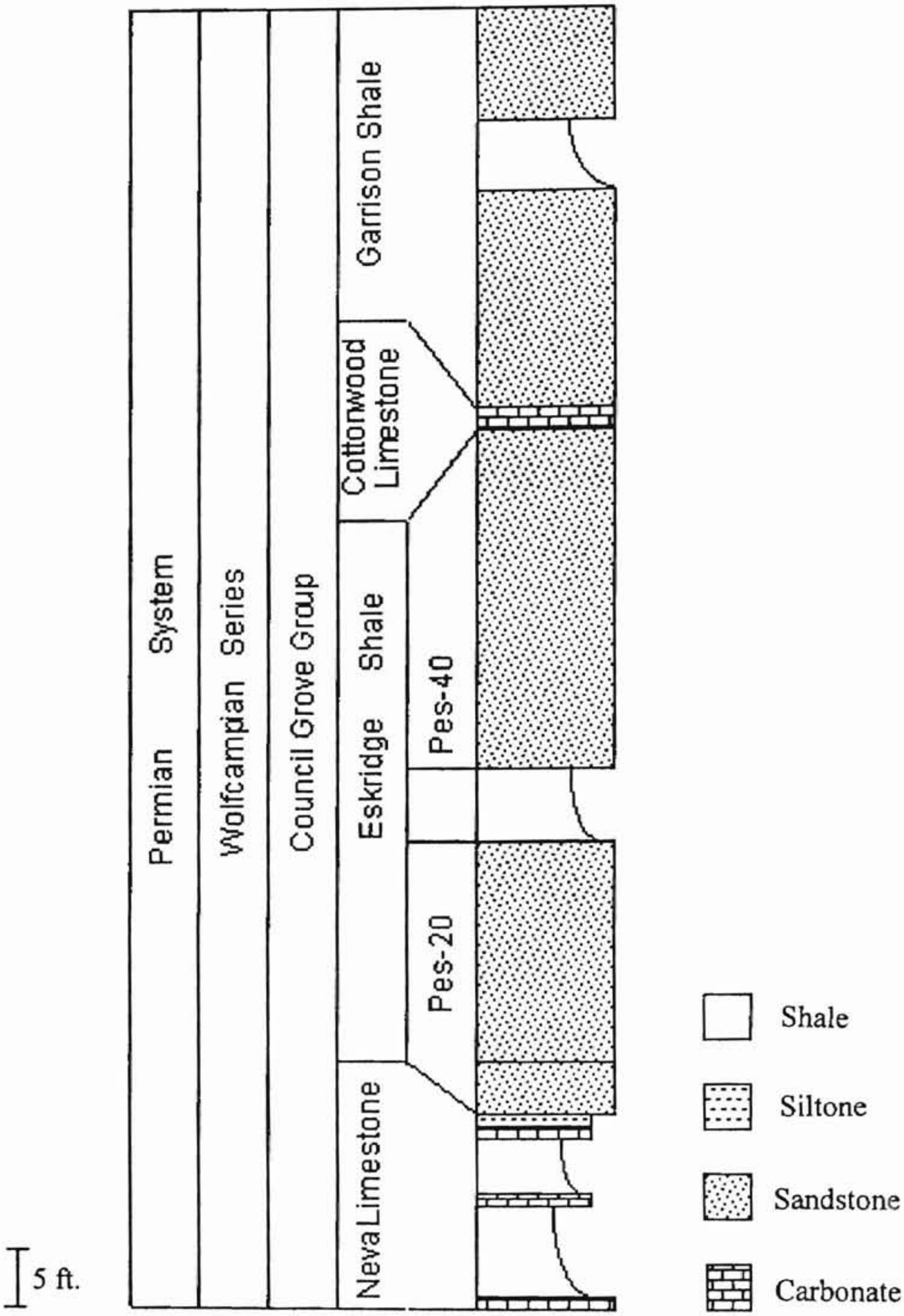

Figure 4. Generalized stratigraphic column, showing relative position of Neva Limestone, Eskridge Shale, Cottonwood Limestone and Garrison Shale.

The Pes-20 sandstone (Figure 6) is approximately 20 feet thick. It is predominantly a multistoried channel-fill complex that includes cutouts, clay-pebble conglomerate, trough cross-bedding, small-scale cross bedding, deformed bedding, ripple marks, and abundant ripple-marked bedding planes. The channel sandstones have an upward decrease in grain size from fine- to very fine-grained. In Sec. 19, T.18N., R.4E., a sandstone approximately 5 feet thick is below the channel-fill complex. This sandstone grades from silt to very fine-grained sand and contains burrows near the base and small-scale cross bedding near the top. It is cut out along the outcrop by the overlying channel sandstones (Figure 7).

The Pes-40 sandstone is approximately 30 feet thick (Figure 8). The sandstone decreases upward in grain size from fine- to very fine-grained and shows evidence medium-scale cross-bedding and deformed bedding (Ross 1970, p. 22).

Figure 5. Neva Limestone in NW/4, Sec. 19, T. 18 N., R. 4 E.

Figure 6. Pes-20 Sandstone in NW/4, Sec. 19, T. 18 N., R. 4 E.

Figure 7. Pes-20 Sandstone in NW/4, Sec. 19, T. 18 N., R. 4 E.

Figure 8. Pes-40 Sandstone in NW/4, Sec. 19, T. 18 N., R. 4 E.

CHAPTER III

PETROPHYSICAL PROPERTIES OF THE PES-20 SANDSTONE

Overview

The Pes-20 sandstone was sampled at outcrops and tested in the laboratory for petrophysical properties. In much of the study area the sandstone is fractured and very friable. Coring of highly friable samples results in cores of odd-shapes with diameters too small to fit properly in the permeameter or in the resistance cell. Additionally, cores of fractured rock break easily, commonly before they can be removed from the large sample block. Therefore, samples were taken from the "freshest" outcrop, considered to be closer in physical characteristics to sandstone in the shallow subsurface. Resistivities and formation factors recovered from these samples were used with well logs in estimating water quality of the aquifer. The outcrop (Figure 6) is on the north side of the county road, north of the Cimarron River in the NE/4, Sec. 19, T.18N., R.4E. The sandstone is 15 to 20 feet above the river and is in contact with the river only during floods. Care was taken in sampling this locality because at many places along the outcrop, especially in the few feet above the underlying shale, cement had been leached by ephemeral water. Other outcrops also were sampled. Most of these outcrops have very little vertical relief (Figures 9 and 10). As will be shown, samples from such outcrops generally had higher permeability and porosity than samples from the outcrop in NE/4, Sec. 19., T.18N., R.4E.

Figure 9. Pes-20 Sandstone,W. Line, Sec. 28, T. 19 N., R. 4 E.

Figure10. Pes-20 Sandstone,W. Line, Sec. 21, T. 19 N., R. 4 E.

Laboratory Methods and Analyses of Rock-properties

One-hundred sixty-three core plugs, each one-inch in diameter, were taken from block-samples of sandstone and trimmed to 1 3/8 inches in length. Diameter and length of each core plug were measured with calipers. The dry weight of each core was recorded. These data were entered into a spreadsheet, where volume, density, porosity and permeability were calculated. Conductivity of each fluid used to charge plugs was measured with a conductivity meter. This data was entered into another spreadsheet and converted to resistivity. Resistances of core plugs charged with selected fluids were measured, entered into the spreadsheet, and converted to resistivity. Because resistivity of fluids in the cores varies inversely with temperature, each resistivity value was corrected to 77° F. Resistivity was the basis for calculation of a formation factor for each core plug.

Dimensions of core plugs conform to petroleum-industry standards and to size requirements of the Ruska gas permeameter. Methods of measuring permeability and porosity of core plugs were qualified by a previous research project (see Appendix F). Of the 166 core plugs, 105 were charged with water from the aquifer. Of the 105 cores, 70 were from the outcrop in the NE/4 of Sec. 19, T.18N., R.3E, 29 were from other outcrops (specified in Appendix E), and six were excluded because of a difference of treatment in the resistance measurements. Summary statistics of porosity, permeability, and formation factor of the 70 core plugs were computed (see Appendixes C and D). Sixty of the core plugs were from a large block-sample, roughly 14 in. by 8 in. by 8 in.; the other ten came from a sample of similar size. Both samples came from the channel-fill sandstone facies of the outcrop in Sec. 19, T. 18 N., R. 4 E., described above.

Of the 60 core plugs taken from the one sample, the first set of 30 plugs is referred to here as "Set A"; the second group is referred to as "Set B". The pooled set of 60 plugs is referred to as "Set C". The group of 10 core plugs is referred to as "Set S". Sets A and B were compared first, then Sets C and S were compared. Formulas for standard deviation, variance, student's t-test and F-test were obtained from the second edition of Steel and Torrie's "Principles and Procedures of Statistics".

Porosity

Porosity of the Pes-20 sandstone was calculated using a matrix density value of 2.656. Porosities are reported in Appendix C.

Estimates of porosity, Set A:

Number of core plugs: 30
Average porosity: 29.86 percent
Standard deviation: 0.7150 percent
Variance: 0.5092

Estimates of porosity, Set B:

Number of core plugs: 30
Average porosity: 29.94 percent
Standard deviation: 0.6746 percent
Variance: 0.4403

Two working hypotheses arise in the comparison of the variances: (1) No significant difference exists between the variances of the porosity data-sets; the numerical difference is due solely to chance. (2) A significant difference exists between the variances of the porosity data-sets. The working hypothesis of equality of variances was evaluated by the variance-ratio test (Steel and Torrie, 1980, pp. 111-112.)

F(sample) = Variance(Set A)/Variance(Set B)
F(sample) = 0.5092/0.4403
F(sample) = 1.1565
F(0.05, 29,29) ≅ 2.0 (Rohlf and Sokal, p. 192)
F(sample) of 1.1565 is not significant

No evidence described here requires rejection of the working hypothesis that the variances of the two porosity data sets are equal. Therefore, the alternate hypothesis is accepted as being true: Variances of the two sets are equal: the absolute numerical difference (0.5092 of 0.4403) occurred because of random error.

Two working hypotheses arise in the comparison of the means: (1) No significant difference exists between the means of the porosity data-sets. (2) A significant difference exists between the means of the porosity data-sets. The working hypothesis of equality of means was tested by the Student's 't' test (see Steele and Torrie, 1980, p.96):

$$t = \frac{\overline{Y_1} - \overline{Y_2}}{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}(\frac{1}{n_1} + \frac{1}{n_2})}$$

t(sample) = 0.4497; 58 degrees of freedom
t(0.05, 58) ≅ 2.0,
t(sample) of 0.4497 is not significant

No evidence described here requires rejection of the hypothesis that the means of the two porosity data sets are equal. Therefore the samples are regarded as having come from a single population with properties described as those of Set C. Of course, on a qualitative basis alone, this outcome was expected; all 60 samples were extracted from a single block of sandstone that showed little evidence of variation, on the basis of visual inspection alone. The result of comparison of variances and means indicates that the methods of measuring porosity and permeability are consistent; they will be regarded as being so, and in similar tests to follow, significant differences in variances or means will be attributed to significant differences in lithic properties of sandstone.

Summary Statistics for Set C and Set S are as follows:

Estimates of porosity, Set C:

Number of core plugs: 60
Average porosity: 29.90 percent
Standard deviation: 0.6903 percent
Variance: 0.4765

Estimates of porosity, Set S:

Number of core plugs: 10
Average porosity: 30.94 percent
Standard deviation: 0.2795 percent
Variance: 0.0781

Two working hypotheses arise in the comparison of the variances: (1) No significant difference exists between the variances of the porosity data-sets. (2) A significant difference exists between the variances of the porosity data-sets. The working hypothesis of equality of variances was evaluated by the variance-ratio test:

F(sample) = Variance(Set C)/Variance(Set S)
F(sample) = 0.4765/0.0781
F(sample) = 6.1012
$F(0.05, 29,09) \cong 3.5$
F(sample) of 6.1012 is significant.

The evidence described here requires rejection of the hypothesis that the variances of the two data-sets are equal.

Two working hypotheses arise in comparison of the means: (1) No significant difference exists between the means of the porosity data-sets. (2) A significant difference exists between the means of the porosity data-sets. The working hypothesis of equality of means was tested by the Student's 't' test (Steele and Torrie, 1980 p. 106):

$$t = \overline{Y}_1 - \overline{Y}_2 / \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

t(sample) = 8.2864; 32 degrees of freedom
t(0.05, 32) ≅ 2.03
t(sample) of 8.2864 is significant

The evidence described here requires rejection of the working hypothesis that means of the two data-sets are equal. The general conclusion is that samples were drawn from two discrete populations, inasmuch as variances and means are quite different -- but there is no practical difference in the means of the two sets. The difference between the two reported means is roughly 1 % porosity. Three standard deviations from both means yields a composite range of porosities only of 5%, from 28% to 32%. As will be shown, in practical application to the problem of evaluating the Pes-20/Pes-40 aquifer, this difference of porosity of 1 % is not significant.

Permeability

Permeability of each core plug was measured in a Ruska permeameter, using nitrogen gas. Data are in Appendix C. Sets A and B were compared, then Sets C and S were compared. Summary statistics for Set A and Set B are as follows:

Estimates of permeability, Set A:

Number of core plugs: 30
Average: permeability: 1.7099 darcies
Standard deviation: 0.7084 darcies
Variance: 0.5019

Estimates of permeability, Set B:

Number of core plugs: 30
Average permeability: 1.7513 darcies
Standard deviation: 0.7217 darcies
Variance: 0.5209

Two working hypotheses arise in the comparison of the variances: (1) No significant difference exists between the variances of the permeability data-sets. (2) A significant difference exists between the variances of the permeability data-sets. The working hypothesis of equality of variances was evaluated by the variance-ratio test:

F(sample) = Variance(Set A)/Variance(Set B)
F(sample) = 0.5209/0.5019
F(sample) = 1.0379
$F(0.05, 29,29) \cong 2.09$
F(sample) of 1.0379 is not significant

No evidence described here requires rejection of the hypothesis that the variances of the two permeability data sets are equal. Therefore, the alternate hypothesis is accepted as being true: Variances of the two sets are equal: the absolute numerical difference (0.5209 of 0.5019) occurred because of random error.

Two working hypotheses arise in the comparison of the means: (1) No significant difference exists between the means of the permeability data-sets. (2) A significant difference exists between the means of the permeability data-sets. The working hypothesis of equality of means was tested by the Student's 't' test (see Steele and Torrie, 1980, p.96):

$$t = \frac{\overline{Y_1} - \overline{Y_2}}{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

t(sample) = 1.2143; 58 degrees of freedom
t(0.05, 58) ≅ 2.0
t(sample) not significant

No evidence described here requires rejection of the hypothesis that the means of the two permeability data sets are equal. With regard to the property of permeability, Sets A and B were drawn from one population.

Summary statistics for Sets C and S are as follows:

Estimates of permeability, Set C:

Number of core plugs: 60
Average permeability: 1.7306 darcies
Standard deviation: 0.7093 darcies
Variance: 0.5032

Estimates of permeability, Set S:

Number of core plugs: 10
Average permeability: 1.6719 darcies
Standard deviation: 0.3004 darcies
Variance: 0.0903

In comparison of variances, the two working hypotheses described above are in effect:

(1) No significant difference exists between variances of the permeability data-sets. (2) A significant difference exists between variances of the permeability data-sets. Working hypothesis 1 was evaluated by the variance-ratio test:

F(sample) = Variance(Set C)/Variance(Set S)
F(sample) = 0.5032/0.0903
F(sample) = 5.5725
F(0.05, 29,09) ≅ 3.5
F(sample) of 5.5 is significant.

Evidence described here requires rejection of the hypothesis that variances of the two data-sets are equal.

Means were compared on the basis of these hypotheses: (1) No significant difference exists between means of the permeability data-sets. (2) A significant difference exists between means of the permeability data-sets. The working hypothesis of equality of means was tested by the Student's 't' test (Steele and Torrie, 1980 p. 106):

$$t = \overline{Y_1} - \overline{Y_2} \,/\, \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

t(sample) = 0.4448; 30 degrees of freedom
t(0.05, 32) ≅ 2.04
t(sample) of 0.4448 is not significant

No evidence described here requires rejection of the hypothesis that the means of the two porosity data sets are equal.

<u>Formation Factor</u>.

The Formation Factor of rock can be estimated by measuring the resistances of core plugs that are saturated with fresh water (in the context of this research). The concept of the Formation Factor can be described by the following example. Resistance of a volume of fresh water is measured. Resistance of an equal volume of porous, permeable rock that is saturated with the fresh water is greater, because of the reduced volume of the more-conductive water and the impeding effect of the rock. Assume that the resistance of the water-saturated rock were 10 times that of the equal volume of water alone. The Formation Factor could be described as being 10. By convention in analysis of wireline logs, the units of measurement are expressed not as resistance, but as resistivities of materials, in ohms per cubic meter, or ohm-meters.

Resistances of core plugs were measured using a resistance cell. The resistance cell was constructed at the OSU Electronics Laboratory based on a design outlined by Evers and Iyer 1985 p. 3. The procedure for measuring resistance is set out in Appendix A; data about resistance, resistivity and formation factor are in Appendix D.

Summary statistics for Sets A and B are as follows:

<u>Estimates of Formation Factor, Set A</u>:

Number of core plugs: 30
Average formation factor: 10.88
Standard deviation: 1.43
Variance: 2.04

<u>Estimates of Formation Factor, Set B</u>:

Number of core plugs: 30
Average formation factor: 11.39
Standard deviation: 1.47
Variance: 2.17

Working hypotheses that are the basis for comparison of variances are: (1) No significant difference exists between the variances of the formation factor data-sets. (2)

A significant difference exists between the variances of the formation factor data-sets.

The working hypothesis of equality of variances was evaluated by the variance-ratio test:

F(sample) = Variance(Set A)/Variance(Set B)
F(sample) = 2.24/2.11
F(sample) = 1.0616
F(0.05, 29,29) ≅ 2.0
F(sample) of 1.06 is not significant.

No evidence described here requires rejection of the hypothesis that the variances of the two Formation-factor data sets are equal.

Two working hypothesis arise in the comparison of the means: (1) No significant difference exists between the means of the formation factor data-sets. (2) A significant difference exists between the means of the formation factor data-sets. The working hypothesis of equality of means was tested by the Student's 't' test (Steele and Torrie, 1980, p.96):

$$t = \frac{\overline{Y_1} - \overline{Y_2}}{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$$

t(sample) = 0.2626; 58 degrees of freedom.
t(0.05, 58) ≅ 0.5
t(sample) of 0.16 is not significant

No evidence described here requires rejection of the hypothesis that the means of the two formation factor data sets are equal.

Summary statistics of Sets C and S are as follows:

Estimates of formation factor, Set C:

Number of core plugs: 60
Average formation factor: 11.17
Standard deviation: 1.4623

Variance: 2.1383

Estimates of formation factor, Set S:

Number of core plugs: 10
Average formation factor: 10.08
Standard deviation: 2.11
Variance: 4.47

Variances were compared on the basis of the two working hypotheses (1) No significant difference exists between the variances of the formation factor data-sets. (2) A significant difference exists between the variances of the formation factor data-sets. The working hypothesis of equality of variances was evaluated by the variance-ratio test:

F(sample) = Variance(Set C)/Variance(Set S)
F(sample) = 0.4765/0.0781
F(sample) = 6.1012
F(0.05, 29,09) ≅ 0.01
F(sample) of 6.1 definitely is significant

The evidence described here requires rejection of the hypothesis that the variances of the two data-sets are equal. The working hypothesis of equality of means was tested by the Student's 't' test (Steele and Torrie, 1980 p. 106):

$$t = \overline{Y_1} - \overline{Y_2} / \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

t(sample) = 8.2864; 32 degrees of freedom
t(0.05, 32) ≅ 2.04
t(sample) of 8.2 definitely is significant

The evidence described here requires rejection of the hypothesis that means of the two data-sets are equal.

The summary statistics, viewed as a whole, suggest that sets A and B were drawn from one population, represented better by the summary statistics of the combined set S. The Formation Factor of the Pes-20 sandstone seems to be in the range of 9 to 12.

CHAPTER IV

ESTIMATION OF WATER QUALITY

Wireline Logs

Wireline logs of oil wells were used to create a log-map (Plate 2) of the Eskridge Shale in T.18N., R.3E. and in the southern half of T.19N., R.3E. The section of strata posted on the map extends from the Neva Limestone upward to the Cottonwood Limestone, where possible. Sixty well logs are posted on the map, which covers 54 square miles. This group of 60 well logs is all that was obtainable through normal avenues of research. This is not to imply that only 60 oil wells are in the area, but rather 60 of the available wells were logged through the fresh-water-bearing sandstone. Resistivity signatures on the well logs suggest contact of water of relatively low resistivity (brackish or salty water) with water of relatively high resistivity (highly probable to be fresh water) about one-half mile east of the north-south center-line of T.18N., R.3E. This contact is approximately one-half mile farther to the west in the southern half of T.19N., R.3E. (Plate 2). To show a well-defined boundary between the fresh-water aquifer and the salt-water aquifer is not feasible with the amount of control available. Four correlation cross-sections were constructed (Plates 3, 4, 5 and 6).

Estimation of Water Quality

Resistivity recorded by the deep induction log was used in the estimation of water quality, as this log records the presumedly uninvaded zone of the formation, several feet from the borehole. The values recorded by the deep induction log (Rt) should represent the resistivity of the sandstone and the formation fluid within it. Permeability, porosity and clay content of the sandstone also affect the resistivity readings.

Estimates of water quality were made by recording the resistivity from the deep induction log and, using by the experimentally derived formation factor of 11, calculating the resistivity of the water (Rw). The basic equation is the Archie Equation for water saturation: $Sw = \frac{(F \times Rw)^{\frac{1}{n}}}{Rt}$, where Sw is the water saturation of the uninvaded zone, F is the formation factor, Rw is formation water resistivity, and Rt is formation resistivity of the uninvaded zone. Water saturation is assumed to be 1 (100 % saturation) and the value of n generally used is 2. The equation can now be simplified to $Rw = \frac{Rt}{F}$. An estimation of water quality was made in Sec. 26, T.18N., R.3E. Resistivity of approximately 100 ohm-m was taken from logs of the Myric #1 and Hanks #1 wells (Appendix G) in Sec. 26, T.18N., R.3E. Using the average formation factor of 11 from Set C, an Rw value of 9.1 ohm-m was calculated. Conversion to conductivity ($\frac{10000}{\text{Re}\,sistivity}$) yields a value of 1099 μ-siemens/cm squared. Multiplying the conductivity by the conversion factor of 0.75 gives an approximate TDS of 824 ppm. The conversion factor was derived by dividing total dissolved salts by conductivity, using values reported in the water analysis (Appendix H).

A water well located in the SW/4, SW/4, NE/4 Sec. 26, T.18N., R.3E was sampled. The well is believed to produce water from the Pes-20 sandstone in the interval

125 to 135 feet below land surface. The water sample was analyzed by the Oklahoma State University Soil, Water, and Forage Analytical Laboratory (Appendix H). Total soluble salts of 798 was reported in the analysis. Total soluble salts is equivalent to total dissolved solids.

CHAPTER V

SUMMARY AND CONCLUSIONS

In Payne County, Oklahoma, several formations include sandstones that are of sufficient thickness and extent to contain potable water. The Eskridge Shale is one such formation. These aquifers are largely unmapped and are penetrated sparsely by private water wells. However, many oil wells are in the county, most have been logged, and well logs are readily available.

This research has shown the feasibility of estimating general water quality in shallow sandstone aquifers by use of information from well logs and petrophysical properties of sandstone in outcrops. This method works if four major conditions can be satisfied: (1) As demonstrated in this study and in previous works, the Pes-20 sandstone of the Eskridge shale can be mapped. Well logs are sufficient to map the sandstone in the subsurface. (2) Outcrops can be sampled adequately. (3) Core plugs from samples can be tested effectively for petrophysical properties, including permeability, porosity and resistivity. (4) Data from laboratory tests can be summarized usefully and used in calculation of formation factors of sandstone in the fresh-water zone. The formation factor can be used in conjunction with well logs to make reliable estimates of water quality in places where the aquifer has not been sampled for quality.

CHAPTER VI

RECOMMENDATIONS

Future research could include the Pes-20 and the Pes-40 sandstones, since both produce fresh water at shallow depths. Petrophysical data for the Pes-40 sandstone could be generated and compared with properties of the Pes-20 sandstone. Sandstones of the overlying Garrison shale also could be investigated. Many water wells, including two municipally operated wells used by the City of Perkins, in south-central Payne County, penetrate and produce from several of the Garrison Shale sandstones. Sampling of the rock by means of a large coring device or other implements should be considered.

As to laboratory testing equipment developed for this research: a new procedure for measuring resistances of core plugs should be examined. This might include construction of a new housing for the resistivity cell, which would accept a core placed in a rubber stopper. The purpose of this device would be to reduce the surface area from which excess fluid is "brushed". A new procedure may reduce the variance of core plug "wetness" and the random error inherent in measurement.

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APPENDIXES

APPENDIX A

APPENDIX A

PROCEDURE FOR CORING SAMPLES

1.1 Attach air-supply line to core drill.

1.2 Place vacuum-line assembly over core-drill bit.

1.3 Place sample in vise on drill deck, with bedding perpendicular to deck. Trim sample to fit in vise, if necessary.

1.4 Adjust sample to desired position under core-drill bit by adjusting drill deck.

1.5 Switch vacuum on. The vacuum need not be switched off until all coring is completed.

1.6 Open valve on air system. The valve should be approximately 75 % open to cool the core-drill bit effectively.

1.7 Make sure core-drill bit is in the fully retracted position, then switch core-drill power on.

1.8 Begin coring slowly and position the vacuum-line assembly on the sample. This minimizes debris released into the air.

1.9 Option: The core-drill can be set on automatic feed by pushing the manual feed handles to the 'automatic feed' position. If the automatic-feed option is to be used, the automatic drill depth should be set before coring the first sample. Failure to do so may result in damage to the core drill bit, the drill deck, or both.

1.10 After the sample has been cored and the core-drill bit is in the fully retracted position, switch the core-drill power off.

1.11 Switch the air-supply valve to the 'off' position.

1.12 Remove core. This may require removing the sample, adjusting the drill deck, or both.

1.13 Mark the core and the core bore-hole for dual identification.

1.14 Repeat procedure as necessary.

1.15 Trim cores to correct length of 1.375 inches

1.16 Using a caliper, measure the distance between the trim saw blade and the adjustable block on the trim saw deck. If necessary, adjust distance to 1.375 inches by loosening the set screw on the block and moving the block.

1.17 Trim off end of core while holding it firmly against the set block to the right of the blade. This ensure a straight cut perpendicular to the lengthwise direction of the core.

1.18 After the initial cut, slide the cut end of the core against the adjustable block and trim core. Measure the length of the core using the calipers. It should be close to 1.375 inches. Adjust block if needed.

1.19 Mark individual cores for identification.

1.20 Repeat procedure as necessary.

APPENDIX B

APPENDIX B

LABORATORY TESTING PROCEDURES

Permeability Measurements

1.1 Ensure tube selector valve is in off position and regulator valve on permeater is closed.

1.2 Open main valve on nitrogen bottle.

1.3 Open the first regulator valve until a reading of 200 psi is reached.

1.4 Open the second regulator valve until a reading of 40 psi is reached.

1.5 Remove core housing from permeameter.

1.6 Place core in a rubber stopper.

1.7 Place rubber stopper contain core into the core plug housing.

1.8 Replace core plug housing into permeater and tighten into position until a "snug" fit is achieved.

1.9 Switch tube selector valve to "Large" position.

2.0 Open regulator valve on permeameter until pressure valve on permeater is reading 0.25 atm and is stable.

2.1 Record reading (in cm.) on large tube.

2.2 Record temperature reading (in °C) on thermometer.

2.3 Close regulator valve on permeameter.

2.4 Turn tube selector valve to "off" position.

2.5 Wait until pressure valve is reading zero and remove core.

2.6 Measure permeability three times for each core plug.

Resistance Measurement

1.1 Select cores to be used in resistance tests.

1.2 Place cores, on end, in plastic container such as a beaker.

1.3 Select fluid, mix if necessary, with which the core plugs are to be charged. Fill container with fluid to a level at least two inches above the core plugs. Note: The conductivity and temperature of the fluid should be measured before filling the container.

1.4 Place the container in the center of the large vacuum chamber located in the OSU Electronics Laboratory.

1.5 Tighten the door and make sure the valve on the side of the chamber is in the closed position.

1.6 Check the oil level in the vacuum pump.

1.7 Switch the master, light and altitude toggle switches to their 'ON' positions, in the order they are listed here.

1.8 Leave cores in vacuum chamber for one hour to ensure proper evacuation.

1.9 Turn toggle switches to their 'OFF' positions in reverse order of step 1.7.

1.10 Open the valve on the side of the vacuum slightly (about 35 to 40 % open).

1.11 When the gauge on the side of the chamber is reading 14.75 psi and air can no longer be heard entering the valve, open door and remove cores.

1.12 Leave cores under fluid until test are to be made. Note: Temperature of cores and fluid should be allowed to stabilize to room temperature before testing.

1.13 Turn resistance meter on.

1.14 Press the mode selection button "LCR" until the meter is in the resistance mode.

1.15 Plug the "negative" lead (black wire) of the resitance chamber into the resistance meter socket marked with the white stripe.

1.16 Plug the "positive" lead (red wire) into the resistance meter socket marked by the red stripe.

1.17 Remove top of resistance cell.

1.18 Use tongs to remove a core plug from the container.

1.19 Using a small nylon-bristled brush, quikly and carefully brush excess fluid from core until the core plug appears damp, but does not have excess water on the surface.

1.20 Place the core plug into the resistance chamber.

1.21 Replace top of resistance chamber. Note: The top need only be tightened 1/2 turn.

1.22 Plug positive lead into socket of the resistance chamber top.

1.23 Record intial reading diplayed on meter, noting and recording units.

1.24 Remove red lead from the socket on resistance chamber top.

1.25 Remove resistance chamber top.

1.26 Remove core and replace it in the fluid.

1.27 Clean resistance chamber contacts and inside the housing.

1.28 Measure the resistance three times for each core plug.

APPENDIX C

APPENDIX C

DIMENSIONS, WEIGHTS, POROSITY AND PERMEABILITY OF CORE PLUGS

S1:1 to S1:10

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S1:1.A	28.8	1.027	1.027	1.027	1.027	1.375	35.3
S1:1.B	29.3	1.026	1.026	1.028	1.027	1.377	35.1
S1:1.C	29.6	1.028	1.028	1.028	1.028	1.375	35.0
S1:2.A	30.2	1.027	1.028	1.026	1.027	1.375	34.6
S1:2.B	30.6	1.029	1.028	1.027	1.028	1.376	34.5
S1:2.C	29.9	1.027	1.028	1.027	1.027	1.376	34.8
S1:3.A	29.8	1.021	1.021	1.020	1.021	1.371	34.3
S1:3.B	29.3	1.022	1.028	1.024	1.025	1.376	34.9
S1:3.C	29.1	1.026	1.028	1.024	1.026	1.376	35.1
S1:4.A	29.2	1.026	1.026	1.027	1.026	1.373	35.0
S1:4.B	29.1	1.024	1.027	1.027	1.026	1.376	35.1
S1:4.C	29.4	1.027	1.028	1.028	1.028	1.376	35.1
S1:5.A	30.4	1.025	1.026	1.026	1.026	1.375	34.4
S1:5.B	29.8	1.025	1.026	1.026	1.026	1.374	34.7
S1:5.C	29.7	1.027	1.026	1.027	1.027	1.377	34.9

S1:1 to S1:10

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC	AVG. DENSITY	FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.344	18.67	1.891	1.868	LG.	0.25	23.8	24.0	24.0
5.341	18.68	1.879		LG.	0.25	24.0	24.0	24.0
5.355	18.70	1.871		LG.	0.25	24.0	24.0	24.1
5.344	18.67	1.854		LG.	0.25	25.4	25.5	25.5
5.355	18.72	1.843		LG.	0.25	25.5	25.5	25.5
5.348	18.69	1.862		LG.	0.25	25.6	25.6	25.7
5.279	18.38	1.866		LG.	0.25	25.8	25.8	25.8
5.320	18.59	1.877		LG.	0.25	25.9	26.0	26.0
5.334	18.64	1.883		LG.	0.25	26.0	26.1	26.1
5.337	18.61	1.880		LG.	0.25	26.1	26.1	26.2
5.334	18.64	1.883		LG.	0.25	26.3	26.3	26.3
5.351	18.70	1.877		LG.	0.25	26.4	26.4	26.5
5.331	18.62	1.848		LG.	0.25	26.5	26.5	26.5
5.331	18.60	1.865		LG.	0.25	26.5	26.5	26.5
5.341	18.68	1.868		LG.	0.25	26.5	26.5	26.5

S1:1 to S1:10

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
23.9	12.40	12.25	12.30	0.01763	0.01764	0.01764
24.0	12.80	12.50	12.70	0.01764	0.01764	0.01764
24.0	12.10	12.30	12.20	0.01764	0.01764	0.01764
25.5	8.20	8.30	8.30	0.01770	0.01770	0.01770
25.5	9.40	9.50	9.55	0.01770	0.01770	0.01770
25.6	9.70	9.75	9.80	0.01771	0.01771	0.01771
25.8	3.70	3.90	4.00	0.01771	0.01771	0.01771
26.0	3.60	3.60	3.70	0.01772	0.01772	0.01772
26.1	4.15	4.15	4.20	0.01772	0.01773	0.01773
26.1	12.20	12.05	12.10	0.01773	0.01773	0.01773
26.3	11.90	11.85	11.90	0.01774	0.01774	0.01774
26.4	11.70	11.75	11.75	0.01774	0.01774	0.01774
26.5	7.90	7.95	8.20	0.01774	0.01774	0.01774
26.5	8.70	8.80	8.60	0.01774	0.01774	0.01774
26.5	9.25	9.10	9.20	0.01774	0.01774	0.01774

S1:1 to S1:10

FLOWRATE CC/SEC	N2-PERM. DARCYS	AVG. PERM. DARCYS	AVG. POR. %
54.06	2.4918	1.7099	29.86
55.66	2.5718		
53.52	2.4629		
35.16	1.6269		
40.90	1.8902		
42.15	1.9512		
14.54	0.6796		
13.49	0.6281		
15.90	0.7388		
53.14	2.4620		
52.06	2.4200		
51.37	2.3809		
33.98	1.5802		
37.21	1.7292		
39.49	1.8355		

S1:1 to S1:10

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S1:6.A	30.2	1.021	1.022	1.022	1.022	1.376	34.3
S1:6.B	29.6	1.022	1.022	1.019	1.021	1.375	34.5
S1:6.C	29.8	1.024	1.026	1.025	1.025	1.376	34.7
S1:7.A	29.4	1.021	1.018	1.017	1.019	1.373	34.4
S1:7.B	29.2	1.028	1.021	1.027	1.025	1.372	34.9
S1:7.C	29.6	1.026	1.027	1.027	1.027	1.375	34.9
S1:8.A	30.1	1.022	1.026	1.024	1.024	1.377	34.5
S1:8.B	29.9	1.027	1.026	1.026	1.026	1.378	34.8
S1:8.C	29.9	1.028	1.029	1.027	1.028	1.377	34.9
S1:9.A	30.3	1.027	1.027	1.027	1.027	1.372	34.5
S1:9.B	29.4	1.027	1.026	1.020	1.024	1.374	34.8
S1:9.C	29.7	1.027	1.028	1.025	1.027	1.373	34.8
S1:10.A	31.5	1.027	1.022	1.028	1.026	1.367	33.7
S1:10.B	31.5	1.019	1.023	1.027	1.023	1.371	33.6
S1:10.C	31.7	1.027	1.026	1.027	1.027	1.370	33.7

S1:1 to S1:10

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC		FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.289	18.49	1.856		LG.	0.25	26.5	26.5	26.5
5.282	18.45	1.870		LG.	0.25	26.4	26.4	26.4
5.324	18.61	1.865		LG.	0.25	26.4	26.3	26.3
5.258	18.34	1.876		LG.	0.25	26.2	26.2	26.2
5.327	18.56	1.880		LG.	0.25	26.2	26.2	26.2
5.341	18.65	1.871		LG.	0.25	26.2	26.2	26.3
5.313	18.58	1.856		LG.	0.25	26.3	26.3	26.3
5.337	18.68	1.863		LG.	0.25	26.4	26.4	26.5
5.355	18.73	1.863		LG.	0.25	26.5	26.5	26.5
5.344	18.62	1.852		LG.	0.25	26.5	26.5	26.5
5.317	18.55	1.876		LG.	0.25	26.5	26.5	26.5
5.341	18.63	1.868		LG.	0.25	26.5	26.5	26.5
5.331	18.51	1.821		LG.	0.25	26.5	26.4	26.4
5.303	18.47	1.820		LG.	0.25	26.3	26.3	26.3
5.341	18.59	1.813		LG.	0.25	26.3	26.3	26.3

S1:1 to S1:10

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
26.5	3.70	3.60	4.00	0.01774	0.01774	0.01774
26.4	4.25	4.20	4.15	0.01774	0.01774	0.01774
26.3	4.80	4.80	4.75	0.01774	0.01774	0.01774
26.2	11.55	11.35	11.25	0.01773	0.01773	0.01773
26.2	11.30	11.10	11.40	0.01773	0.01773	0.01773
26.2	11.15	11.00	10.80	0.01773	0.01773	0.01774
26.3	8.70	8.40	8.50	0.01774	0.01774	0.01774
26.4	9.60	9.55	9.40	0.01774	0.01774	0.01774
26.5	10.30	10.15	10.15	0.01774	0.01774	0.01774
26.5	4.25	4.30	4.40	0.01774	0.01774	0.01774
26.5	4.05	4.10	4.10	0.01774	0.01774	0.01774
26.5	4.50	4.45	4.65	0.01774	0.01774	0.01774
26.4	9.10	9.10	9.10	0.01774	0.01774	0.01774
26.3	11.05	10.90	10.90	0.01774	0.01774	0.01774
26.3	13.35	13.30	13.35	0.01774	0.01774	0.01774

S1:1 to S1:10

FLOWRATE CC/SEC	N2-PERM. DARCYS
14.09	0.6607
16.05	0.7532
18.74	0.8727
49.75	2.3405
49.21	2.2834
47.90	2.2218
36.43	1.7010
41.06	1.9107
44.26	2.0517
16.59	0.7677
15.52	0.7232
17.58	0.8148
39.10	1.8073
47.75	2.2244
58.72	2.7142

S1:11 to S1:20

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S1:11.A	29.5	1.018	1.019	1.022	1.020	1.373	34.4
S1:11.B	31.0	1.027	1.027	1.025	1.026	1.373	34.1
S1:11.C	31.1	1.023	1.024	1.023	1.023	1.371	33.8
S1:12.A	30.9	1.027	1.021	1.019	1.022	1.376	34.0
S1:12.B	29.9	1.019	1.022	1.023	1.021	1.372	34.3
S1:12.C	28.8	1.026	1.019	1.018	1.021	1.371	34.8
S1:13.A	30.1	1.028	1.029	1.023	1.027	1.370	34.5
S1:13.B	30.0	1.028	1.028	1.026	1.027	1.373	34.7
S1:13.C	29.6	1.027	1.027	1.026	1.027	1.372	34.8
S1:14.A	30.3	1.026	1.024	1.028	1.026	1.375	34.5
S1:14.B	30.0	1.024	1.027	1.025	1.025	1.371	34.5
S1:14.C	30.5	1.025	1.027	1.026	1.026	1.372	34.3
S1:15.A	30.7	1.015	1.021	1.018	1.018	1.373	33.7
S1:15.B	30.4	1.021	1.021	1.020	1.021	1.371	34.0
S1:15.C	29.8	1.024	1.025	1.018	1.022	1.375	34.5

S1:11 to S1:20

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC	AVG. DENSITY	FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.268	18.37	1.872	1.861	LG.	0.25	25.6	25.6	25.7
5.337	18.61	1.832		LG.	0.25	25.8	26.0	26.0
5.306	18.48	1.829		LG.	0.25	26.0	26.0	26.0
5.296	18.51	1.837		LG.	0.25	26.0	26.0	26.0
5.286	18.42	1.862		LG.	0.25	26.1	26.1	26.1
5.282	18.39	1.892		LG.	0.25	26.2	26.2	26.2
5.341	18.59	1.856		LG.	0.25	26.2	26.2	26.2
5.348	18.65	1.861		LG.	0.25	26.1	26.1	26.1
5.341	18.61	1.870		LG.	0.25	26.0	26.0	26.0
5.334	18.63	1.852		LG.	0.25	26.0	26.0	26.0
5.327	18.55	1.860		LG.	0.25	25.9	25.9	25.9
5.334	18.59	1.845		LG.	0.25	25.9	25.9	25.9
5.251	18.31	1.840		LG.	0.25	25.8	25.8	25.8
5.279	18.38	1.850		LG.	0.25	25.7	25.7	25.7
5.296	18.50	1.865		LG.	0.25	25.7	25.7	25.6

S1:11 to S1:20

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
25.6	5.50	5.30	5.30	0.01771	0.01771	0.01771
25.9	8.50	7.90	7.75	0.01771	0.01772	0.01772
26.0	9.60	9.60	9.85	0.01772	0.01772	0.01772
26.0	5.95	5.90	5.90	0.01772	0.01772	0.01772
26.1	5.00	5.00	5.05	0.01773	0.01773	0.01773
26.2	4.55	4.70	4.70	0.01773	0.01773	0.01773
26.2	11.70	12.15	11.75	0.01773	0.01773	0.01773
26.1	12.40	12.60	12.30	0.01773	0.01773	0.01773
26.0	12.50	12.40	12.50	0.01772	0.01772	0.01772
26.0	4.60	4.70	4.65	0.01772	0.01772	0.01772
25.9	6.90	6.85	6.90	0.01772	0.01772	0.01772
25.9	7.50	7.40	7.40	0.01772	0.01772	0.01772
25.8	6.10	6.15	6.15	0.01771	0.01771	0.01771
25.7	5.75	5.70	5.80	0.01771	0.01771	0.01771
25.7	5.60	5.55	5.60	0.01771	0.01771	0.01771

S1:11 to S1:20

FLOWRATE CC/SEC	N2-PERM. DARCYS	AVG. PERM. DARCYS	AVG. POR. %
21.45	1.0059	1.7513	29.94
34.14	1.5810		
41.84	1.9465		
24.04	1.1245		
19.82	0.9266		
18.12	0.8473		
51.99	2.4025		
54.59	2.5243		
54.75	2.5323		
18.12	0.8411		
28.61	1.3254		
31.22	1.4454		
25.06	1.1792		
23.25	1.0866		
22.47	1.0496		

S1:11 to S1:20

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S1:16.A	30.1	1.025	1.025	1.026	1.025	1.378	34.6
S1:16.B	29.2	1.019	1.026	1.025	1.023	1.372	34.8
S1:16.C	29.8	1.028	1.029	1.026	1.028	1.373	34.8
S1:17.A	29.0	1.018	1.019	1.021	1.019	1.372	34.6
S1:17.B	29.9	1.027	1.022	1.026	1.025	1.370	34.5
S1:17.C	29.4	1.024	1.021	1.024	1.023	1.369	34.6
S1:18.A	30.9	1.026	1.021	1.025	1.024	1.372	34.0
S1:18.B	30.2	1.016	1.020	1.026	1.021	1.376	34.2
S1:18.C	29.6	1.023	1.025	1.026	1.025	1.374	34.7
S1:19.A	30.5	1.023	1.022	1.023	1.023	1.372	34.1
S1:19.B	30.3	1.024	1.024	1.021	1.023	1.372	34.2
S1:19.C	29.8	1.019	1.018	1.023	1.020	1.373	34.3
S1:20.A	29.2	1.025	1.026	1.027	1.026	1.374	35.0
S1:20.B	28.8	1.027	1.027	1.027	1.027	1.374	35.3
S1:20.C	28.8	1.028	1.028	1.027	1.028	1.376	35.4

S1:11 to S1:20

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC		FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.327	18.65	1.856		LG.	0.25	25.6	25.6	25.6
5.306	18.49	1.882		LG.	0.25	25.5	25.5	25.5
5.351	18.66	1.865		LG.	0.25	25.5	25.5	25.4
5.265	18.35	1.886		LG.	0.25	25.4	25.4	25.4
5.324	18.53	1.862		LG.	0.25	25.4	25.4	25.4
5.303	18.44	1.876		LG.	0.25	25.3	25.3	25.3
5.313	18.52	1.836		LG.	0.25	25.4	25.5	25.5
5.279	18.45	1.854		LG.	0.25	25.5	25.5	25.5
5.320	18.57	1.869		LG.	0.25	25.6	25.7	25.7
5.299	18.47	1.846		LG.	0.25	25.8	25.8	25.8
5.303	18.48	1.851		LG.	0.25	25.8	25.8	25.8
5.272	18.38	1.866		LG.	0.25	25.8	25.8	25.8
5.334	18.62	1.880		LG.	0.25	25.7	25.7	25.7
5.344	18.65	1.893		LG.	0.25	25.7	25.7	25.7
5.351	18.70	1.893		LG.	0.25	25.6	25.6	25.6

S1:11 to S1:20

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
25.6	12.40	12.30	12.10	0.01771	0.01771	0.01771
25.5	13.25	13.25	13.50	0.01770	0.01770	0.01770
25.5	13.40	13.00	13.20	0.01770	0.01770	0.01770
25.4	13.70	13.70	13.70	0.01770	0.01770	0.01770
25.4	13.70	13.40	13.30	0.01770	0.01770	0.01770
25.3	12.85	12.90	12.70	0.01769	0.01769	0.01769
25.5	8.25	8.60	8.25	0.01770	0.01770	0.01770
25.5	9.20	9.30	9.20	0.01770	0.01770	0.01770
25.7	10.00	9.90	10.15	0.01771	0.01771	0.01771
25.8	4.70	4.50	4.45	0.01771	0.01771	0.01771
25.8	4.75	4.90	4.80	0.01771	0.01771	0.01771
25.8	4.40	4.15	4.20	0.01771	0.01771	0.01771
25.7	10.90	11.00	10.75	0.01771	0.01771	0.01771
25.7	10.90	11.00	10.75	0.01771	0.01771	0.01771
25.6	11.00	11.10	10.90	0.01771	0.01771	0.01771

S1:11 to S1:20

FLOWRATE CC/SEC	N2-PERM. DARCYS
53.83	2.5047
58.72	2.7307
58.11	2.6813
60.41	2.8304
59.34	2.7455
56.35	2.6152
35.64	1.6549
39.73	1.8624
43.40	2.0167
17.66	0.8228
18.89	0.8797
16.28	0.7632
47.44	2.1987
47.44	2.1944
47.98	2.2193

S2

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S2:1.A	30.8	1.026	1.027	1.024	1.026	1.371	34.1
S2:1.B	30.7	1.020	1.021	1.028	1.023	1.372	34.0
S2:2.A	31.8	1.025	1.027	1.027	1.026	1.360	33.4
S2:2.B	30.9	1.025	1.027	1.027	1.026	1.366	34.0
S2:3.A	31.2	1.025	1.027	1.029	1.027	1.371	34.0
S2:3.A	31.4	1.027	1.027	1.027	1.027	1.366	33.8
S2:4.A	31.0	1.028	1.027	1.027	1.027	1.358	33.8
S2:4.B	31.4	1.029	1.027	1.028	1.028	1.371	34.0
S2:5.A	30.8	1.026	1.028	1.024	1.026	1.373	34.2
S2:5.B	30.4	1.022	1.025	1.024	1.024	1.371	34.2
S2:6.A	30.5	1.026	1.024	1.027	1.026	1.376	34.4
S2:6.B	30.8	1.025	1.024	1.025	1.025	1.377	34.2
S2:7.A	30.8	1.020	1.021	1.026	1.022	1.378	34.1
S2:7.B	30.5	1.025	1.024	1.025	1.025	1.37	34.2
S2:8.A	30.3	1.011	1.018	1.026	1.018	1.376	34.0
S2:8.B	30.3	1.025	1.024	1.024	1.024	1.375	34.4
S2:9.A	31.1	1.024	1.020	1.020	1.021	1.375	33.8
S2:9.B	31.0	1.013	1.021	1.026	1.020	1.377	33.8

S2

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC	AVG. DENSITY	FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.331	18.56	1.837	1.837	LG.	0.25	17.0	17.0	17.1
5.303	18.48	1.840		LG.	0.25	17.1	17.2	17.3
5.337	18.44	1.812		LG.	0.25	17.4	17.5	17.6
5.337	18.52	1.836		LG.	0.25	17.8	17.9	18.0
5.344	18.61	1.827		LG.	0.25	18.0	18.0	18.1
5.344	18.54	1.823		LG.	0.25	18.1	18.2	18.3
5.348	18.45	1.832		LG.	0.25	18.4	18.4	18.5
5.355	18.65	1.823		LG.	0.25	18.5	18.6	18.6
5.334	18.60	1.839		LG.	0.25	16.7	16.9	17.0
5.310	18.49	1.850		LG.	0.25	17.2	17.2	17.4
5.331	18.63	1.846		LG.	0.25	29.3	29.4	29.4
5.320	18.61	1.838		LG.	0.25	29.4	29.5	29.5
5.296	18.54	1.840		LG.	0.25	29.5	29.5	29.5
5.320	18.51	1.847		LG.	0.25	29.6	29.6	29.7
5.255	18.36	1.851		LG.	0.25	29.8	29.8	29.9
5.317	18.57	1.853		LG.	0.25	29.9	29.9	29.9
5.286	18.46	1.831		LG.	0.25	29.9	29.9	29.9
5.272	18.44	1.833		LG.	0.25	30	30	30

S2

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M.M RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
17.0	10.90	11.00	11.10	0.01734	0.01734	0.01735
17.2	9.15	9.50	9.25	0.01735	0.01735	0.01735
17.5	8.15	8.15	8.15	0.01736	0.01736	0.01737
17.9	7.35	7.40	7.45	0.01737	0.01738	0.01738
18.0	8.50	7.70	7.80	0.01738	0.01738	0.01739
18.2	7.90	7.70	7.50	0.01739	0.01739	0.01740
18.4	7.75	7.40	7.25	0.01740	0.01740	0.01740
18.6	7.40	7.20	7.35	0.01740	0.01741	0.01741
16.9	7.10	7.50	7.65	0.01733	0.01734	0.01734
17.3	7.65	7.65	7.75	0.01735	0.01735	0.01736
29.4	9.70	9.75	9.50	0.01786	0.01787	0.01787
29.5	10.60	9.90	9.90	0.01787	0.01787	0.01787
29.5	8.50	8.20	8.50	0.01787	0.01787	0.01787
29.6	7.50	7.60	7.55	0.01788	0.01788	0.01788
29.8	11.40	11.10	11.90	0.01788	0.01788	0.01789
29.9	10.15	10.40	10.10	0.01789	0.01789	0.01789
29.9	9.90	9.65	9.55	0.01789	0.01789	0.01789
30.0	9.70	10.50	9.50	0.01789	0.01789	0.01789

S2

FLOWRATE CC/SEC	N2-PERM. DARCYS	AVG. PERM. DARCYS	AVG. POR. %
47.98	2.1743	1.7404	30.87
40.04	1.8261		
34.61	1.5557		
31.06	1.4035		
33.90	1.5361		
32.48	1.4669		
31.37	1.4085		
30.66	1.3884		
31.14	1.4116		
32.40	1.4749		
41.68	1.9531		
43.95	2.0651		
35.80	1.6911		
31.77	1.4859		
50.14	2.3859		
44.34	2.0838		
41.92	1.9818		
42.86	2.0349		

S3

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S3:1.A	30.2	1.020	1.008	1.013	1.014	1.399	34.3
S3:1.B	31.2	1.017	1.009	1.011	1.012	1.389	33.5
S3:1.C	30.6	1.008	1.012	1.015	1.012	1.383	33.6
S3:2.A	30.1	1.015	1.025	1.022	1.021	1.366	34.0
S3:2.B	29.7	1.022	1.016	1.024	1.021	1.366	34.2
S3:2.C	29.3	1.019	1.010	1.012	1.014	1.372	34.1
S3:3.A	27.9	1.025	1.023	1.027	1.025	1.370	35.5
S3:3.B	27.0	1.021	1.021	1.026	1.023	1.372	35.8
S3:3.C	27.0	1.027	1.029	1.027	1.028	1.370	36.1
S3:4.A	29.7	1.025	1.021	1.021	1.022	1.373	34.5
S3:4.B	30.1	1.013	1.007	1.019	1.013	1.371	33.6
S3:4.C	29.5	1.016	1.022	1.023	1.020	1.371	34.4
S3:5.A	30.4	1.025	1.021	1.027	1.024	1.373	34.3
S3:5.B	31.0	1.027	1.025	1.029	1.027	1.375	34.2
S3:5.C	31.2	1.029	1.027	1.029	1.028	1.370	34.1
S3:6.A	30.1	1.024	1.022	1.027	1.024	1.368	34.3
S3:6.B	29.9	1.026	1.024	1.025	1.025	1.370	34.5
S3:7.A	30.3	1.027	1.027	1.027	1.027	1.368	34.4
S3:7.B	28.9	1.022	1.024	1.026	1.024	1.369	34.9
S3:7.C	31.1	1.029	1.027	1.022	1.026	1.371	34.0

S3

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC	DENSITY GM/CC	FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.207	18.50	1.854	1.866	LG.	0.25	15.1	15.1	15.2
5.193	18.32	1.829		LG.	0.25	15.5	15.5	15.6
5.186	18.22	1.844		LG.	0.25	15.8	15.9	16.0
5.279	18.32	1.856		LG.	0.25	16.0	16.1	16.2
5.279	18.32	1.867		MED.	0.50	16.3	16.4	16.5
5.207	18.14	1.879		LG.	0.25	16.6	16.7	16.8
5.324	18.53	1.916		MED.	0.50	17.0	17.0	17.0
5.299	18.47	1.939		MED.	0.50	17.0	17.2	17.2
5.351	18.62	1.939		MED.	0.50	17.3	17.4	17.5
5.296	18.47	1.868		LG.	0.25	17.5	17.5	17.6
5.200	18.11	1.856		LG.	0.25	17.7	17.7	17.8
5.275	18.37	1.873		LG.	0.25	17.8	17.9	18.0
5.317	18.54	1.850		LG.	0.25	18.0	18.0	17.9
5.344	18.67	1.832		LG.	0.25	16.5	16.7	16.8
5.358	18.65	1.829		LG.	0.25	17.8	17.8	17.8
5.317	18.47	1.857		LG.	0.25	17.8	17.8	17.8
5.324	18.53	1.862		LG.	0.25	17.8	17.9	17.9
5.344	18.57	1.852		MED.	0.50	17.9	17.9	17.9
5.313	18.48	1.889		MED.	0.50	17.9	17.9	17.9
5.334	18.57	1.830		LG.	0.25	17.9	17.9	17.9

S3

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
15.1	2.50	2.30	2.30	0.01726	0.01726	0.01726
15.5	2.85	2.85	2.80	0.01728	0.01728	0.01728
15.9	2.70	2.70	2.70	0.01729	0.01729	0.01730
16.1	2.20	2.15	2.15	0.01730	0.01730	0.01731
16.4	11.60	11.60	11.65	0.01731	0.01732	0.01732
16.7	2.20	2.20	2.20	0.01732	0.01733	0.01733
17.0	12.25	12.20	12.10	0.01734	0.01734	0.01734
17.1	8.10	8.10	8.20	0.01734	0.01735	0.01735
17.4	9.20	9.00	9.00	0.01735	0.01736	0.01736
17.5	2.20	2.20	2.20	0.01736	0.01736	0.01737
17.7	2.20	2.15	2.15	0.01737	0.01737	0.01737
17.9	2.10	2.10	2.05	0.01737	0.01738	0.01738
18.0	2.20	2.20	2.20	0.01738	0.01738	0.01738
16.7	2.40	2.40	2.45	0.01732	0.01733	0.01733
17.8	2.75	2.75	2.75	0.01737	0.01737	0.01737
17.8	2.50	2.50	2.50	0.01737	0.01737	0.01737
17.9	2.30	2.30	2.25	0.01737	0.01738	0.01738
17.9	12.45	12.35	12.35	0.01738	0.01738	0.01738
17.9	12.50	12.50	12.30	0.01738	0.01738	0.01738
17.9	2.65	2.70	2.60	0.01738	0.01738	0.01738

S3

FLOWRATE CC/SEC	N2-PERM. DARCYS	AVG. PERM. DARCYS	AVG. POR. %
7.96	0.3751	0.5853	29.75
9.96	0.4676		
9.38	0.4396		
7.12	0.3238		
50.83	1.1571		
7.26	0.3367		
53.44	1.2116		
34.53	0.7879		
38.94	0.8791		
7.26	0.3319		
7.12	0.3312		
6.77	0.3107		
7.26	0.3310		
8.17	0.3701		
9.60	0.4332		
8.52	0.3872		
7.61	0.3456		
54.36	1.2285		
54.59	1.2419		
9.17	0.4160		

S4

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S4:1.A	32.6	1.021	1.022	1.022	1.022	1.376	33.1
S4:1.B	32.1	1.021	1.011	1.010	1.014	1.370	32.7
S4:1.C	35.6	1.022	1.016	1.010	1.016	1.360	30.9
S4:2.A	32.2	1.015	1.019	1.008	1.014	1.372	32.7
S4:2.B	32.2	1.019	1.022	1.015	1.019	1.364	32.8
S4:2.C	32.5	1.022	1.018	1.020	1.020	1.367	32.8
S4:3.A	32.2	1.016	1.014	1.016	1.015	1.365	32.6
S4:3.B	32.6	1.012	1.020	1.018	1.017	1.360	32.4
S4:3.C	32.8	1.016	1.023	1.019	1.019	1.369	32.7
S4:4.A	31.4	1.014	1.016	1.012	1.014	1.368	33.0
S4:4.B	32.9	1.010	1.007	1.015	1.011	1.365	32.0
S4:4.C	32.6	1.019	1.018	1.015	1.017	1.366	32.6

S4

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC	AVG. DENSITY	FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.289	18.49	1.791	1.789	LG.	0.25	24.0	24.0	24.0
5.210	18.13	1.804		LG.	0.25	24.0	24.0	24.0
5.231	18.07	1.710		LG.	0.25	24.0	24.0	24.0
5.210	18.16	1.801		LG.	0.25	24.0	24.0	24.0
5.258	18.22	1.801		LG.	0.25	24.0	24.0	24.0
5.272	18.30	1.792		LG.	0.25	24.0	24.0	24.0
5.224	18.11	1.800		LG.	0.25	24.0	24.0	24.0
5.237	18.09	1.791		LG.	0.25	24.0	24.0	24.0
5.265	18.31	1.786		LG.	0.25	24.0	24.0	24.0
5.210	18.10	1.823		LG.	0.25	24.0	24.0	24.0
5.176	17.94	1.783		LG.	0.25	24.0	24.0	24.0
5.244	18.20	1.792		LG.	0.25	24.0	24.0	24.0

S4

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764

S4

FLOWRATE CC/SEC	N2-PERM. DARCYS	AVG. PERM. DARCYS	AVG. POR. %
61.78	2.8804	2.8906	32.6
61.78	2.9114	STD. DEV.	STD. DEV.
61.78	2.8788	0.0181	1.0182
61.78	2.9156	VAR	VAR
61.78	2.8721	0.0003	1.0368
61.78	2.8709		
61.78	2.8931		
61.78	2.8750		
61.78	2.8789		
61.78	2.9071		
61.78	2.9199		
61.78	2.8839		

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S5:1.A	31.9	1.019	1.016	1.019	1.018	1.372	33.1
S5:1.B	32.2	1.015	1.012	1.019	1.015	1.369	32.7
S5:1.C	36.0	1.012	1.013	1.017	1.014	1.374	30.9
S5:2.A	32.5	1.012	1.018	1.023	1.018	1.369	32.7
S5:2.B	32.1	1.015	1.017	1.012	1.015	1.373	32.8
S5:2.C	32.9	1.021	1.020	1.018	1.020	1.375	32.8
S5:3.A	33.1	1.019	1.019	1.018	1.019	1.373	32.6
S5:3.B	33.4	1.014	1.022	1.019	1.018	1.372	32.4
S5:3.C	32.7	1.018	1.015	1.019	1.017	1.374	32.7
S5:4.A	32.0	1.015	1.020	1.015	1.017	1.374	33.0
S5:4.B	33.8	1.013	1.014	1.021	1.016	1.370	32.0
S5:4.C	32.6	1.015	1.013	1.018	1.015	1.373	32.6
S6:1.A	28.1	1.022	1.025	1.024	1.024	1.374	35.4
S6:1.B	27.7	1.026	1.022	1.025	1.024	1.372	35.6
S6:1.C	27.4	1.027	1.027	1.026	1.027	1.376	36.0
S6:2.A	27.4	1.021	1.021	1.026	1.023	1.371	35.6
S6:2.B	26.8	1.026	1.025	1.018	1.023	1.374	36.0

S5-S6

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC	AVG. DENSITY	FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.251	18.30	1.809	1.781	LG.	0.25	24.0	24.0	24.0
5.224	18.16	1.800		LG.	0.25	24.0	24.0	24.0
5.210	18.18	1.699		LG.	0.25	24.0	24.0	24.0
5.248	18.25	1.792		LG.	0.25	24.0	24.0	24.0
5.217	18.19	1.803		LG.	0.25	24.0	24.0	24.0
5.268	18.40	1.783		LG.	0.25	24.0	24.0	24.0
5.258	18.34	1.778		LG.	0.25	24.0	24.0	24.0
5.255	18.31	1.769		LG.	0.25	24.0	24.0	24.0
5.244	18.30	1.787		LG.	0.25	24.0	24.0	24.0
5.237	18.28	1.805		LG.	0.25	24.0	24.0	24.0
5.231	18.20	1.758		LG.	0.25	24.0	24.0	24.0
5.224	18.22	1.790		LG.	0.25	24.0	24.0	24.0
5.310	18.53	1.910	1.927	LG.	0.25	24.0	24.0	24.0
5.317	18.53	1.921		LG.	0.25	24.0	24.0	24.0
5.341	18.67	1.929		LG.	0.25	24.0	24.1	24.2
5.299	18.45	1.929		LG.	0.25	24.3	24.3	24.4
5.303	18.51	1.945		LG.	0.25	24.5	24.5	24.5

S5-S6

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	14.00	14.00	14.00	0.01764	0.01764	0.01764
24.0	5.10	5.40	5.40	0.01764	0.01764	0.01764
24.0	3.80	3.80	3.75	0.01764	0.01764	0.01764
24.1	4.00	4.00	3.90	0.01764	0.01764	0.01765
24.3	4.75	4.75	4.60	0.01765	0.01765	0.01765
24.5	4.00	4.00	4.00	0.01766	0.01766	0.01766

S5-S6

FLOWRATE CC/SEC	N2-PERM. DARCYS	AVG. PERM. DARCYS	AVG. POR. %
61.78	2.8928	2.9003	33.0
61.78	2.9016	STD. DEV.	STD. DEV.
61.78	2.9199	0.0103	1.1225
61.78	2.8883	VAR	VAR
61.78	2.9139	0.0001	1.2599
61.78	2.8896		
61.78	2.8911		
61.78	2.8909		
61.78	2.9008		
61.78	2.9046		
61.78	2.8999		
61.78	2.9101		
		AVG. PERM.	AVG. POR.
21.14	0.9804	0.7766	27.5
14.16	0.6550	STD. DEV.	STD. DEV.
14.99	0.6923	0.1363	0.4796
18.35	0.8515	VAR	VAR
15.14	0.7040	0.0186	0.2301

S7-S8

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S7:1.A	26.8	1.026	1.026	1.027	1.026	1.377	36.3
S7:1.B	29.6	1.027	1.027	1.027	1.027	1.378	35.0
S7:1.C	29.8	1.027	1.027	1.027	1.027	1.375	34.8
S7:2.A	28.8	1.024	1.021	1.025	1.023	1.376	35.1
S7:2.B	30.7	1.025	1.026	1.026	1.026	1.376	34.3
S7:2.C	31.1	1.023	1.025	1.022	1.023	1.375	33.9
S7:3.A	31.5	1.023	1.025	1.022	1.023	1.374	33.7
S7:3.B	31.7	1.023	1.024	1.020	1.022	1.373	33.5
S7:4.A	30.4	1.027	1.024	1.025	1.025	1.371	34.3
S7:4.B	32.6	1.026	1.025	1.023	1.025	1.372	33.2
S8:1.A	31.5	1.021	1.022	1.019	1.021	1.369	33.4
S8:1.B	30.1	1.025	1.026	1.022	1.024	1.375	34.5
S8:1.C	29.8	1.023	1.027	1.019	1.023	1.382	34.7
S8:2.A	31.4	1.026	1.022	1.027	1.025	1.371	33.8
S8:2.B	32.0	1.025	1.026	1.028	1.026	1.376	33.7
S8.3.A	30.8	1.026	1.023	1.023	1.024	1.371	34.0
S8:3.B	30.6	1.028	1.027	1.027	1.027	1.370	34.3
S8.4.A	31.4	1.025	1.028	1.024	1.026	1.377	34.0
S8:4.B	31.2	1.027	1.025	1.021	1.024	1.378	34.0
S8:5.A	31.8	1.016	1.024	1.027	1.022	1.378	33.6
S8:5.B	31.5	1.028	1.029	1.028	1.028	1.372	34.0

S7-S8

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC	AVG. DENSITY	FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEMP2 DEG-C	N2-TEMP3 DEG-C
5.337	18.67	1.944	1.852	LG.	0.25	25.5	25.5	25.5
5.344	18.71	1.871		LG.	0.25	25.6	25.7	25.8
5.344	18.67	1.864		LG.	0.25	25.9	26.0	26.0
5.306	18.55	1.893		LG.	0.25	26.0	26.0	26.1
5.331	18.63	1.841		LG.	0.25	26.1	26.3	26.3
5.306	18.53	1.829		LG.	0.25	26.4	26.5	26.5
5.306	18.52	1.820		LG.	0.25	26.6	26.8	26.8
5.296	18.47	1.814		LG.	0.25	26.8	26.8	26.9
5.327	18.55	1.849		LG.	0.25	27.0	27.0	27.0
5.320	18.54	1.791		LG.	0.25	27.0	27.0	27.0
5.279	18.36	1.820	1.831	LG.	0.25	27.2	27.2	27.2
5.317	18.57	1.858		MED.	0.50	27.3	27.4	27.5
5.303	18.61	1.864		LG.	0.25	27.5	27.5	27.5
5.324	18.54	1.823		LG.	0.25	27.6	27.6	27.7
5.337	18.65	1.807		LG.	0.25	27.7	27.8	27.9
5.313	18.50	1.838		MED.	0.50	28.0	28.0	28.0
5.348	18.61	1.843		MED.	0.50	28.0	28.0	28.0
5.331	18.64	1.824		LG.	0.25	28.0	28.0	28.0
5.317	18.61	1.827		LG.	0.25	28.1	28.1	28.1
5.296	18.54	1.813		LG.	0.25	28.1	28.1	28.2
5.358	18.67	1.821		LG.	0.25	28.2	28.3	28.3

S7-S8

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
25.5	6.75	6.60	6.80	0.01770	0.01770	0.01770
25.7	9.40	9.65	9.55	0.01771	0.01771	0.01771
26.0	9.85	9.55	10.10	0.01772	0.01772	0.01772
26.0	8.80	8.60	8.80	0.01772	0.01772	0.01773
26.2	10.10	9.60	10.20	0.01773	0.01774	0.01774
26.5	11.10	10.90	10.75	0.01774	0.01774	0.01774
26.7	8.75	8.50	8.15	0.01775	0.01776	0.01776
26.8	7.80	8.35	8.30	0.01776	0.01776	0.01776
27.0	7.40	7.10	6.90	0.01776	0.01776	0.01776
27.0	9.00	8.65	9.20	0.01776	0.01776	0.01776
27.2	2.10	2.10	2.10	0.01777	0.01777	0.01777
27.4	12.10	12.00	12.10	0.01778	0.01778	0.01779
27.5	2.05	2.05	2.05	0.01779	0.01779	0.01779
27.6	2.45	2.40	2.45	0.01779	0.01779	0.01779
27.8	2.20	2.10	2.15	0.01779	0.01780	0.01780
28.0	12.60	12.70	12.70	0.01781	0.01781	0.01781
28.0	12.05	12.00	12.00	0.01781	0.01781	0.01781
28.0	2.05	2.05	2.05	0.01781	0.01781	0.01781
28.1	2.40	2.40	2.45	0.01781	0.01781	0.01781
28.1	3.00	3.05	3.00	0.01781	0.01781	0.01782
28.3	2.80	2.80	2.75	0.01782	0.01782	0.01782

S7-S8

FLOWRATE CC/SEC	N2-PERM. DARCYS	AVG. PERM. DARCYS	AVG. POR. %
27.82	1.2907	1.7622	30.3
41.14	1.9085		
42.54	1.9707		
37.37	1.7450		
43.17	2.0075		
47.59	2.2231		
36.11	1.6866		
34.61	1.6190		
29.79	1.3840		
38.39	1.7870		
6.84	0.3203	0.6138	31.092
52.91	1.2360		
6.63	0.3123		
8.24	0.3837		
7.05	0.3286		
55.66	1.2993		
52.68	1.2207		
6.63	0.3099		
8.17	0.3832		
10.76	0.5065		
9.74	0.4516		

S9

Sample #	Porosity %	D1 IN.	D2 IN.	D3 IN.	D IN.	L IN.	DRY WT. GM.
S9:1.A	32.6	1.025	1.023	1.027	1.025	1.375	33.3
S9:1.B	32.8	1.027	1.027	1.028	1.027	1.37	33.2
S9:1.C	33.6	1.028	1.028	1.028	1.028	1.372	32.9
S9:2.A	35.0	1.027	1.025	1.024	1.025	1.373	32.1
S9:2.B	35.0	1.024	1.026	1.026	1.025	1.374	32.1
S9:2.C	34.8	1.024	1.025	1.026	1.025	1.374	32.2
S9:3.A	35.3	1.021	1.025	1.026	1.024	1.375	31.9
S9:3.B	34.8	1.024	1.026	1.025	1.025	1.371	32.1
S9:3.C	34.1	1.026	1.026	1.026	1.026	1.375	32.6
S9:4.A	34.9	1.023	1.023	1.026	1.024	1.371	32.0
S9:4.B	34.6	1.027	1.027	1.026	1.027	1.371	32.3
S9:4.C	35.0	1.025	1.027	1.026	1.026	1.372	32.1
S9:5.A	34.4	1.021	1.025	1.026	1.024	1.373	32.3
S9:5.B	34.8	1.025	1.025	1.025	1.025	1.37	32.1
S9:5.C	34.2	1.024	1.025	1.023	1.024	1.373	32.4

S9

AREA-C.S. SQ-CM	VOLUME CC	DENSITY GM/CC	AVG. DENSITY	FM-SCALE LG-MED-SM	N2-PRESS. ATM.	N2-TEMP1 DEG-C	N2-TEM 2 DEG-C	N2-TEMP3 DEG-C
5.324	18.59	1.791	1.743	LG.	0.25	20.4	20.5	20.5
5.348	18.61	1.784		LG.	0.25	20.6	20.7	20.8
5.355	18.66	1.763		LG.	0.25	20.9	21.0	21.0
5.327	18.58	1.728		LG.	0.25	21.5	21.5	21.5
5.327	18.59	1.727		LG.	0.25	21.5	21.5	21.5
5.324	18.58	1.733		LG.	0.25	21.5	21.5	21.5
5.313	18.56	1.719		LG.	0.25	21.5	21.5	21.5
5.324	18.54	1.732		LG.	0.25	21.5	21.5	21.5
5.334	18.63	1.750		LG.	0.25	21.5	21.5	21.5
5.313	18.50	1.730		LG.	0.25	21.5	21.5	21.5
5.341	18.60	1.737		LG.	0.25	21.5	21.5	21.5
5.334	18.59	1.727		LG.	0.25	21.5	21.5	21.5
5.313	18.53	1.743		LG.	0.25	21.5	21.5	21.5
5.324	18.53	1.733		LG.	0.25	21.5	21.5	21.5
5.313	18.53	1.749		LG.	0.25	21.5	21.5	21.5

S9

N2-TEMP AVG DEG-C	F.M. RDG.1 CM	F.M. RDG.2 CM	F.M. RDG.3 CM	N2-VIS 1 CP	N2-VIS 2 CP	N2-VIS 3 CP
20.5	10.50	10.35	10.30	0.01748	0.01749	0.01749
20.7	12.35	12.40	11.90	0.01749	0.01750	0.01750
21.0	12.40	12.35	12.25	0.01751	0.01751	0.01751
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753
21.5	14.00	14.00	14.00	0.01753	0.01753	0.01753

S9

FLOWRATE CC/SEC	N2-PERM. DARCYS	AVG. PERM. DARCYS	AVG. POR. %
45.11	2.0703	2.7352	34.39
53.60	2.4409		
54.13	2.4674		
61.78	2.8365		
61.78	2.8385		
61.78	2.8404		
61.78	2.8480		
61.78	2.8342		
61.78	2.8369		
61.78	2.8397		
61.78	2.8250		
61.78	2.8307		
61.78	2.8439		
61.78	2.8321		
61.78	2.8439		

APPENDIX D

APPENDIX D

RESISTIVITY DATA

Core and fluid resistivity data were entered into Excel 5.0 spreadsheets. All necessary equations for calculations were also entered into the spreadsheets.

S1:1 to S1:10

Sample	R1 ohms	R2 ohms	R3 ohms	Resistance ohms	Temp. deg. C	fluid type	Fluid Cond. micro s.	Fluid temp. deg. C	Resistivity1 (Ro) ohm-m	Resistivity2 (Ro) ohm-m
S1:1.A	5670	5000	4790	5153	23.3	W#2	1040	24	117.27	103.41
S1:1.B	4380	4890	4890	4720	23.3	W#2	1040	24	90.59	101.14
S1:1.C	4670	3440	3860	3990	23.3	W#2	1040	24	96.59	71.15
S1:2.A	5420	4930	5050	5133	25.2	W#2	1040	24	112.10	101.96
S1:2.B	4760	4690	5140	4863	25.2	W#2	1040	24	98.45	97.00
S1:2.C	5410	5190	4860	5153	25.2	W#2	1040	24	111.89	107.34
S1:3.A	4900	4610	4440	4650	25.2	W#2	1040	24	101.34	95.35
S1:3.B	4720	5040	4660	4807	25.2	W#2	1040	24	97.62	104.24
S1:3.C	4490	4900	4140	4510	25.2	W#2	1040	24	92.86	101.34
S1:4.A	6270	4280	3870	4807	25.2	W#2	1040	24	129.68	88.52
S1:4.B	6070	6110	5720	5967	25.2	W#2	1040	24	125.54	126.37
S1:4.C	6700	5260	5570	5843	25.2	W#2	1040	24	138.57	108.79
S1:5.A	5070	4690	4650	4803	25.2	W#2	1040	24	104.86	97.00
S1:5.B	5570	5510	5220	5433	25.2	W#2	1040	24	115.20	113.96
S1:5.C	5080	5150	4880	5037	25.2	W#2	1040	24	105.07	106.51

S1:1 to S1:10

Resistivity3 (Ro) ohm-m	Avg. Resistivity (Ro) ohm-m	Resistivity (Rw) ohm-m	Ro at 77 F ohm-m	Rw at 77 F ohm-m	Frm. Factor
99.07	106.58	9.62	102.70	9.41	10.91
101.14	97.62	9.62	94.07	9.41	10.00
79.83	82.52	9.62	79.52	9.41	8.45
104.45	106.17	9.62	106.63	9.41	11.33
106.31	100.59	9.62	101.02	9.41	10.74
100.52	106.58	9.62	107.04	9.41	11.38
91.83	96.17	9.62	96.59	9.41	10.26
96.38	99.41	9.62	99.84	9.41	10.61
85.63	93.28	9.62	93.68	9.41	9.96
80.04	99.41	9.62	99.84	9.41	10.61
118.30	123.41	9.62	123.93	9.41	13.17
115.20	120.85	9.62	121.37	9.41	12.90
96.17	99.35	9.62	99.77	9.41	10.60
107.96	112.38	9.62	112.86	9.41	11.99
100.93	104.17	9.62	104.62	9.41	11.12

MEAN resistivity77	STD. DEV. resistivity77	VAR. resistivity77
104.63	14.07	197.93

MEAN Frm. Factor	STD. DEV. Frm. Factor	VAR. Frm. Factor
11.12	1.50	2.24

S1:1 to S1:10

Sample	R1 ohms	R2 ohms	R3 ohms	Resistance ohms	Temp. deg. C	fluid type	Fluid Cond. micro s.	Fluid temp. deg. C	Resistivity1 (Ro) ohm-m	Resistivity2 (Ro) ohm-m
S1:6.A	4840	5220	4940	5000	25.2	W#2	1040	24	100.10	107.96
S1:6.B	4300	4450	4120	4290	25.2	W#2	1040	24	88.93	92.04
S1:6.C	4460	4480	4370	4437	25.2	W#2	1040	24	92.24	92.66
S1:7.A	6990	6140	5460	6197	25.2	W#2	1040	24	144.57	126.99
S1:7.B	7080	5810	5650	6180	25.2	W#2	1040	24	146.43	120.17
S1:7.C	6280	5420	6240	5980	25.2	W#2	1040	24	129.89	112.10
S1:8.A	4980	4920	4880	4927	25.2	W#2	1040	24	103.00	101.76
S1:8.B	5530	5310	5330	5390	25.2	W#2	1040	24	114.37	109.82
S1:8.C	6120	6410	6130	6220	25.2	W#2	1040	24	126.58	132.57
S1:9.A	4190	4230	4540	4320	25.2	W#2	1040	24	86.66	87.49
S1:9.B	4110	4240	4050	4133	25.2	W#2	1040	24	85.01	87.69
S1:9.C	4040	4080	4100	4073	25.2	W#2	1040	24	83.56	84.38
S1:10.A	4390	4370	4710	4490	25.2	W#2	1040	24	90.80	90.38
S1:10.B	5830	5460	4820	5370	25.2	W#2	1040	24	120.58	112.93
S1:10.C	6420	5620	5390	5810	25.2	W#2	1040	24	132.78	116.24

S1:1 to S1:10

Resistivity3 (Ro) ohm-m	Avg. Resistivity (Ro) ohm-m	Resistivity (Rw) ohm-m	Ro at 77 F ohm-m	Rw at 77 F ohm-m	Frm. Factor
102.17	103.41	9.62	103.86	9.41	11.04
85.21	88.73	9.62	89.11	9.41	9.47
90.38	91.76	9.62	92.15	9.41	9.79
112.93	128.16	9.62	128.71	9.41	13.68
116.86	127.82	9.62	128.37	9.41	13.64
129.06	123.68	9.62	124.21	9.41	13.20
100.93	101.90	9.62	102.33	9.41	10.88
110.24	111.48	9.62	111.96	9.41	11.90
126.78	128.65	9.62	129.20	9.41	13.73
93.90	89.35	9.62	89.73	9.41	9.54
83.76	85.49	9.62	85.85	9.41	9.12
84.80	84.25	9.62	84.61	9.41	8.99
97.41	92.86	9.62	93.26	9.41	9.91
99.69	111.07	9.62	111.54	9.41	11.85
111.48	120.17	9.62	120.68	9.41	12.83

S1:11 to S1:20

Sample	R1 ohms	R2 ohms	R3 ohms	Resistance ohms	Temp. deg. C	fluid type	Fluid Cond. micro s.	Fluid temp. deg. C	Resistivity1 (Ro) ohm-m	Resistivity2 (Ro) ohm-m
S1:11.A	4560	4300	4330	4397	24.7	W#2	1040	25.4	94.31	88.93
S1:11.B	4780	5000	4530	4770	24.7	W#2	1040	25.4	98.86	103.41
S1:11.C	5360	4650	4590	4867	24.7	W#2	1040	25.4	110.86	96.17
S1:12.A	5840	6050	5020	5637	24.7	W#2	1040	25.4	120.79	125.13
S1:12.B	4650	4580	4430	4553	24.7	W#2	1040	25.4	96.17	94.73
S1:12.C	5040	4570	5160	4923	24.7	W#2	1040	25.4	104.24	94.52
S1:13.A	5620	5670	5580	5623	24.7	W#2	1040	25.4	116.24	117.27
S1:13.B	5560	6090	6240	5963	24.7	W#2	1040	25.4	114.99	125.96
S1:13.C	7440	6500	5990	6643	24.7	W#2	1040	25.4	153.88	134.44
S1:14.A	5220	4560	4290	4690	24.7	W#2	1040	25.4	107.96	94.31
S1:14.B	5250	4650	4670	4857	24.7	W#2	1040	25.4	108.58	96.17
S1:14.C	4020	5000	4400	4473	24.7	W#2	1040	25.4	83.14	103.41
S1:15.A	5340	5680	5400	5473	24.7	W#2	1040	25.4	110.44	117.48
S1:15.B	5670	4690	4310	4890	24.7	W#2	1040	25.4	117.27	97.00
S1:15.C	5490	4970	4870	5110	24.7	W#2	1040	25.4	113.55	102.79

S1:11 to S1:20

Resistivity3 (Ro) ohm-m	Avg. Resistivity (Ro) ohm-m	Resistivity (Rw) ohm-m	Ro at 77 F ohm-m	Rw at 77 F ohm-m	Frm. Factor	MEAN resistivity77	STD. DEV. resistivity77	VAR. resistivity77
89.56	90.93	9.62	90.35	9.70	9.32	108.83	14.08	198.38
93.69	98.66	9.62	98.02	9.70	10.11			
94.93	100.65	9.62	100.01	9.70	10.31	MEAN	STD. DEV.	VAR.
103.83	116.58	9.62	115.83	9.70	11.94	Frm. Factor	Frm. Factor	Frm. Factor
91.62	94.17	9.62	93.57	9.70	9.65	11.22	1.45	2.11
106.72	101.83	9.62	101.17	9.70	10.43			
115.41	116.30	9.62	115.56	9.70	11.92			
129.06	123.34	9.62	122.54	9.70	12.64			
123.89	137.40	9.62	136.52	9.70	14.08			
88.73	97.00	9.62	96.38	9.70	9.94			
96.59	100.45	9.62	99.80	9.70	10.29			
91.00	92.52	9.62	91.93	9.70	9.48			
111.69	113.20	9.62	112.47	9.70	11.60			
89.14	101.14	9.62	100.49	9.70	10.36			
100.72	105.69	9.62	105.01	9.70	10.83			

S1:11 to S1:20

Sample	R1 ohms	R2 ohms	R3 ohms	Resistance ohms	Temp. deg. C	fluid type	Fluid Cond. micro s.	Fluid temp. deg. C	Resistivity1 (Ro) ohm-m	Resistivity2 (Ro) ohm-m
S1:16.A	5780	5830	5620	5743	24.7	W#2	1040	25.4	119.54	120.58
S1:16.B	5520	5350	5440	5437	24.7	W#2	1040	25.4	114.17	110.65
S1:16.C	6730	7650	6610	6997	24.7	W#2	1040	25.4	139.19	158.22
S1:17.A	6660	6830	6300	6597	24.7	W#2	1040	25.4	137.75	141.26
S1:17.B	5310	5800	5830	5647	24.7	W#2	1040	25.4	109.82	119.96
S1:17.C	5730	5410	5420	5520	24.7	W#2	1040	25.4	118.51	111.89
S1:18.A	5810	6060	4600	5490	24.7	W#2	1040	25.4	120.17	125.34
S1:18.B	5340	4990	5790	5373	24.7	W#2	1040	25.4	110.44	103.21
S1:18.C	5550	5110	5280	5313	24.7	W#2	1040	25.4	114.79	105.69
S1:19.A	4720	4500	4420	4547	24.7	W#2	1040	25.4	97.62	93.07
S1:19.B	5200	4320	4770	4763	24.7	W#2	1040	25.4	107.55	89.35
S1:19.C	4510	3810	3860	4060	24.7	W#2	1040	25.4	93.28	78.80
S1:20.A	5240	5000	5230	5157	24.7	W#2	1040	25.4	108.38	103.41
S1:20.B	5900	5330	5690	5640	24.7	W#2	1040	25.4	122.03	110.24
S1:20.C	5850	5290	6020	5720	24.7	W#2	1040	25.4	120.99	109.41

S1:11 to S1:20

Resistivity3 (Ro) ohm-m	Avg. Resistivity (Ro) ohm-m	Resistivity (Rw) ohm-m	Ro at 77 F ohm-m	Rw at 77 F ohm-m	Frm. Factor
116.24	118.79	9.62	118.02	9.70	12.17
112.51	112.44	9.62	111.72	9.70	11.52
136.71	144.71	9.62	143.78	9.70	14.83
130.30	136.44	9.62	135.56	9.70	13.98
120.58	116.79	9.62	116.04	9.70	11.97
112.10	114.17	9.62	113.43	9.70	11.70
95.14	113.55	9.62	112.82	9.70	11.63
119.75	111.13	9.62	110.42	9.70	11.39
109.20	109.89	9.62	109.19	9.70	11.26
91.42	94.04	9.62	93.43	9.70	9.63
98.66	98.52	9.62	97.88	9.70	10.09
79.83	83.97	9.62	83.43	9.70	8.60
108.17	106.65	9.62	105.97	9.70	10.93
117.68	116.65	9.62	115.90	9.70	11.95
124.51	118.30	9.62	117.54	9.70	12.12

S2

Sample	R1 ohms	R2 ohms	R3 ohms	Resistance ohms	Temp. deg. C	fluid type	Fluid Cond. micro s.	Fluid temp. deg. C	Resistivity1 (Ro) ohm-m	Resistivity2 (Ro) ohm-m
S2:1.A	5240	5270	5190	5233	25.4	W#2	1040	25.4	108.38	109.00
S2:1.B	5280	7610	6870	6587	25.4	W#2	1040	25.4	109.20	157.39
S2:2.B	3760	3900	4100	3920	25.4	W#2	1040	25.4	77.77	80.66
S2:3.A	3620	3640	3600	3620	25.4	W#2	1040	25.4	74.87	75.28
S2:3.B	4770	3840	4290	4300	25.4	W#2	1040	25.4	98.66	79.42
S2:4.A	4090	4040	3800	3977	25.4	W#2	1040	25.4	84.59	83.56
S2:5.A	4650	4610	4430	4563	25.4	W#2	1040	25.4	96.17	95.35
S2:5.B	4870	4320	4450	4547	25.4	W#2	1040	25.4	100.72	89.35
S2:9.A	4360	3890	3810	4020	25.4	W#2	1040	25.4	90.18	80.46
S2:9.B	6640	5850	5740	6077	25.4	W#2	1040	25.4	137.33	120.99

S2

Resistivity3 (Ro) ohm-m	Avg. Resistivity (Ro) ohm-m	Resistivity (Rw) ohm-m	Ro at 77 F ohm-m	Rw at 77 F ohm-m	Frm. Factor	MEAN resistivity77	STD. DEV. resistivity77	VAR. resistivity77
107.34	108.24	9.62	109.17	9.70	11.26	97.71	20.51	420.59
142.09	136.23	9.62	137.40	9.70	14.17			
84.80	81.08	9.62	81.77	9.70	8.43	MEAN	STD. DEV.	VAR.
74.46	74.87	9.62	75.51	9.70	7.79	Frm. Factor	Frm. Factor	Frm. Factor
88.73	88.93	9.62	89.70	9.70	9.25	10.08	2.11	4.47
78.59	82.25	9.62	82.95	9.70	8.55			
91.62	94.38	9.62	95.19	9.70	9.82			
92.04	94.04	9.62	94.84	9.70	9.78			
78.80	83.14	9.62	83.86	9.70	8.65			
118.72	125.68	9.62	126.76	9.70	13.07			

S4

Sample	R1 ohms	R2 ohms	R3 ohms	Resistance ohms	Temp. deg. C	fluid type	Fluid Cond. micro s.	Fluid temp. deg. C	Resistivity1 (Ro) ohm-m	Resistivity2 (Ro) ohm-m
S4:1.A	6420	7770	8190	7460	21.2	W#2	1040	25.4	132.78	160.70
S4:1.B	7920	7220	6180	7107	21.2	W#2	1040	25.4	163.81	149.33
S4:1.C	7380	7330	6210	6973	21.2	W#2	1040	25.4	152.64	151.60
S4:2.A	6340	6140	7520	6667	21.2	W#2	1040	25.4	131.13	126.99
S4:2.B	7400	6110	6280	6597	21.2	W#2	1040	25.4	153.05	126.37
S4:2.C	9230	7930	7510	8223	21.2	W#2	1040	25.4	190.90	164.01
S4:3.A	8930	7590	6930	7817	21.2	W#2	1040	25.4	184.69	156.98
S4:3.B	9630	7040	8310	8327	21.2	W#2	1040	25.4	199.17	145.60
S4:3.C	7140	5910	6190	6413	21.2	W#2	1040	25.4	147.67	122.23
S4:4.A	6980	6890	7140	7003	21.2	W#2	1040	25.4	144.36	142.50
S4:4.B	8920	7990	8510	8473	21.2	W#2	1040	25.4	184.49	165.25
S4:4.C	8990	6840	7950	7927	21.2	W#2	1040	25.4	185.94	141.47

S4

Resistivity3 (Ro) ohm-m	Avg. Resistivity (Ro) ohm-m	Resistivity (Rw) ohm-m	Ro at 77 F ohm-m	Rw at 77 F ohm-m	Frm. Factor	MEAN resistivity77	STD. DEV. resistivity77	VAR. resistivity77
169.39	154.29	9.62	141.73	9.70	14.61	140.88	13.70	187.77
127.82	146.98	9.62	135.02	9.70	13.92			
128.44	144.23	9.62	132.48	9.70	13.66	MEAN	STD. DEV.	VAR.
155.53	137.88	9.62	126.66	9.70	13.06	Frm. Factor	Frm. Factor	Frm. Factor
129.89	136.44	9.62	125.33	9.70	12.92	14.53	1.41	2.00
155.33	170.08	9.62	156.23	9.70	16.11			
143.33	161.67	9.62	148.50	9.70	15.31			
171.87	172.22	9.62	158.19	9.70	16.31			
128.02	132.64	9.62	121.84	9.70	12.56			
147.67	144.85	9.62	133.05	9.70	13.72			
176.01	175.25	9.62	160.98	9.70	16.60			
164.43	163.94	9.62	150.59	9.70	15.53			

S5-S6

Sample	R1 ohms	R2 ohms	R3 ohms	Resistance ohms	Temp. deg. C	fluid type	Fluid Cond. micro s.	Fluid temp. deg. C	Resistivity1 (Ro) ohm-m	Resistivity2 (Ro) ohm-m
S5:1.A	5620	5430	5360	5470	21.5	W#2	1040	25.4	116.24	112.31
S5:1.B	5530	5200	5090	5273	21.5	W#2	1040	25.4	114.37	107.55
S5:1.C	5200	5160	5190	5183	21.5	W#2	1040	25.4	107.55	106.72
S5:2.A	5590	5220	4700	5170	21.5	W#2	1040	25.4	115.62	107.96
S5:2.B	6250	5850	5650	5917	21.5	W#2	1040	25.4	129.27	120.99
S5:2.C	6010	5530	5440	5660	21.5	W#2	1040	25.4	124.30	114.37
S5:3.A	5270	5290	4960	5173	21.5	W#2	1040	25.4	109.00	109.41
S5:3.B	4870	5320	4490	4893	21.5	W#2	1040	25.4	100.72	110.03
S5:3.C	5230	5160	5060	5150	21.5	W#2	1040	25.4	108.17	106.72
S5:4.A	5630	5320	4590	5180	21.5	W#2	1040	25.4	116.44	110.03
S5:4.B	4510	5040	4640	4730	21.5	W#2	1040	25.4	93.28	104.24
S5:4.C	4690	4830	4850	4790	21.5	W#2	1040	25.4	97.00	99.90
Sample	R1 ohms	R2 ohms	R3 ohms	Resistance ohms	Temp. deg. C	fluid type	Fluid Cond. micro s.	Fluid temp. deg. C	Resistivity1 (Ro) ohm-m	Resistivity2 (Ro) ohm-m
S6:1.A	3590	3400	3870	3620	21.8	W#2	1040	25.4	74.25	70.32
S6:1.B	3600	3970	4250	3940	21.8	W#2	1040	25.4	74.46	82.11
S6:1.C	4340	3860	3680	3960	21.8	W#2	1040	25.4	89.76	79.83
S6:2.A	3620	3780	3710	3703	21.8	W#2	1040	25.4	74.87	78.18
S6:2.B	3570	3660	4040	3757	21.8	W#2	1040	25.4	73.84	75.70

S5-S6

Resistivity3 (Ro) ohm-m	Avg. Resistivity (Ro) ohm-m	Resistivity (Rw) ohm-m	Ro at 77 F ohm-m	Rw at 77 F ohm-m	Frm. Factor	MEAN resistivity77	STD. DEV. resistivity77	VAR. resistivity77
110.86	113.13	9.62	104.65	9.70	10.79	99.79	6.55	42.87
105.27	109.07	9.62	100.89	9.70	10.40			
107.34	107.20	9.62	99.16	9.70	10.23	MEAN	STD. DEV.	VAR.
97.21	106.93	9.62	98.91	9.70	10.20	Frm. Factor	Frm. Factor	Frm. Factor
116.86	122.37	9.62	113.19	9.70	11.67	10.29	0.68	0.46
112.51	117.06	9.62	108.28	9.70	11.17			
102.59	107.00	9.62	98.97	9.70	10.21			
92.86	101.21	9.62	93.62	9.70	9.65			
104.65	106.51	9.62	98.53	9.70	10.16			
94.93	107.14	9.62	99.10	9.70	10.22			
95.97	97.83	9.62	90.49	9.70	9.33			
100.31	99.07	9.62	91.64	9.70	9.45			

Resistivity3 (Ro) ohm-m	Avg. Resistivity (Ro) ohm-m	Resistivity (Rw) ohm-m	Ro at 77 F ohm-m	Rw at 77 F ohm-m	Frm. Factor	MEAN resistivity77	STD. DEV. resistivity77	VAR. resistivity77
80.04	74.87	9.62	69.74	9.70	7.19	73.13	2.87	8.23
87.90	81.49	9.62	75.90	9.70	7.83			
76.11	81.90	9.62	76.29	9.70	7.87	MEAN	STD. DEV.	VAR.
76.73	76.59	9.62	71.34	9.70	7.36	Frm. Factor	Frm. Factor	Frm. Factor
83.56	77.70	9.62	72.37	9.70	7.46	7.54	0.30	0.09

APPENDIX E

APPENDIX E

SAMPLE LOCATION

Sample	Location
S1	NE/4 Sec. 19, T.18N., R.4E.
S2	NE/4 Sec. 19, T.18N., R.4E.
S3	NE/4 Sec. 19, T.18N., R.4E.
S4	CN/2 Sec. 21, T.18N., R.4E.
S5	SE/4, SE/4, SE/4 Sec. 8, T.18N., R.4E.
S6	SW/4, NW/4 Sec. 34, T.18N., R.4E.
S7	NE/4 Sec. 19, T.18N., R.4E.
S8	NE/4 Sec. 19, T.18N., R.4E.
S9	NE/4 Sec. 19, T.18N., R.4E.

APPENDIX F

APPENDIX F

COMPARATIVE ANALYSIS OF CORE PLUG POROSTIY AND PERMEABILITY MEASUREMENTS

APPENDIX I

POROSITY AND PERMEABILITY: CORE PLUGS

INTRODUCTION

In preparation for analysis in the Mud-cake and Permeability system, several hundred core plugs were analyzed for permeability to nitrogen; the instrument used was a Ruska permeameter. Of this set of hundreds, two representative subsets were chosen: 99 plugs were tested for mud-cake buildup and permeability to water, and for the purpose of independent checking, 32 plugs were analyzed at the OSU laboratory, then sent to K & A Laboratories, Tulsa, Oklahoma, for comparative analyses. These 32 plugs were a fair sample with attributes strongly similar to those of the set of 99 plugs described above. Properties evaluated by K & A were grain density, porosity, permeability to nitrogen, and permeability to water. In the collection of 32 plugs, 12 were samples of natural sandstone; the remainder were artificial rock composed of quartz sand and epoxy.

Samples of artificial sandstone analyzed for permeability to nitrogen at Oklahoma State University were not dried by heating. Likewise, no attempt was made to dehydrate core plugs of natural sandstone, but in all cases the rock was regarded as having been dried appropriately under room conditions. The set of 32 samples analyzed by K & A Laboratories were dried in an oven at 220 deg. F. for 24 hrs. Figure I1 shows that in 30 of 32 samples, permeability measured by K & A was greater than permeability measured at Oklahoma State University. (See "diamond" curve, Figure I1. Data shown in Table I1; samples of natural sandstone are identified by prefixes "PC," "RS," and "HC.")

The value of comparative analyses is to address these questions: (1) Of the 32 samples analyzed, are estimates of porosity made by the OSU laboratory significantly different from measurements made by K & A Laboratories? (2) Of the remaining scores of samples analyzed by the OSU laboratory (Appendix M), are estimates of porosity made by the OSU laboratory significantly different from measurements that would be made by K & A Laboratories? (3) Are estimates of permeability made by the OSU laboratory significantly different from measurements that were made, or that would be made, by K & A Laboratories?

TABLE I1 CORE-PLUG ANALYSES, K & A LABORATORIES

Column 1: Core-plug number, as shown in Figure I1. Column 2: Grain density, gm/cm^3. Column 3: Porosity, percent, K & A Laboratories. Column 4: Porosity, percent, OSU laboratory, computed from scaled measurements and grain densities reported by K & A Laboratory. Column 5: Porosity, percent, OSU laboratory, computed from scaled measurements and average grain densities, artificial sandstone (2.374 gm/cm^3), and natural sandstone (2.656 gm/cm^3). Column 6: Permeability to nitrogen, millidarcies, K & A Laboratory. Column 7: Permeability to nitrogen, millidarcies, OSU laboratory. Column 8: Differences of permeabilities (Column 6 - Column 7), millidarcies. Column 9: Permeability, percent difference. Note: Last 12 rows show data concerning samples of natural sandstone.

1	2	3	4	5	6	7	8	9
6	2.2	9	9.97	16.75	12.3	465.8	-453.5	-3686.99
5	2.26	10.9	11.44	15.69	685	457.6	227.4	33.20
7	2.33	14.6	14.88	16.46	760	573.7	186.3	24.51
13	2.36	15.6	15.55	16.05	1200	967.7	232.3	19.36
16	2.37	15.6	15.85	15.99	1240	1031.4	208.6	16.82
20	2.36	15.8	16.25	16.74	1600	1302.6	297.4	18.59
17	2.37	16.2	16.3	16.44	1450	1178.5	271.5	18.72
14	2.36	16.3	16.6	17.09	914	973.1	-59.1	-6.47
15	2.36	16.3	16.49	16.98	1240	1028.4	211.6	17.06
18	2.38	16.6	17.34	17.13	1490	1192.8	297.2	19.95
19	2.37	17.1	17.7	17.84	1700	1301.7	398.3	23.43
8	2.38	17.3	17.66	17.46	2260	574.3	1685.7	74.59
27	2.37	17.4	18.16	18.3	2000	1528.1	471.9	23.60
28	2.38	17.4	17.75	17.55	1980	1528.9	451.1	22.78
26	2.38	17.7	18.15	17.94	2170	1475.5	694.5	32.00
25	2.37	17.9	18.13	18.27	1870	1473.1	396.9	21.22
29	2.4	18	18.29	17.4	2340	1961.5	378.5	16.18
30	2.4	18.8	18.86	17.97	2290	1973.9	316.1	13.80
31	2.4	18.9	18.98	18.09	2460	2010.2	449.8	18.28
32	2.39	19.2	19.77	19.23	3060	2047.6	1012.4	33.08
1	2.65	22.8	23.56	23.73	174	155.3	18.7	10.75
2	2.65	23.6	24.09	24.26	191	159.7	31.3	16.39
3	2.65	24	24.44	24.61	185	165.8	19.2	10.38
4	2.65	25.1	25.42	25.59	191	180.6	10.4	5.45
11	2.66	25.7	26.36	26.25	718	603.6	114.4	15.93
10	2.66	26.2	27.26	27.16	734	589.6	144.4	19.67
21	2.65	26.3	26.89	27.06	1260	1210.6	49.4	3.92
23	2.66	26.5	27.74	27.63	1400	1312.4	87.6	6.26
9	2.65	26.7	27.3	27.46	649	536.5	112.5	17.33
24	2.67	27.1	28.22	27.84	1410	1316.9	93.1	6.60
12	2.66	27.2	30.19	30.09	770	628.3	141.7	18.40
22	2.66	27.2	27.94	27.83	1360	1285.7	74.3	5.46

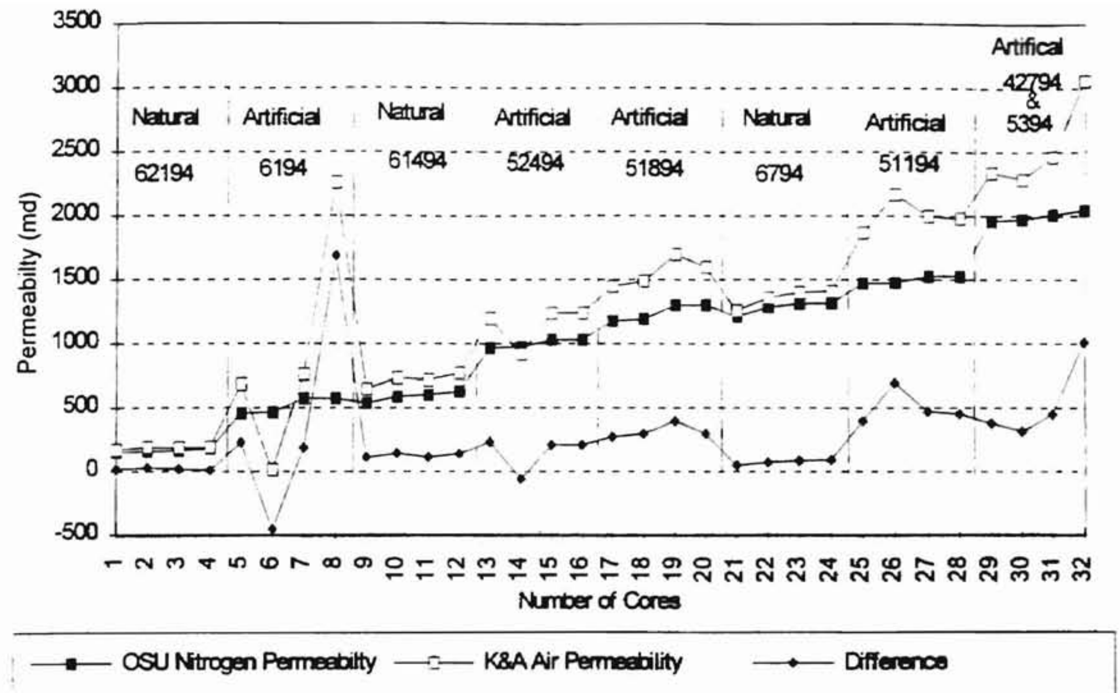

Figure I1. Comparison of permeability measurements by OSU laboratory and K & A Laboratories. Observe divergence of measurements toward samples with high porosity. Observe also that measurements converge among samples of natural sandstone. Data suggest differential effects of heat-drying of samples. Data shown in Table I1.

ESTIMATES OF POROSITY

THE SET OF 32 CORE PLUGS

Comparison of two data-sets of porosity is based on Table I1, columns 4 and 5. Measurements of porosity by the OSU laboratory were based on individual grain densities reported by K & A Laboratories. Bulk density of each core plug was derived from three measurements of diameter and one measurement of length. Summary statistics are as follows:

Estimates of porosity, Oklahoma State:

Number of samples: 32
Average porosity: 20.4228 percent
Standard deviation: 5.2688 percent
Variance: 27.7599

Measurement of porosity, K & A Laboratories:

Number of samples: 32
Average porosity: 19.8438 percent
Standard deviation: 5.0089 percent
Variance: 25.8967

Clearly, measurements of porosity made by the OSU laboratory are the greater by approximately 0.6 of 1 percent (absolute), and by the ratio of about 1.03. Measurements made by the OSU laboratory are somewhat more variable and uniformly are slightly the larger (cf. Table I1, columns 4 and 5), the latter fact suggesting a slight positive bias in measurement of volumes of core plugs.

To evaluate the significance of such difference requires consideration of the effects of using porosity-data in the context of this research, and the question can be reduced as follows. Assume that measurements of porosity by K & A Laboratories are taken to be the truth or a close approximation of the truth. Then were measurements of porosity by the OSU laboratory so distant from the mark that they would invalidate conclusions drawn from use of the core plugs in Mud-cake and Permeability tests? Or would they bias seriously the inferences to be drawn from Mud-cake and Permeability tests and extended to predictions of behavior of reservoirs in the subsurface? The answer is "no," because unpreventable errors of greater proportion arise elsewhere in the total chain of experiments; the average error of 0.6 percent porosity is of no operational significance.

THE SET OF 99 CORE PLUGS

This question was asked in passages above: Of the 99 samples analyzed by the OSU laboratory (Appendix M), are estimates of porosity made by the OSU laboratory significantly different from measurements that would be made by K & A Laboratories?

In estimating porosity of the set of 99 core plugs from data compiled in the course of work at Oklahoma State University (see also Appendix M), the averages of matrix densities of artificial sandstone and of natural sandstone -- as reported by K & A Laboratories (Table I1) -- were accepted as reliable approximations of mean matrix densities of the two populations (Appendix M).

Artificial sandstone:

Number of samples: 18. (Core-plugs 5 and 6 were excluded; matrix densities were judged to be unrepresentative of artificial sandstone.)

Average matrix density: 2.3739 gm/cm^3

Standard deviation: 0.0170 gm/cm^3

Natural sandstone:

Number of samples: 12

Average matrix density: 2.6558 gm/cm^3

Standard deviation: 0.0067 gm/cm^3

Assume that measurements of porosity from the set of 32 core plugs would be representative of all similar measurements to be made by the OSU laboratory and by K & A Laboratories. Assume also that the OSU laboratory would estimate true matrix densities of artificial sandstone and of natural sandstone as 2.374 gm/cu cm and 2/656 gm/cu cm, respectively; these numbers are means of matrix densities reported by K & A Laboratories. The two data-sets (OSU cf. K & A) would be independent estimates of the porosity of one population. Assume further that measurements of porosity by K & A Laboratories are the truth or a close approximation of the truth. Two working hypotheses arise: (1) No significant difference exists between the averages of porosities computed by personnel at Oklahoma State and K & A Laboratories; therefore no significant difference exists in the effectiveness of methods. (2) A significant difference exists between the averages of porosities computed by personnel at Oklahoma State and K & A Laboratories; therefore a significant difference exists in the effectiveness of methods. If significant difference exists in this single variable of porosity, the difference should be manifest in the variances of the two sets of data, or in the means of the two sets of data, or both.

Discrimination between the null and the alternate hypothesis by Student's t-test is appropriate.

Estimates of porosity, Oklahoma State:

Number of samples: 32
Average porosity: 20.7775 percent
Standard deviation: 4.7813 percent
Variance: 22.8609

Measurement of porosity, K & A Laboratories:

Number of samples: 32
Average porosity: 19.8438 percent
Standard deviation: 5.0889 percent
Variance: 25.8967

The working hypothesis of equality of variances was evaluated by the variance-ratio test:

F(sample) = Variance (K & A)/ Variance (OSU)
F(sample) = 25.8967/22.8609
F(sample) = 1.1328
F(0.05, 31,31) = 2.06 (very nearly)
F(sample) = 1.0951, not significant

No evidence described here requires the rejection of the proposition that the variances of the two sets of samples of porosity are equal, having been computed from one population or from two populations, neither of which is more variable than the other; the observed variation would be expected to occur more than 25 times in 100 similar trials.

The working hypothesis of equality of means was tested by Student's "t" test:

t(sample) = ((ave. por., OSU) - (ave. por., K & A))/
((1/n (sum of variances))$^{0.5}$), where"n" is 32.
t(sample) = 0.7564; 62 degrees of freedom
t(0.05, 62) = 2.0 (very nearly)

The probability of occurrence of the t-statistic of 0.75 is between 40 and 50 in 100 similar trials, if samples were drawn from a single population, or from populations with equal means. No evidence set out directly above requires the rejection of the proposition that estimates of porosity by the two laboratories are effectively the same; that is, the two sets of estimates were drawn from one population with mean porosity near 20% and standard deviation near 5 percent. However, inspection of Table I1, columns 3 and 5 shows that 29 of 32 estimates of porosity by the OSU laboratory were greater than measurements by K & A Laboratories. These data are consistent with the trend toward slightly larger estimates by the OSU laboratory, a trend described above and regarded as being real. The difference, on the average, is approximately 0.9 percent porosity, an amount judged to be of no serious consequence. The method of estimating porosity from average grain densities of 2.374 gm/cu cm (artificial sandstone) and 2.656 gm/cu cm (natural sandstone) is considered to be sufficient for the purposes at hand.

ESTIMATES OF POROSITY, M & P TESTS

Core plugs of artificial sandstone were used in Mud-cake and Permeameter tests with the expectation of reasoning from the results of such tests to draw inferences about behavior of the large artificial reservoir of the Simulated Injection System -- and ultimately about behavior of natural reservoir rock. Considerable effort was expended to learn to make artificial rock in cores of 5-in. diameter in a consistent manner, so that core plugs from these small samples would have porosity and permeability consistent with the large reservoir of the SIS system. However, variation of porosity and permeability also was introduced to some degree, for one purpose of the research was to reason by analogy from experiments with artificial sandstone to predictions about reservoirs of natural sandstone. Of course, at the scale of field operations, aquifers show much variation in porosity and permeability.

A large core was extracted from the SIS reservoir (Figure 4.14); 85 plugs from this core were analyzed for porosity. The average porosity was 18.75 percent; the standard deviation was 0.5787 percent. Fifty plugs from 5-in.-diameter cores (Figure 4.16) were evaluated in the Mud-cake and Permeameter system, with the expectation that porosity and permeability would be similar to those of the large reservoir. The average porosity was 17.05 percent; the standard deviation was 1.0841 percent. Clearly the rock made in small batches is the more variable, but the average porosity is about 0.9 that of the large reservoir. The rock made in small batches was constituted with various proportions of epoxy and sand, and compacted in several ways. Its greater variation is a product of the empirical approach, in attempting to stabilize the porosity and minimize the variation in porosity and permeability. The central question is whether porosity is so different that conclusions drawn from Mud-cake and Permeability tests cannot validly be extended to inferences about the SIS reservoir.

Estimates of porosity, SIS reservoir:

Number of samples: 85
Average porosity: 18.7488 percent
Standard deviation: 0.5787 percent
Variance: 0.3349

Measurement of porosity, M & P samples:

Number of samples: 50
Average porosity: 17.0509 percent
Standard deviation: 1.0835 percent
Variance: 1.1740

The hypothesis of equality of variances, evaluated by the variance-ratio test:

F(sample) = Variance (SIS)/ Variance (M&P)
F(sample) = 1.1740/0.3349
F(sample) = 3.5
F(0.02, 49,84) = 1.78 (approximately)
F(sample) = 3.5, quite significant

The variance-ratio test is strong evidence that variation of core-plugs from 5-in. samples is much the greater, as expected from inspection of the basic statistics. Whether the mean are significantly different can be estimated by Student's t-test, of this form:

$$t(\text{smpl.}) = ((\text{ave. por., SIS}) - (\text{ave. por., M\&P}))/(((\text{var., SIS})/85) + ((\text{var., M\&P})/50))^{0.5}$$

$$t(\text{smpl.}) = (18.7488-17.0509)/((0.3349/85)+(1.1740/50))^{0.5}$$

t(smpl.) = 10.22, which is highly significant. ($t_{0.05}$ is approximately 2.01)

Thus the supposition that core plugs from the large artificial-sandstone reservoir and core plugs from numerous cores 5-in. in diameter represent one population must be rejected. The two kinds of rock are indeed different, especially with respect to variation in porosity. The effort to approximate porosity of the large artificial reservoir by sampling from small "reservoirs" was not successful. But the question arises: "Is this conclusion is the result of extraordinarily large variation in the M & P samples, or extraordinarily small variation of porosity in the SIS reservoir?" The M & P samples could be considered to be extraordinarily variable if they are more variable than natural sandstone; then their utility would be compromised.

The 50 samples of artificial sandstone used in M & P tests are compared below to samples of natural sandstone used in Mud-cake and Permeability tests:

Porosity, M & P samples, artificial rock:

Number of samples: 50
Average porosity: 17.0509 percent
Standard deviation: 1.0835 percent
Variance: 1.17401

Porosity, M & P samples, natural sandstone:

Number of samples: 33
Average porosity: 26.0234 percent
Standard deviation: 2.7471 percent
Variance: 7.54649

If the sample of natural sandstones described here are considered to be a representative collection of such rocks -- as they probably are -- then the core plugs of artificial sandstone used in M & P tests are appreciably less varied; thus their usefulness for qualitative reasoning about natural reservoirs seems to established, and by extension, so does the usefulness of the SIS artificial reservoir.

ESTIMATES OF POROSITY, M & P TESTS, WET CORE PLUGS

Porosities of core plugs used in M & P tests were calculated from dry-weights and wet-weights. Summary statistics are shown below:

1. Artificial sandstone, 50 core plugs:

Porosity, dry	Porosity, wet
Average: 17.05%	Average: 21.42%
Std. deviation: 1.08%	Std. deviation: 2.42%

2. Artificial sandstone, SIS reservoir, 9 core plugs:

Porosity, dry	Porosity, wet
Average: 18.99%	Average: 24.61%
Std. deviation: 0.57%	Std. deviation: 2.79%

3. Natural sandstone:

Porosity, dry, 33 plugs	Porosity, wet, 17 plugs
Average: 26.02%	Average: 36.44%
Std. Deviation: 2.75%	Std. deviation: 5.03%

In each instance, wet-weight porosity is the greater, on the average; moreover, wet-weight porosity is the more variable. In computation of wet-weight porosity, core-plugs are assumed to be totally saturated. Because calculated porosity is a function of bulk density, saturation of less than 100% of the pores would produce erroneously large estimates of porosity. Data shown above lead to the conclusion that samples were not completely saturated with water, although they were hydrated in a vacuum chamber in each instance. In brief, dry-weight porosities are regarded as the better estimates of true porosity.

ESTIMATES OF PERMEABILITY

PERMEABILITY TO NITROGEN

Permeabilities of the set of 32 samples were measured at both laboratories. As a matter of routine query, the working hypothesis of equality of measurements was entertained. Figure I1 indicates forcefully that measurements of permeability by K & A Laboratories were systematically greater than measurements made by the OSU laboratory, especially wherein permeability of artificial sandstone is concerned. As described above, before analysis by K & A Laboratories the core plugs were dried by heating to 220^{o} F., a treatment sufficient to mobilize the epoxy cement. On the assumption that such drying changed configuration of pore throats and increased permeability of the artificial sandstone, comparison of measurements was based on data concerning natural sandstone. Drying of natural sandstone is a "treatment;" this suggests that to evaluate the working hypothesis of equal results by paired comparisons would be in order. Table I1, column 8, shows differences in permeabilities of natural sandstones, wherein measurements by K & A Laboratories uniformly are the greater. The hypothesis to be evaluated is that these differences are a matter of chance. The paired-comparisons test is as follows:

Number of differences: 12 (Table I1)
Average difference: 74.75 millidarcies
Standard deviation of differences: 48.3656 md.
Standard error of differences: 13.96
t(sample) = (mean of differences)/(standard error of differences)
t(sample) = 74.75/13.96
t(sample) = 5.3546
t(0.001,11) = 4.437

If measurements of permeabilities of natural sandstones made by the two laboratories were equal, and if the samples measured were identical, the probability of a t-statistic of 5.355 having occurred by chance alone is less than 1 in 1000 similar trials. One of these conclusions is warranted: (a) methods of analysis are significantly different, (b) methods of analysis were essentially the same, but the samples analyzed were not identical, or (c) methods of analysis were significantly different and the samples analyzed were not identical. Methods of analysis seem to have been similar. We believe that the consistent positive difference in permeability measured by K & A Laboratories probably is the result of drying of the core-plugs of natural sandstone. This inference is indicated by inspection of Figure I2, which shows permeability measured by K & A Laboratories and the OSU laboratory plotted in relation to porosity measured by K & A Laboratories. Data are shown as columns 6, 7 and 3, respectively, in Table I1.

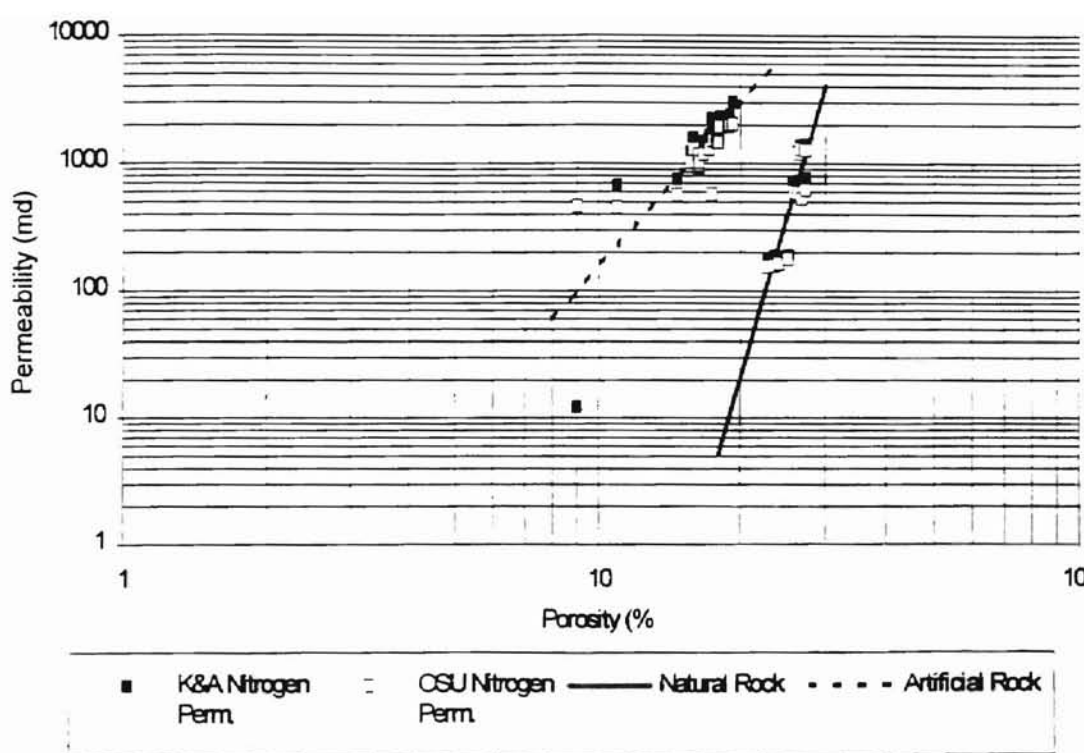

Figure I2. Porosity-permeability least-squares cross-plot. Data shown in Table I1.
Porosity measured by K&A Laboratories.

Observe that permeability measured by K & A (black squares) and by OSU (white squares) cluster, but permeability recorded by OSU is consistently the smaller.
A similar general relationship is observed from measurements of permeability of artificial rock, although scatter of points tends to increase in rock with porosity less than about 15 percent.

In granular porous rocks, an inverse relation between porosity and permeability probably is the general case.

SELECTED REFERENCES

1. Sokal, R. R., and Rohlf, F. J., 1969, Biometry: W. H. Freeman and Company, 776 p.

2. Rohlf, F. J., and Sokal, R. R., 1969, Statistical tables: W. H. Freeman and Company, 253 p.

APPENDIX G

APPENDIX G

WELL LOGS

Company	Well	Location	Casing
Wilcox Oil Co.	1 W.B. Davis	SW-SW-NE sec. 2-18N-3E	116
Apache Oil Co.	1 MC Kaughn	C-NW-NW sec. 4-18N-3E	160
H. A. Tully	1 Long	SE-SE-NW sec. 5-18N-3E	164
Ned Biffle	1 Sumner	NW-NW-SW sec. 6-18N-3E	128
Appleton Oil Co.	1 Manke	C-NW-NE sec. 7-18N-3E	399
Appleton Oil Co.	1 Marvin	S/2-NE-NW sec. 7-18N-3E	430
Davidor and Davidor	1 Campbell	NW-SW-NE sec. 7-18N-3E	135
Wolf and Patton	1 Nelson	NW-NW-SE sec. 8-18N-3E	89
Fleet & Roodhouse	1 Kate Switzer	SE-SE-SW sec. 9-18N-3E	158
Russel Maguire	1 Leka	NE-SE-NW sec. 10-18N-3E	109
Patton Bros. Drlg.	1 Fultz	SE-SW-SW sec. 10-18N-3E	92
Russel Maguire	4 Tully	NW-SW-NE sec. 10-18N-3E	157
Davis Bros.	1 Stewart	NE-NW-SE sec. 12-18N-3E	42
Foster, Grimm & Estes et. al.	1 Tietz	NW-NW-SW sec. 12-18N-3E	79
Patton Bros. Drlg.	1 Ross	NW-NW NE sec. 12-18N-3E	89
Delaney Drlg. Co.	2 Grace Mayo	NE-SW-SW sec. 14-18N-3E	112
Republic Natural Gas	1 Evans	SE-NW-SW sec. 14-18N-3E	106
Republic Natural Gas	3 Evans	NE-SE-SW sec. 14-18N-3E	112
T. N. Berry & Co.	1 Wells	NE-NW-SW sec. 15-18N-3E	114
John E. Hughes	1 Gray	SW-SW-NE sec. 15-18N-3E	68
R.C. Jones & Co. & Thompson	1 Trank	NE-SW-NW sec. 15-18N-3E	109
C.U. Bay & T. N. Berry & Co.	1-E State	SE-SE-NW sec. 16-18N-3E	102
Fleet & Roodhouse	1 State	SE-SE-NW sec. 16-18N-3E	95
S & K Oil Co.	1 Cty. Stillwater	SW-SW-NE sec. 18-18N-3E	156
Crawford Prod. Co.	1 Stout	NE-SW-NW sec. 19-18N-3E	94
W.A. Delaney, Jr.	1 Derry Ringwald	SW-NW-SE sec. 23-18N-3E	70
W.A. Delaney, Jr.	2 Ringwald-Shannon	SW-NW-SE sec. 23-18N-3E	96
Sunray Oil Co.	1 Testerman	NE-NE-NW sec. 24-18N-3E	54
Bay Pet. & Red Patton Drlg Co.	1 Myrick	C-N/2-NE-NW sec. 26-18N-3E	70
T. N. Berry & Co.	1 Hanks	NE-NE-SW sec. 26-18N-3E	103
Jones-Shlbrn & Pellow Oil Co.	1 Courtwright	NW-NW-NW sec. 28-18N-3E	150
H.E.R. Drilling Co.	1Johnson	NW-NW-SW sec. 29-18N-3E	134
Mitchell & Gage	1 Darrow Cochran	NE-NE-SE sec. 30-18N-3E	147
Mitchell & Gage	1 Ross	NW-NW-SW sec. 30-18N-3E	164

Gulf Oil Co.	1 Wirz	NW-NW-SW sec. 31-18N-3E	273
Gulf Oil Co.	1 Hattie Offield	SW-SW-NE sec. 31-18N-3E	232
Fred T. Haddock	1 Nelson	NW-NW-NE sec. 33-18N-3E	93
J.R. McLean & W.C. McBride	1 Kirk	SW-SW-SW sec. 34-18N-3E	128
Hill & Hill and Delaney	1 Stockton	NW-NW-SW sec. 35-18N-3E	146
Republic Nat. Gas Co.	1 Lovell Bros.	SW-SW-NW sec. 35-18N-3E	174
J.E. Trigg	1 State	SE-SE-NW sec. 36-18N-3E	100
C.V. Richardson	1 Russell	C-SW-NW sec. 19-19N-3E	151
E.J. Athens	1 Focht	NE-SW-NW sec. 20-19N-3E	133
Flynn Oil Co.	1 Hunt	NE-NE-SE sec. 21-19N-3E	138
George P. Caulkins	1 Keyes	NE-NE-NW sec. 22-19N-3E	172
Lion Oil Co.	1 Murray-Zarker	SE-SE-NW sec. 23-19N-3E	162
Russel Cobb, Jr.	1 Danuser	SW-SW-NE sec. 23-19N-3E	142
H.A. Tully	1 Fisher	NW-NW-NE sec. 24-19N-3E	96
T.N. Berry & Co.	2 Fisher	SE-NW-NE sec. 24-19N-3E	104
H. Waggoner	1 Fisher	SE-SW-SE sec. 25-19N-3E	86
Dooley Enginerring Co.	1 Bauman	SE-SE-NE sec. 25-19N-3E	113
Royal Oil and Gas Corp.	1 Jones	SW-SW-NE sec. 26-19N-3E	122
Royal Oil and Gas Corp.	1 Brattain	SW-SE-SE sec. 26-19N-3E	132
Royal Oil and Gas Corp.	2 Brattain	NE-SE-NE sec. 26-19N-3E	105
Magaw and Zimmer	1 Berry Patton	N/2-S/2-SW sec. 27-19N-18E	180
Magaw and Zimmer	1 Jones-Davis	SW-NE-SW sec. 27-19N-3E	150
Thompson Drlg. Co.	1 Freideman	SE-SE-SE sec. 28-19N-3E	110
W.H. Martgan	1 Goom	NE-NE-NE sec. 30-19N-3E	140
W.H. Martgan	1 Schroeder	SW-NE-NW sec. 34-19N-3E	140
Patton Bros. Co. & T.N. Berry Co	1 Lovell	SW-SW-NE sec. 35-19N-3E	92
The Texas Co.	1-M State Land	NE-NW-NE sec. 36-19N-3E	135

APPENDIX H

APPENDIX H

WATER ANALYSIS

OKLAHOMA COOPERATIVE EXTENSION SERVICE

SOIL, WATER & FORAGE ANALYTICAL LABORATORY

Division of Agricultural Sciences and Natural Resources • Oklahoma State University
Department of Agronomy • 048 Agricultural Hall • Stillwater, OK 74078

WATER QUALITY REPORT

Gary Stewart **Dale Holman** **105 NRC - Geology** **744-6358**	Name: Location:	**Lab I.D. No.:** 103844 **Customer Code:** 586 **Sample No:** 1 **Received:** 05/01/96 **Report Date:** 05/06/96 **Test No:** 1

TEST RESULTS

Cations		Anions		Other	
Sodium (ppm)	82	Nitrate-N (ppm)	4	pH	8.4
Calcium (ppm)	84	Chloride (ppm)	132	EC (μmhos/cm)	1060
Magnesium (ppm)	46	Sulfate (ppm)	38		
Potassium (ppm)	2	Carbonate (ppm)	12	Boron (ppm)	0.06
		Bicarbonate (ppm)	398		

Derived Values		Derived Values (cont'd)	
Total Soluble Salts (TSS in ppm)	798	Percent Sodium	30.9
Sodium Adsorption Ratio (SAR)	1.8	Hardness (ppm)	398.8
Potassium Adsorption Ratio (PAR)		Hardness Class	Very Hard
		Alkalinity (ppm as $CaCO3$)	346

INTERPRETATIONS FOR ***Irrigation Water***

This water is suitable for use on most crops under most conditions. A problem may arise with continued use on very heavy soils where essentially no leaching occurs. If rainfall is sufficient, it will dilute the salts and reduce the hazard. If sodium is the main problem, gypsum can be used to reduce the problem.

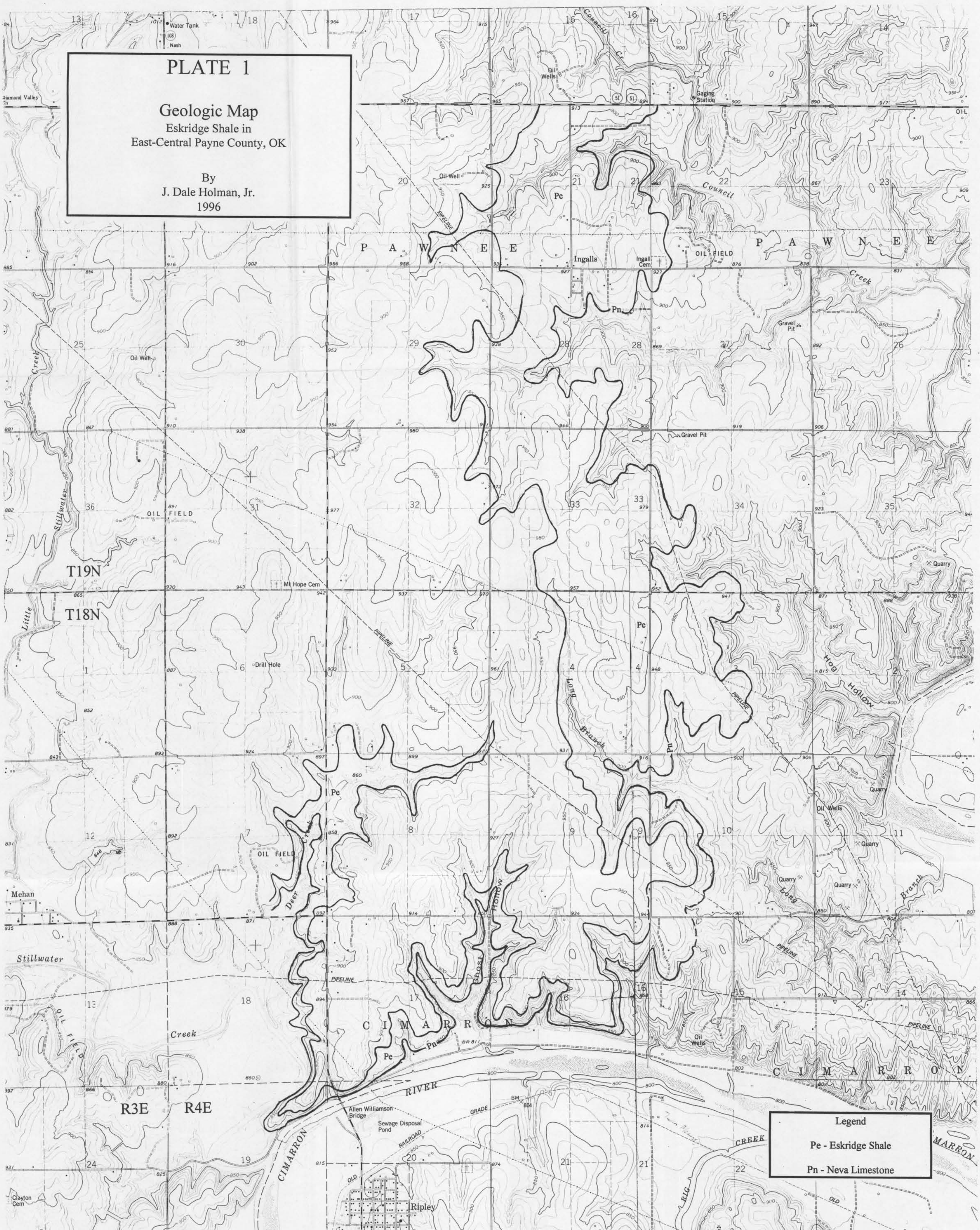
PLATE 1
Geologic Map
Eskridge Shale in
East-Central Payne County, OK
By
J. Dale Holman, Jr.
1996
Legend
Pe - Eskridge Shale
Pn - Neva Limestone
T19N
T18N
R3E
R4E
PAWNEE
CIMARRON
CIMARRON RIVER
Ingalls
Ripley
Mehan
Nash
Mt Hope Cem
Allen Williamson Bridge
Sewage Disposal Pond
Stillwater Creek
Little Stillwater
Council Creek
Long Branch
Hog Hollow
Deer Creek
Ghost Hollow
BIG CREEK
OIL FIELD
PIPELINE
SCALE 1:24 000
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

PLATE 2

Log Signature Map
T18N, R3E - T19N, R3E
Payne County, OK

By
J. Dale Holman, Jr.
1996

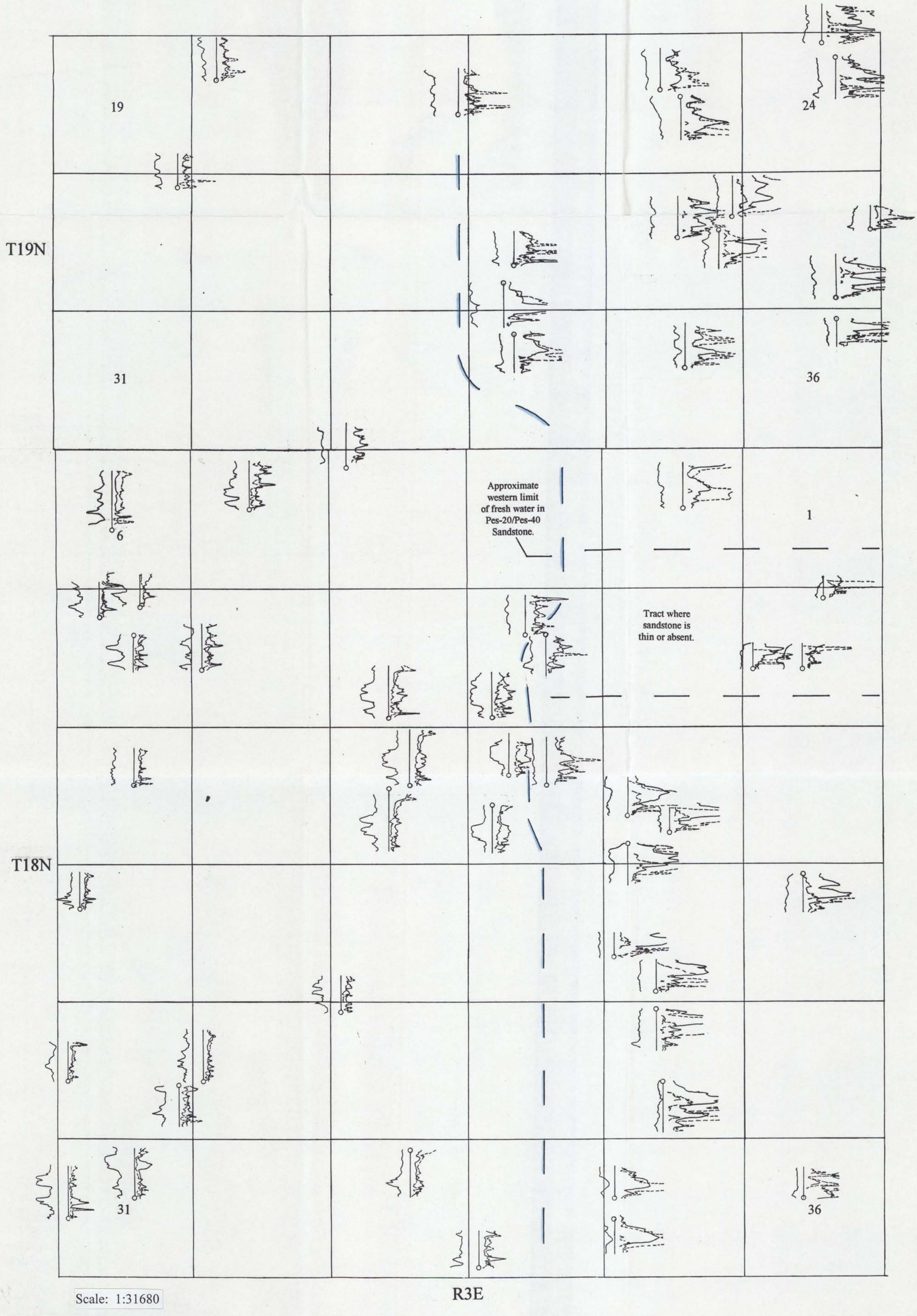

PLATE 3

Cross-Section A
T19N, R3E
Payne County, OK

By
J. Dale Holman, Jr.
1996

Scale: 1:7920

PLATE 4

Cross-Section B
T18N, R3E
Payne County, OK

By
J. Dale Holman, Jr.
1996

Scale: 1:7920

PLATE 5

Cross-Section C
T18N, R3E
Payne County, OK

By
J. Dale Holman, Jr.
1996

Scale: 1:7920

PLATE 6

Cross-Section D
T18N, R3E - T19N, R3E
Payne County, OK

By
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1996

Scale: 1:10560

VITA

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