The Stratigraphy of the Quaternary Alluvium in the Great Bend Prairie, Kansas

by

Malia LaNita Rosner
B.S., Wichita State University, 1986

Submitted to the Department of Geology
and the Faculty of the Graduate School
of the University of Kansas in Partial
fulfillment of the requirements for
the degree of Master of Science

Redacted Signature

Redacted Signature

Redacted Signature
Committee Members

Redacted Signature
For the Department

Redacted Signature
Date thesis accepted

ABSTRACT

The Quaternary alluvial aquifer beneath the Great Bend Prairie in south-central Kansas serves as a major source of water for irrigation and domestic use. Low quality saline water, however, intrudes locally from Permian and possibly Cretaceous bedrock and mixes with the less dense freshwater in the aquifer.

Grain-size analysis of samples from three wells of a natural recharge study was correlated to the respective gamma logs. The correlation was then applied to the gamma logs from an observation well network, established by the Kansas Geological Survey and Groundwater Management District No. 5, to improve the stratigraphic interpretation. The stratigraphy of the area is defined from the surface down as (1) dune sands, (2) near surface silt-clay, (3) a section of variable lithology, (4) basal sand, and (5) bedrock.

The alluvium was mainly deposited by the Arkansas River as it aggraded its channel and moved northward laterally by avulsion to its present position. The gamma logs and grain-size analysis show fining upward sequences in the sediments.

The near surface silt-clay and basal sand are the only two lithologies that are continuous and could be mapped across the study area. The near surface silt-clay can influence aquifer recharge. If saline water and then

freshwater is allowed to come in contact with the silt-clay, then the permeability of the silt-clay will be significantly reduced. This will decrease recharge to the aquifer. The basal sand tends to be thicker in the paleovalleys and thinner over the paleoridges. This sand serves as an aquifer in the area. The variable lithology section is the result of lateral shifting of the streams in the study area.

ACKNOWLEDGMENTS

I would like to thank Tom McClain and Don Whittemore of the Kansas Geological Survey for their guidance and wisdom, Dr. Dort for his advise and belief in my abilities, Dr. Angino for going to bat for me when I needed it the most, my parents Harold and La Rhue Rosner for their faith and support, John French for his advice and encouragement, Rob Shapiro and Jeff Vesperman for their aid in preparing the base maps, and all the other people who have made the completion of this project possible.

This project would not have been possible without the funding and support provided by the Kansas Geological Survey and Groundwater Management District No. 5.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

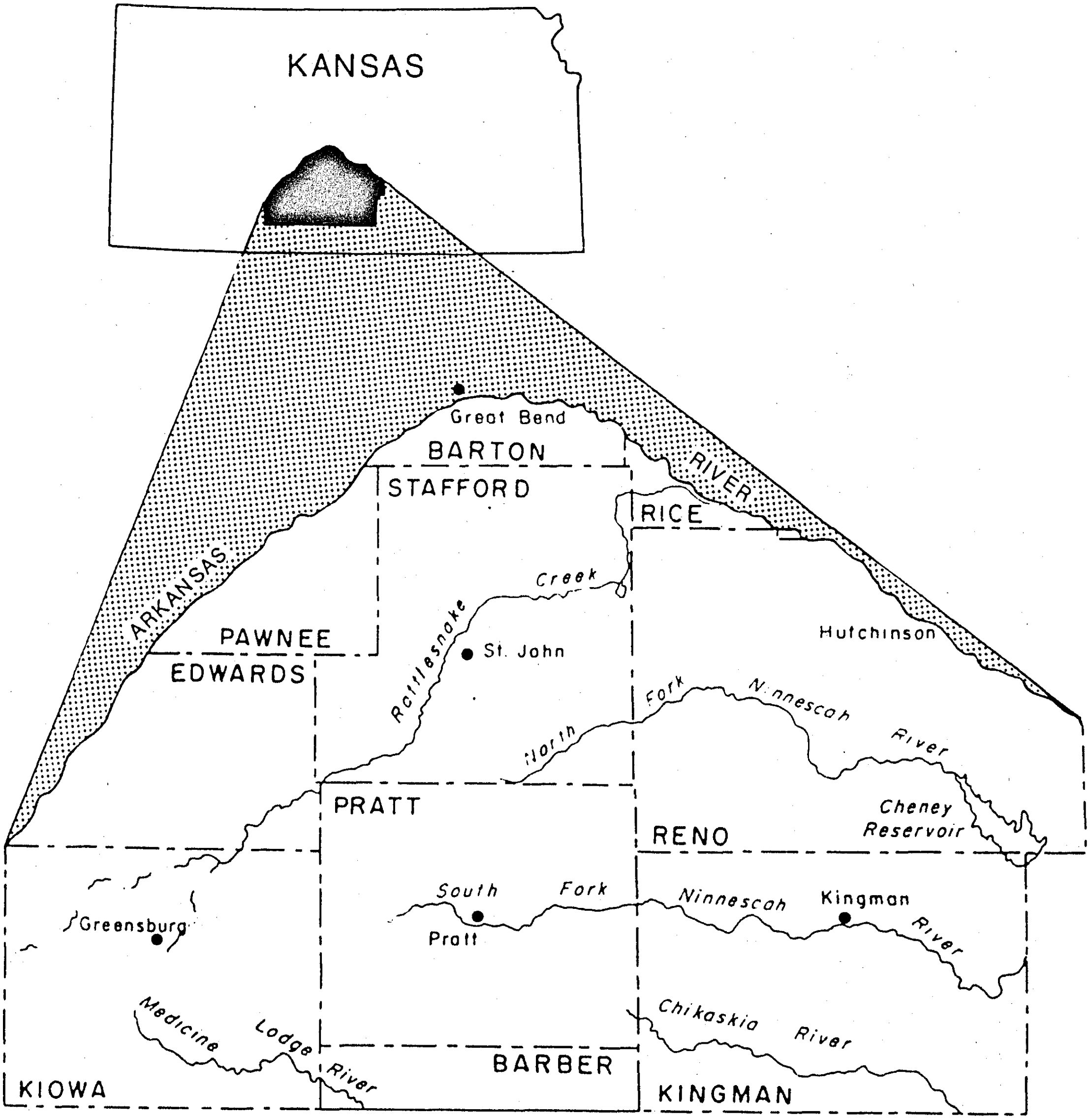
INTRODUCTION

The economy in the Great Bend Prairie, south-central Kansas, is predominantly agrarian. Crop production is dependent on the amount and timing of precipitation. As a result, water has always been important to the economic development of the region. Unfortunately, the distribution of precipitation tends to be uneven. The climate of south-central Kansas has been classified as semi-arid to sub-humid and is characterized by extremes in precipitation and temperature (Fund, 1984).

The land surface is poorly drained and traversed by few streams (Fader and Stullken, 1978). There are four major streams in the area, the Arkansas River, Rattlesnake Creek, the North Fork of the Ninnescah River, and the South Fork of the Ninnescah River (Figure 1). The headwaters of the North and South Forks of the Ninnescah River lie within the study area. The Arkansas River begins in Colorado and flows through the Great Bend Prairie. Historically, during times of drought there has not been enough stream flow in the Arkansas river to support irrigation. Since there is little surface water available, the main source of water for irrigation is the ground water in the Quaternary deposits.

The development of irrigation improved the economy of the area. Irrigation allows the farmer to diversify the types of crops grown, increase the yield of less

Figure 1. Location of rivers in south-central Kansas (after Stullken and Fader, 1976).



productive land, and stabilizes the local economy by minimizing crop losses during droughts.

The Great Bend Prairie is covered with loess deposits and stabilized dune sands (Figure 2). Underlying these is Quaternary Alluvium deposited by the Arkansas River and other regional streams. The alluvium overlies Cretaceous and Permian bedrock (Figure 3). Unfortunately, low-quality saline water intrudes from the Permian and possibly Cretaceous bedrock and forms an interface or mixes with the less dense freshwater in the overlying Quaternary Alluvium. The saline water affects the quality and limits the amount of useable ground water. This has caused concern in the area about the quality and quantity of ground water available for public, private, and agricultural use.

In 1978, the Kansas Geological Survey, in close collaboration with Groundwater Management District No. 5 (GMD 5), began installing a network of observation wells in part of the Great Bend Prairie to monitor saltwater intrusion (Figure 4). The primary purpose of drilling these wells was to obtain water samples to monitor the saltwater intrusion. These wells have been used to measure water quality and potentiometric head values in an effort to determine the general distribution of the saltwater/freshwater interface and the vertical and horizontal movement of the ground water. In addition,

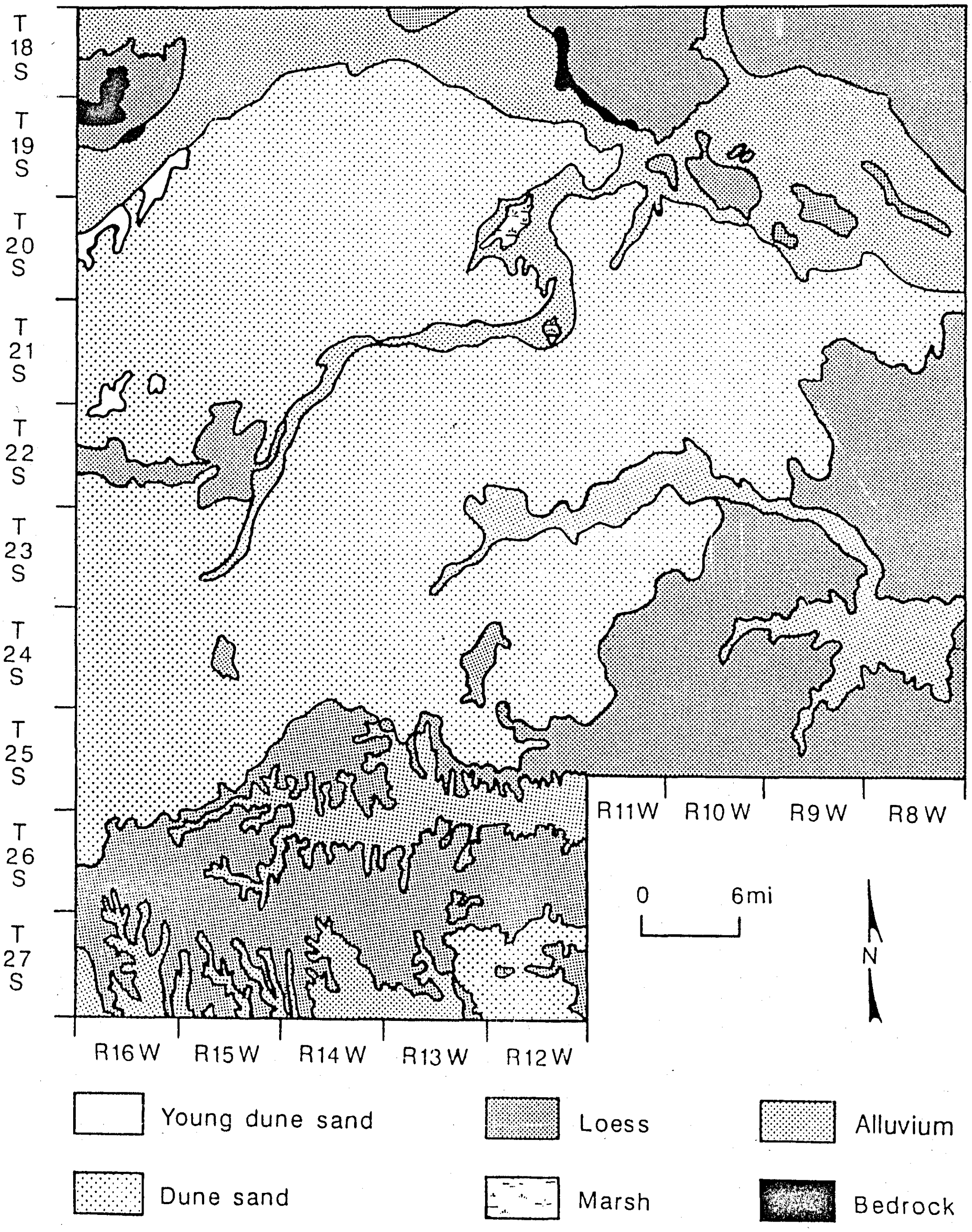


Figure 2. Geologic map showing location of sand dunes and loess deposits (from Bayne, 1956; Bayne and Ward, 1974; Layton and Berry, 1973; and Latta, 1950).

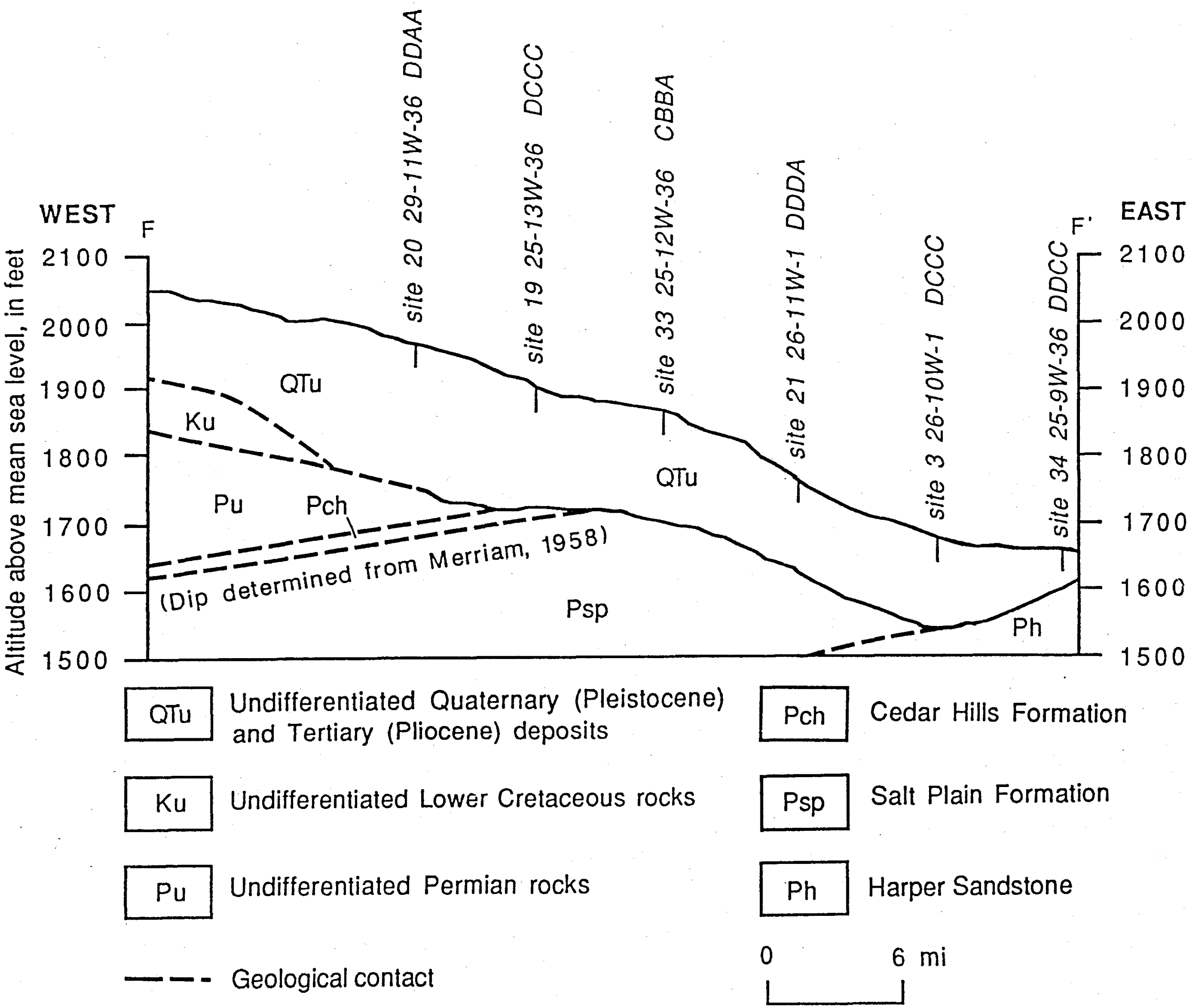


Figure 3. Generalized geologic cross section of study area.

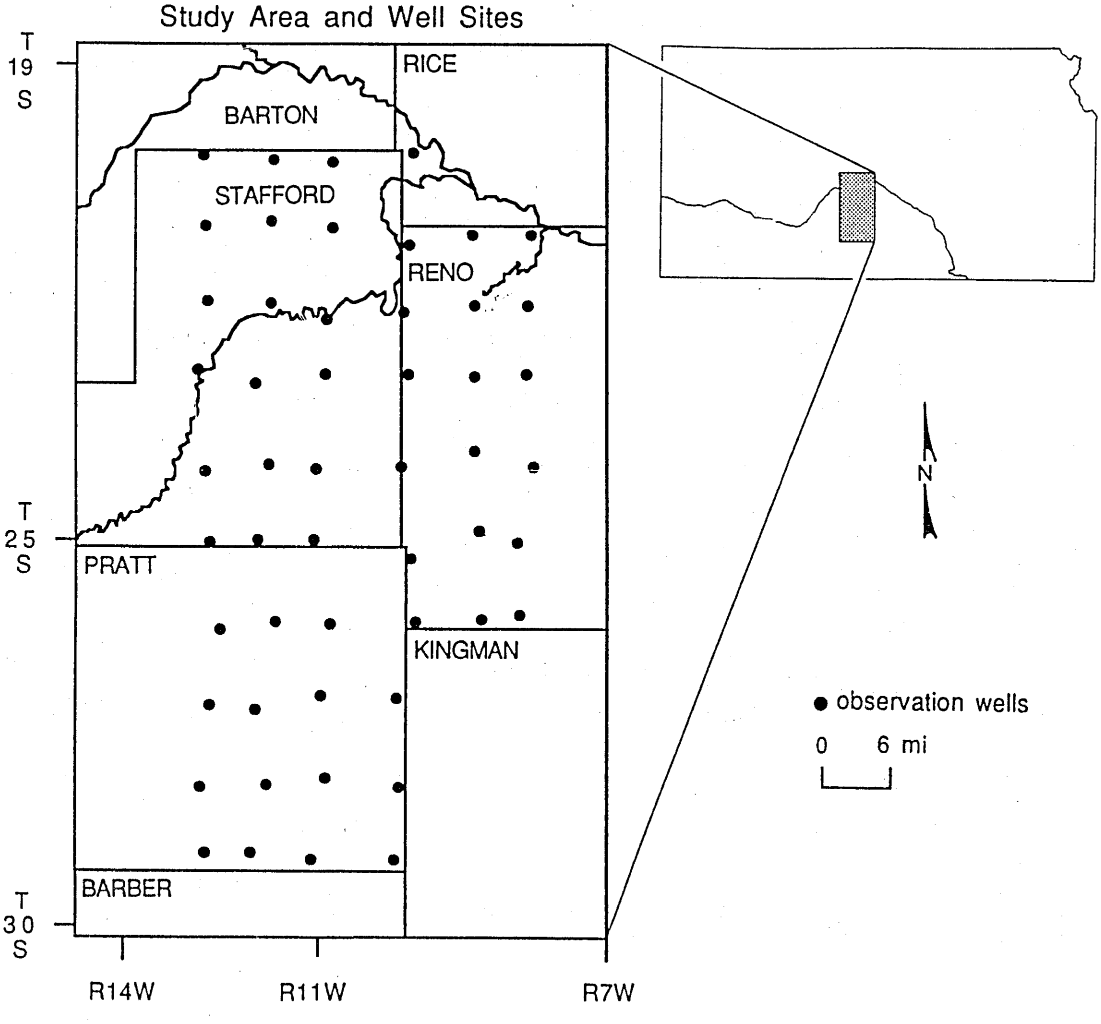


Figure 4. Location of study area and observation well sites.

data from these wells were to be used later to better define the stratigraphy of the alluvial aquifer. No well cuttings were saved from the 158 observation wells because, at the time of drilling, it was not known that samples would be necessary for interpretation of the stratigraphy and lithology of the area. The lack of samples greatly handicapped this study. The primary focus of this study is to better define the hydrogeologic stratigraphy of the alluvium using the information from the observation wells. In addition, the deposition of the alluvium will be examined. This information will assist future studies in determining whether there are any stratigraphic controls on saltwater migration from the bedrock into and through the overlying unconsolidated alluvial aquifer (McClain, 1986, personal communication).

Location

The study area of approximately 1,700 square miles (4,500 square kilometers) is located in south-central Kansas (Figure 4). It includes portions of Stafford, Barton, Pratt, Rice, and Reno counties. It encompasses the area from Township 19 South to Township 30 South and from Range 7 West to Range 15 West. The study area lies primarily within the Arkansas River Lowlands physiographic province, with the southern half of Pratt County in the High Plains physiographic province (Figure 5).

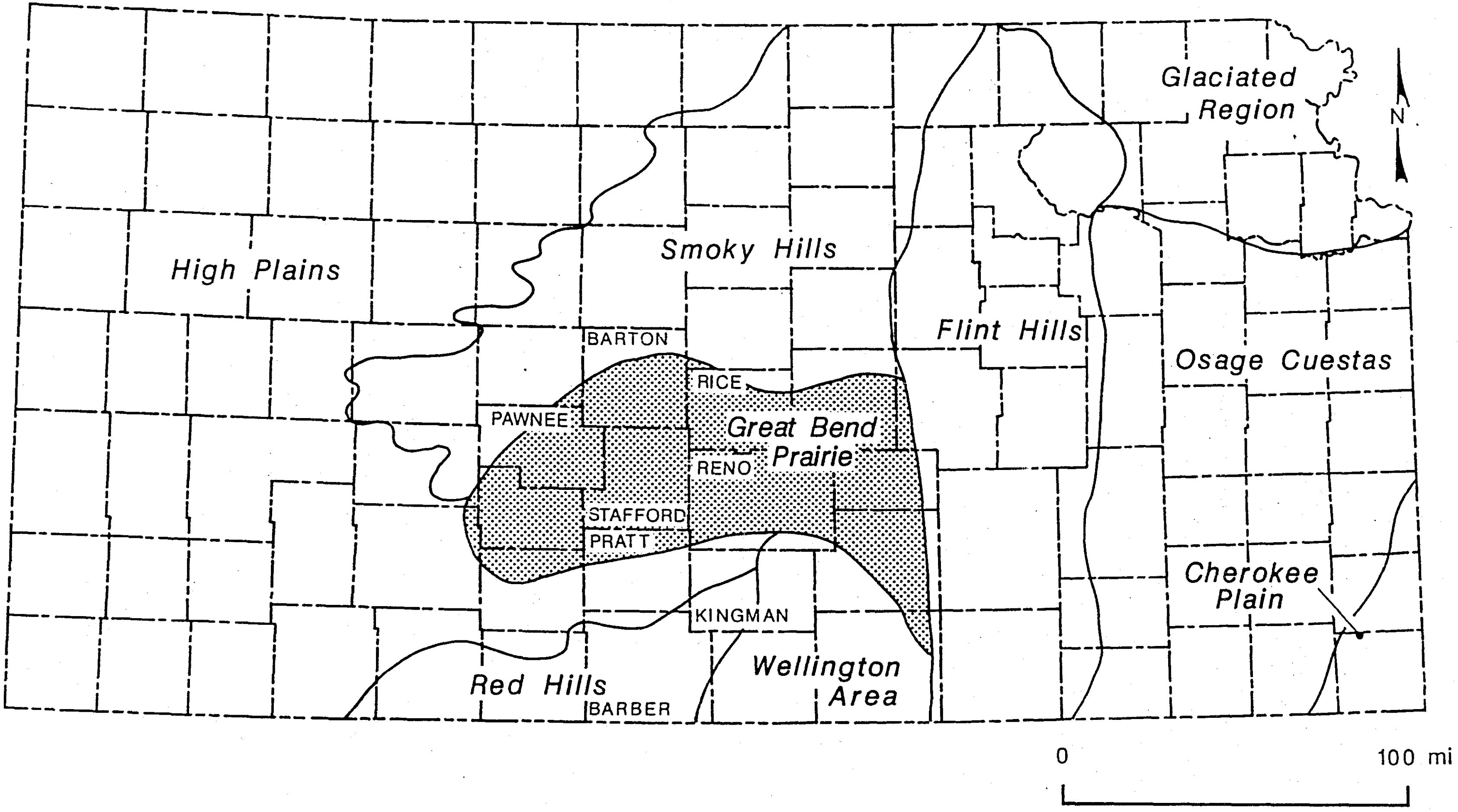


Figure 5. The physiographic provinces of Kansas (from Kansas Geological Survey)

Previous Studies

The geology and ground-water resources of Barton and Stafford Counties were described by Latta (1950), of Rice County by Fent (1950a) and by Bayne and Ward (1974), of Reno county by Bayne (1956), and of Pratt county by Layton and Berry (1973). Basic hydrogeologic data from the Great Bend Prairie was compiled by Stullken and Fader (1976). The use of water for irrigation and geohydrology in the Great Bend Prairie was investigated by Fader and Stullken (1978), who presented a map depicting the bedrock topography and subcropping patterns of the Cretaceous and Permian bedrock. They expressed the need for a network of observation wells to monitor water level and water quality, and better define the lithology.

The unconsolidated sediment that overlies the Permian and Cretaceous bedrock was first studied by Frye and Fent (1947), who examined the late Pleistocene loesses that occur in some areas of the Great Bend Prairie. Frye, et al. (1948) correlated the central Great Plains Pleistocene deposits with those of the upper Mississippi Valley glacial section.

The Pleistocene drainage history of central Kansas was discussed by Fent (1950b). He proposed that the Arkansas River reached its current position by a series of captures. He believed that the Arkansas River aggraded its channel, causing avulsions that allowed the fluvial material to be spread broadly over the area.

A study examining sources and distribution of the saline ground water in Stafford County was made by Cobb (1980). He focused on the distribution and possible mechanisms of saltwater intrusion into the freshwater aquifer and Rattlesnake Creek in Stafford County. He found that saltwater tends to upcone unstably and enter the gaining reaches of Rattlesnake Creek.

METHOD OF INVESTIGATION

This study was based on interpretation of gamma logs and drillers' logs obtained from the GMD 5 observation well network. Grain size analysis of well cuttings and gamma logs obtained from three recharge study wells, and geologic logs from previous Kansas Geological Survey studies were also used.

All the data collected were used to make two isolith maps. The gamma logs were used to make 16 cross sections. The cross sections show the near surface silt-clay, the underlying variable lithology section, and the basal sand that occurs on or near the subcropping bedrock.

Observation Well Network

Since 1978, 158 wells have been drilled by the Kansas Geological Survey and local contract drillers. These wells form a grid consisting of 52 well sites spaced approximately 6 miles (10 kilometers) apart, and are referred to by a number according to the order in which they were drilled (Figure 6). For example, Site 1 was the first well drilled in the network. Each site has a minimum of two wells. Most sites have three wells spaced 10 to 15 feet (3 to 5 meters) apart. The first well (deep) at most sites is screened in the Permian saline bedrock aquifer. It was drilled first to determine the general stratigraphy needed to determine where to screen the other observation wells at that site. This is the well in which a natural gamma log was run at each site (Appendix I). The second well (middle) at most sites is screened at approximately the saline/freshwater interface in the basal unconsolidated alluvium. The third well (shallow) at most sites is screened in the most permeable alluvial stratum above the second well and is in the freshwater part of the aquifer (Figure 7). This study is only concerned with the first (deep) well, therefore, the other types of sites will not be discussed. The well-numbering system that gives the location of the well sites in this report is given in Appendix II.

Natural Recharge Study Wells

It was noted in a preliminary report that samples of the alluvium were necessary to better define the natural gamma-ray response to the lithology (Rosner, 1986). For

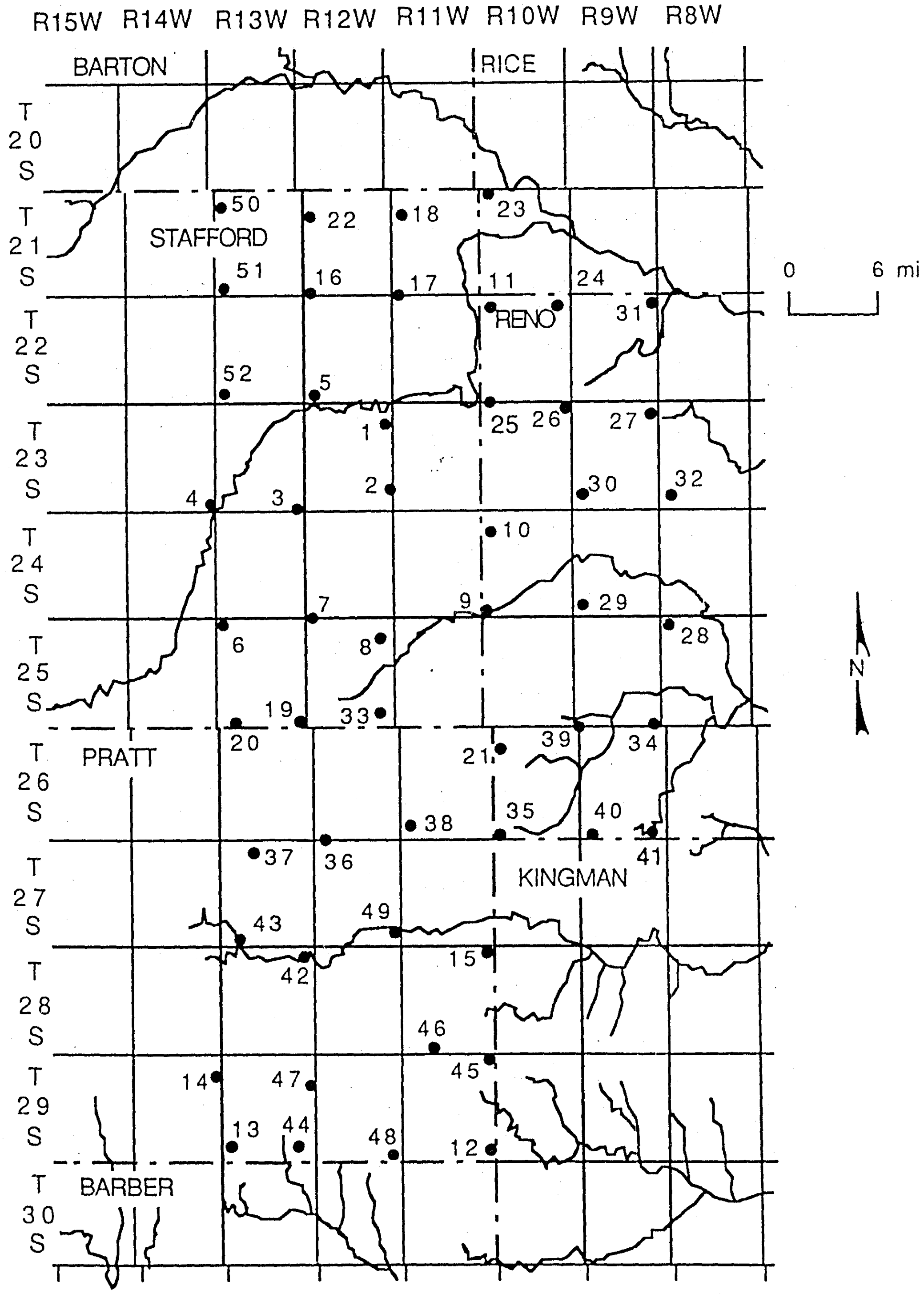


Figure 6. Location of observation wells and the site number.

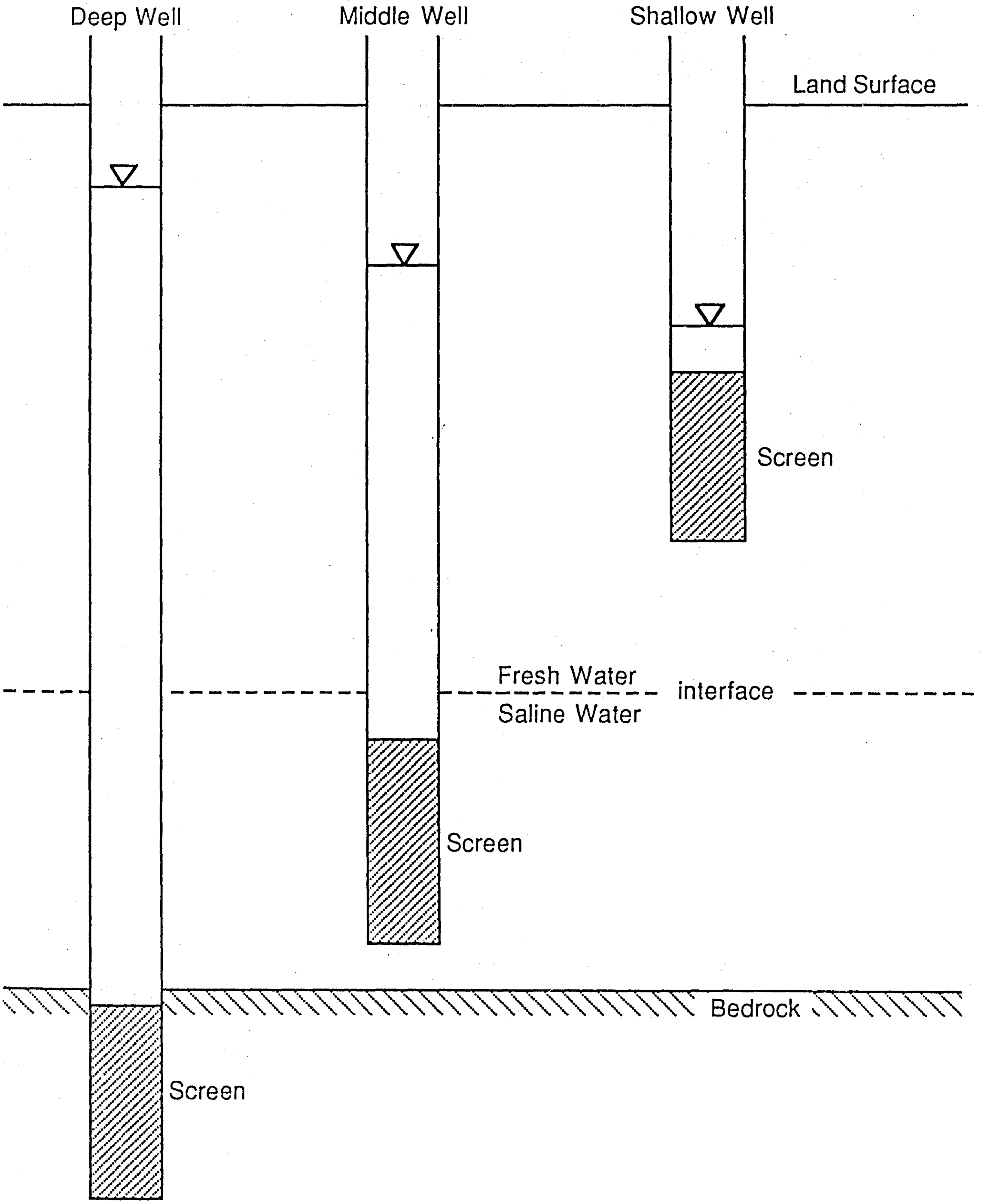


Figure 7. Typical layout of the wells at each site, not to scale.

that report, natural gamma logs of the observation wells were digitized and an attempt was made to correlate the silt-clay and sand beds. It was found that the silt-clay and sand beds were too discontinuous to trace without a better definition of the natural gamma log response to the lithology. Unfortunately, no samples were saved from the unconsolidated sediments of the original 155 wells. If samples and a natural gamma log could be obtained from several wells in the area, then the log response could be better defined in terms of lithology. The lithology could then be used to define the stratigraphy. Samples and natural gamma-logs were available from the well sites of the natural recharge study, and have been included in this study.

In 1987, three sites were drilled in addition to the grid water-quality network as part of a natural recharge study by the Kansas Geological Survey (Figure 8). The grain-size distribution of well cutting samples was determined and correlated with the gamma logs from the three recharge wells to define the natural gamma-log response to the lithology. The interpreted gamma-log response was then used to determine the stratigraphy and lithology at the 52 observation well sites. The grain-size analysis was conducted by using conventional hydrometer and sieving methods to determine the gravel, sand, and silt-clay percentages. For a detailed

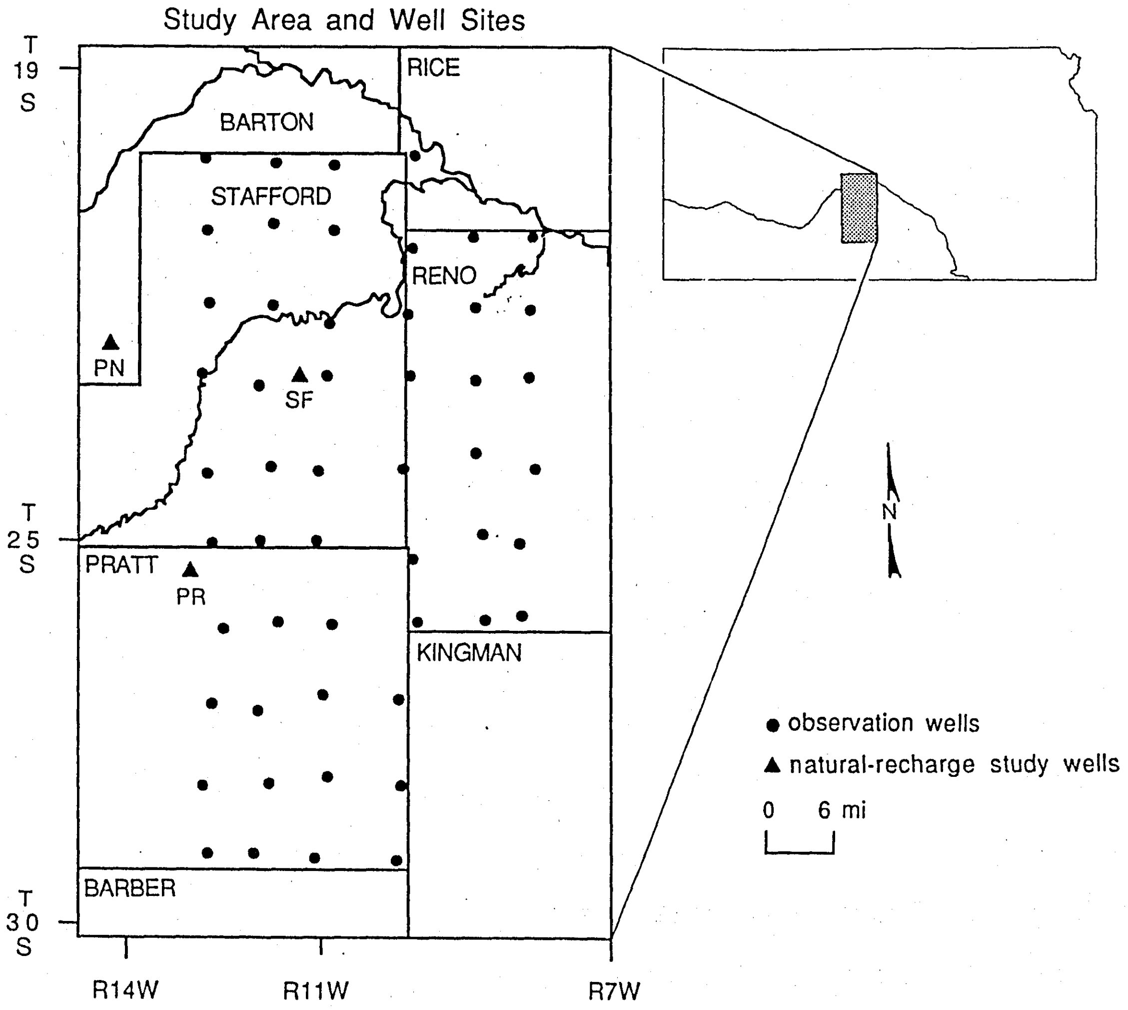


Figure 8. Location of recharge study wells and their location relative to the observation well network.

description of all the analysis methods used, see Appendix III. The method developed for correlating grain-size analysis and natural gamma-ray counts per second (cps) is described in Appendix IV.

Isolith Maps and Cross Sections

Two isolith maps were constructed using gamma-log data and geologic logs from previous studies by the Kansas Geological Survey (Stullken and Fader, 1976, Layton and Berry, 1973, Bayne, 1956, Latta, 1950, and Fent, 1950a). This added 176 data points to the maps. The geologic logs from the previous studies were used for better data control.

The near surface silt-clay and basal sand were initially identified from two lithofacies maps constructed during this study. The two lithofacies maps are not included in this report because they do not show the stratigraphy adequately. The size of the study area precluded their use. They were essential, however, at the beginning of the study to show the general stratigraphy, which is illustrated better by the isolith maps included in this report. The first lithofacies map was the lithology (greater than 2 feet (6 meters) thick) underlying the sand dunes or at the land surface down to the first major change in lithology (identifiable in the gamma logs or well logs). The second lithofacies map was the lithology that directly overlie the bedrock. They showed that a silt-clay lithology predominates on or near the surface, and a sand or gravel lithology predominates overlying the bedrock.

The cross sections were made using the gamma-logs from the observation well network. The near surface silt-clay, variable lithology section, basal sand, and bedrock were traced from log to log. The cross sections show the continuity of the near surface silt-clay and basal sand and the variability of the section between the two stratigraphic units.

LITHOLOGY OF THE SEDIMENTS

The unconsolidated sediments in the Great Bend Prairie were deposited by fluvial, eolian, volcanic, and pedogenic processes. The lithologies are composed of gravel, sand, silt-clay, caliche, and volcanic ash deposits.

Sand and Gravel

The sand and gravel in the area is composed of quartz, potassium feldspar, granitic rock fragments, limestone fragments, and chert. Since there appeared to be no major variations in the composition from one sample to another, a description of the sand and gravel in samples from one of the recharge well is given in Table 1. This site was chosen because it is representative of

Table 1. Description of the well samples from the Pratt County well, depth 80 feet (24 meters).

TEXTURAL ANALYSIS

Phi size	Description
-1.25	61 % Quartz, 50% well-rounded 50% rounded
	30 % K-spar, subrounded to rounded
	1 % Sandstone rock fragments, well rounded
	5 % Granite rock fragments, well rounded
	1 % Limestone rock fragments, well rounded
	1 % Dark minerals (Black chert or tourmaline)
	1 % Caliche fragments
-0.25	61 % Quartz, 30 % well rounded 30 % rounded 15 % subrounded 5 % subangular
	30 % K-spar, subrounded to rounded
	7 % Granite rock fragments, 50 % rounded, 50 % subrounded
	1 % Sandstone rock fragments
	1 % Dark minerals, black chert
0.25	53 % Quartz, 15 % well rounded 20 % subangular 20 % subrounded
	40 % K-spar, subrounded to rounded
	1 % Granite rock fragments, rounded to subrounded
	1 % Sandstone rock fragments
	5 % Dark minerals
1.0	76 % Quartz, 3 % well rounded 3 % rounded 10 % subrounded 15 % subangular 2 % angular
	20 % K-spar, rounded
	2 % Dark minerals, hornblend, subangular
	1 % Caliche
	1 % Granite rock fragments

2.0	75 % Quartz,	1 % well rounded
		1 % rounded
		10 % subrounded
		30 % subangular
		7 % angular
	20 % K-spar, subrounded to rounded	
	5 % Dark minerals, subrounded	
3.0	93 % Quartz,	2 % well rounded
		3 % rounded
		20 % subrounded
		20 % subangular
		10 % angular
	5 % K-spar, subrounded	
	2 % Dark minerals, hornblend and tourmaline, subrounded	
4.0	85 % Quartz,	50 % subangular
		50 % angular
	5% K-spar, subrounded	
	10 % Dark minerals,	hematite (rounded)
		hornblend (angular)
		tourmaline (subangular)

The mineralogy of the sand and gravel is constant between all three sites. Some samples contain more lithic fragments of Dakota Sandstone and Clay. These fragments are locally derived and occur near the bedrock.

The quartz grains are frosted (10 to 30%) or polished (40 to 50 %).

the sands and gravels from the three recharge wells, and contained the least amount of uphole contamination. The description also matches the geologic logs in the study area. It is assumed that the samples are also representative of the sands and gravels in the rest of the study area.

The mineralogy corresponds to the composition of the possible source rocks in Colorado. The source rocks in the drainage of the Arkansas River on the east side of the Sawatch Range are granite, gneiss, quartz monzonite, quartzite, limestone, andesite, and rhyolite (Richmond, 1986). These source rocks would produce abundant quartz, potassium feldspar, and limestone rock fragments.

Previous studies have determined that the predominant depositional environment was fluvial (Bayne, 1956; Fader and Stullken, 1978; Fent, 1950a; Latta, 1950). A fluvial origin is based on previous publications, shape of the natural gamma logs, and fining upward sequences in the grain-size analysis data. With no cores or other samples available, the fluvial depositional environment can not be confirmed. The median grain size of the sieved samples shows fining upward sequences (Table 2). The sequences are coarse to very coarse, granule gravel to very coarse, or granule gravel to fine. The sediment median grain size decreases upward and the coarse strata are better sorted than the

Table 2. Grain size analysis from natural recharge study sites.

Site SF, Stafford Co, grain size analysis results

Sample depth (feet)	Graphic mean (phi)	Median (phi)	Sand grade name	Inclusive graphic standard deviation sorting (phi)	
6	-0.61	-0.45	Very coarse	1.28	Poorly
9	0.84	.45	" "	1.74	"
10	0.17	-0.40	" "	1.93	Very poorly
11	0.52	0.20	Coarse	1.97	" "
15	0.28	-0.2	Very coarse	1.95	" "
17	-0.32	-1.1	Granule gravel	1.74	Poorly
20	-0.15	-0.63	Very coarse	1.65	"
23	0.29	0.1	Coarse	1.84	Very poorly
30	0.535	0.6	"	1.40	Poorly
32	0.04	-0.1	Very coarse	1.05	Moderately
33	0.48	0.38	Coarse	1.07	"
35	0.50	0.4	"	0.86	"
36	0.44	0.3	"	0.83	"
38	0.47	0.27	"	0.90	"
39	0.36	0.3	"	0.74	Moderately well
40	0.25	0.21	"	0.63	"
41	0.33	0.24	"	0.76	"
46	-0.55	-0.55	Very coarse	0.48	Well
50	-0.47	-0.52	" "	0.39	Very well
61	0.55	0.4	Coarse	0.96	Moderately

Site PN, Pawnee Co., grain size analysis

53	-0.28	-0.07	Very coarse	1.72	Poorly
55	0.2	-0.48	" "	2.07	Very poorly

Site PR, Pratt Co., grain size analysis

63	2.08	2.38	Fine	2.27	Very poorly
65	1.32	1.1	Coarse	2.5	" "
68	1.48	1.68	Medium	2.45	" "
72	0.08	-0.13	Granule gravel	1.72	Poorly
75	-1.13	-1.30	" "	0.73	Moderately well
79	-0.82	-1.2	" "	1.14	Moderately
80	-0.89	-1.27	" "	1.09	" "

finer strata. It is interesting to note that the median grain size is from granule gravel to coarse sand. Fluvial depositional fining upward sequences are generally characterized as granule gravel (stream channel) to fine sand and silt (point bar deposits). The paucity of fine sand and silt at the top of each sequence could be a result of the screen size used to catch the samples and the main size the drilling mud carried up, or indicate the bed load of the stream that deposited the sediments. The remaining results of the grain-size analysis from all three wells are given in Appendix V.

Silt-clay

Eight silt-clay samples from the recharge sites were analyzed by X-ray diffraction to determine the dominant clay minerals present. The silt-clay samples were selected by change in color and amount of silt-clay present in the sample, which could indicate a change in source or deposition. It was found that the dominant minerals are non-plastic minerals including quartz and lesser amounts of feldspar and trace to appreciable amounts of calcite. The dominant clay mineral is montmorillonite. Only trace amounts of kaolinite and illite are present. Some of the montmorillonite could be from contamination by the drilling mud (D. Grisafe, 1987, personal communication). However, since kaolinite and illite are only present in trace amounts, montmorillonite is still the dominant fraction regardless of drilling-mud contamination. A summary of the silt-clay mineralogy is given in Table 3.

Caliche

Most of the caliche deposits in the study area are composed of white calcium carbonate surrounding grains of sand. At the present time, there are two generally accepted methods of caliche formation: (1) upward capillary flow of calcium-bicarbonate type water into the vadose (unsaturated) zone with rapid evaporation at the surface (Blake, 1902) and (2) dissolved soil carbonate carried downward into the vadose zone and precipitated when the soil moisture is removed by evapotranspiration (Reeves, 1970). The latter represents the result of pedogenic processes.

Most caliche deposits are found in arid to semi-arid climates. Caliche generally forms in soils where sediment accretion rates are low and the development of paleosols is favorable. It is, however, the relationship between precipitation, temperature, runoff, and topographic relief that determines whether caliche will form (Reeves, 1970). Therefore, caliche formation does not necessarily indicate any particular climatic zone. Regional temperature fluctuations during the Pleistocene glacial events could have allowed the caliche deposits to form (Reeves, 1970). Frye and Leonard (1957) noted the

Table 3. X-ray diffraction results (from Grisafe, 1987, personal communication).

Recharge study site	Depth (feet)	Qtz	Fspar	Other minerals and clays				
				CC	Dolo.	Kaol.	M-I	Mont.
PN	3.5	vs	m	tr?		tr	tr	w
PN	7.5	vs	mw	tr	tr?	tr		m?
PN	27.5	vs	mw	mw		tr	tr	w
PN	43	s	mw	m	tr	tr	tr	tr
PN	55	s	mw	s		tr	tr?	w
PR	11	vs	mw	tr	tr	w	w	m
PR	33	vs	m	tr?	tr?	tr	tr	m?
SF	30	s	mw	s		tr	tr	w

Qtz. - Quartz
Fspar - Feldspar
CC - Calcite
Dolo. - Dolomite
Kaol. - Kaolinite
M-I - Mica-Illite
Mont. - Montmorillonite

vs = very strong
s = strong
m = medium
mw = medium weak
w = weak
tr = trace
blank space not detected

PN - Pawnee County
PR - Pratt County
SF - Stafford County

Note: These peak intensity designations are arbitrary and should not be used in comparing one sample with another.

reappearance of branchiate snails and an increase in the abundance and kinds of terrestrial and aquatic gastropod fauna in the plains at the beginning of the Pleistocene. They interpreted this as indicating a change toward a moist climate, with prairie vegetation dominant and belts of trees and shrubs along the valleys. Following the Kansan glacial episode, the climate has oscillated with a trend toward increasing aridity and the present day climate.

Site 30 contains the most caliche zones. Sites 26, 29, 47, and 48 have 6 caliche zones and site 30 has 7 caliche zones. The number of caliche zones present at site 30 corresponds with the seven glaciation deposits in Colorado reported by Richmond (1986). Table 4 contains a listing of the sites and depths at which caliche zones were noted during the drilling of the observation wells.

Using only well cutting samples, it is difficult to determine if the caliches represent calcic horizons in a paleosol, or if they formed at the water-table capillary fringe. The caliche deposits in the study area seem to be discontinuous because they are not found in each of the geologic logs, and the number of deposits range from none to six. This discontinuity indicates that factors such as rapid accretion rate in the flood basin, discontinuous erosion and deposition, and climatic changes, which allowed the dissolution and removal of

Table 4. Location, depth, and thickness of caliche deposits noted in the observation well geologic logs.

Site	Location	Depth (feet)	Thickness (feet)
2	23S 12W 36ABA	71 - 76	5
3	23S 13W 36DCC	20 - 23	3
		91 - 106	15
		106 - 115	9
		115 - 126	11
		132 - 142	10
4	23S 14W 36DDC	115 - 119	4
		132 - 140	8
8	25S 12W 11AAA	11 - 15	4
		61 - 62	1
		62 - 72	10
		120 - 123	3
12	29S 11W 36ACC	6 - 12	6
		73 - 89	16
13	29S 14W 36AAA	64 - 66	2
		81 - 96	15
		96 - 111	15
14	29S 14W 12ABB	6 - 10	4
		17 - 21	4
		42 - 44	2
		51 - 66	15
		207 - 258	51
15	28S 11W 01AAA	18 - 23	5
		62 - 77	15
		86 - 92	6
16	21S 12W 31CCC	9 - 15	6
		15 - 20	5
17	21S 12W 36DDC	2 - 40	38
18	21S 11W 07BBB	20 - 30	10
19	25S 13W 36DCC	56 - 63	7
		63 - 73	10
		78 - 79	1
		107 - 108	1

Site	Location	Depth (feet)	Thickness (feet)
20	25S 13W 31DDA	28 - 32	4
		41 - 45	4
		82 - 97	15
21	26S 11W 01DDD	46 - 50	4
		50 - 55	5
25	23S 10W 06BBA	58 - 60	2
		71 - 80	9
		85 - 90	5
		100 - 101	1
26	23S 10W 01AAA	50 - 65	5
		80 - 92	12
		116 - 117	1
		120 - 125	5
		150 - 160	10
		160 - 165	5
27	23S 09W 01ADA	5 - 10	5
		87 - 88	1
28	25S 09W 01ADD	41 - 44	3
29	24S 10W 36AAA	9 - 15	6
		65 - 80	25
		85 - 90	5
		95 - 97	2
		138 - 140	2
		140 - 148	8
30	23S 10W 36DAA	30 - 35	5
		40 - 48	8
		49 - 55	6
		59 - 70	11
		71 - 74	3
		77 - 80	3
		125 - 135	10
31	22S 09W 01ADAA	6 - 15	9
		18 - 21	3
		37 - 52	15
		92 - 93	1
32	23S 09W 25DDD	13 - 15	2
		15 - 22	7
33	25S 12W 36CBB	10 - 15	5
		48 - 55	7
		111 - 112	1

Site	Location	Depth (feet)	Thickness (feet)
34	25S 09W 36DDC	21 - 22	1
35	26S 10W 31CCC	97 - 98	1
36	27S 12W 06BAA	22 - 28	6
		41 - 45	4
		92 - 112	10
		116 - 129	13
37	27S 13W 05CAB	87 - 96	9
		165 - 171	6
38	26S 12W 36ADD	1 - 12	11
		12 - 19	7
		19 - 26	7
		30 - 41	11
		85 - 87	2
40	26S 09W 31CDD	20 - 27	7
		39 - 55	16
42	28S 13W 01CBAA	6 - 17	11
		109 - 111	2
		113 - 114	1
43	27S 13W 31DDD	45 - 48	3
44	29S 13W 35ABB	4 - 24	20
		24 - 35	11
		147 - 159	12
45	29S 11W 01DAD	6 - 12	6
		32 - 37	5
46	29S 11W 06AAA	4 - 8	4
		8 - 11	3
		12 - 20	8
		37 - 44	7
		92 - 114	22
47	29S 13W 12ABB	1 - 6	5
		19 - 30	11
		32 - 40	8
		44 - 52	
		67 - 75	8
		104 - 107	3

Site	Location	Depth (feet)	Thickness (feet)
48	29S 12W 36DCC	2 - 9	7
		11 - 19	8
		20 - 32	12
		70 - 73	3
		76 - 79	3
		175 - 178	3
49	27S 12W 35AAA	62 - 72	10
		97 - 101	4
50	21S 13W 06BCC	131 - 135	4

calcium carbonate from the soil, affected caliche preservation. The large amount of clastic material and the discontinuity of caliche deposits favors the idea that there was rapid accretion of the sediments with reworking by the migration of the river, and that some of the caliches represent paleosols. Without core samples, it is impossible to determine if the caliches noted in the geologic logs are paleosol horizons or remnant capillary-fringe deposits. Further study is needed with cores to determine if the caliches are paleosols. Then it may be possible to correlate them with the glacial events at the headwaters of the Arkansas River.

Volcanic Ash

Attempts have been made in the past to correlate Pleistocene deposits in Kansas with the type stratigraphy of the upper Mississippi Valley. Unfortunately, when these correlations were first made it was believed that there was only one volcanic ash in Kansas; it was named the Pearlette ash (Frye, et al, 1948). Work on the Pearlette ash increased interest in the study of the various Pleistocene ash falls. As a result, it has been determined that the Pearlette ash in central Kansas is not one ash, but three or four ash falls. These ashes are believed to have come from Yellowstone Park, Long Valley, California, and the Jemez Mountains of New Mexico (Geil, 1987). For the location of ash deposits in the study area see Layton and Berry (1973), Latta (1950), Fent (1950a), Bayne and Ward (1974), and Bayne (1956).

At this time, more work needs to be done on the volcanic ashes of the central plains. The ashes need to be fission-track dated and correlated with the proper volcanic event. In addition, the correlation of the glacial events with the deep ocean record and fission-track dating of volcanic ashes have produced a need for the redefinition of the Pleistocene geologic formations and stages. It is not within the scope of this paper to deal with the issue nor attempt to correlate the stratigraphy using the Pleistocene stages and volcanic ash deposits.

No attempt was made in this study to separate volcanic ash deposits from silt-clay layers. However, a sample (from 33 feet to 35 feet, 7 to 11 meters) of white clay from the Pratt County recharge well was examined under a petrographic microscope and volcanic glass shards were found. This indicated that the white silt-clays noted in geologic logs may be volcanic ashes. Other samples are needed to determine if these are indeed ashes and, if so, they should be properly identified and dated.

STRUCTURAL GEOLOGY

The study area lies on the southwestern flank of the Central Kansas Uplift (Barton Arch) and contains the

Pratt anticline (Figure 9). The Central Kansas Uplift is a pre-Desmoinesian post-Mississippian structural feature. This uplift trends northwest and separates the Hugoton Embayment on the west from the Salina and Sedgwick Basins on the east (Merriam, 1963). For the most part, the structural development of the uplift was concluded before Mesozoic time.

The Pratt anticline plunges southward and separates the Sedgwick Basin on the east from the Hugoton Embayment on the west. It was structurally active in early Paleozoic time and in pre-Desmoinesian post-Mississippian time.

It is interesting to note that there seems to be a correlation between the faults associated with the uplift and anticline and the trend of the lineaments and streamflow direction (Table 5). If this correlation is valid, then the lineaments would indicate movement along the uplift and anticline since the deposition of the alluvium. To support the theory of movement along the Pratt anticline, earthquakes have been noted on the anticline in Barber County, which is south of the study area (Layton and Berry, 1973).

STRATIGRAPHY

Fader and Stullken (1978) noted that clay lenses, where present, could separate the saline water in the

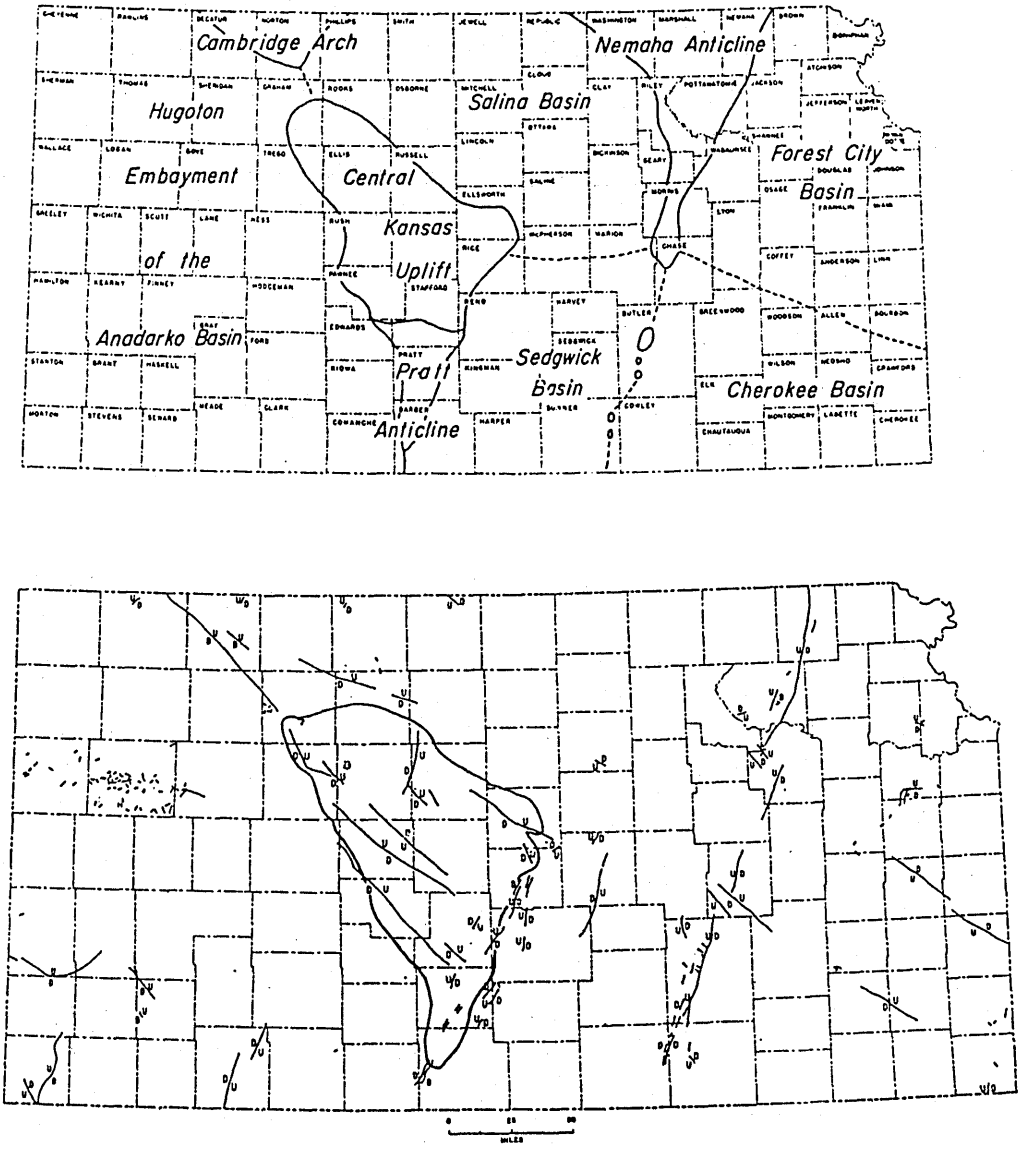


Figure 9. Structural geology of Kansas (from Merriam, 1963).

Table 5. Axis trends of the Central Kansas Uplift, Pratt anticline, and lineaments in the study area (from Merriam, 1963 and McCauley, 1988, personal communication).

Structure	Northwest axis (degrees)	Northeast axis (degrees)
Uplift faults (Merriam, 1963)	50	30
	26	20
	54	10
	42	39
	20	
	60	
	36	
	46	
	64	
	38	
	53	
Anticline faults (Merriam, 1963)		23
		31
		30
		19
Lineaments (McCauley, 1988)	60	36

lower part of the aquifer from freshwater in the upper portion of the aquifer. An irrigation well (21S 10W 1AB) drilled near site 23 (21S 10W 06AAD) supports Fader and Stullkens' comment. The stratigraphy is similar around both wells. The driller noted that below 40 feet (12 meters), or underlying a silt-clay lens, the water was too saline for irrigation. The water overlying the silt-clay lens, however, was suitable for irrigation. At site 23, the shallow well is screened below a silt-clay lens from 46 feet to 53 feet (14 to 16 meters). The water has a high concentration of total-dissolved-solids (TDS) and chloride levels which are not suitable for irrigation. If the shallow well was screened above the silt-clay lens, the water would probably be suitable for irrigation. The irrigation well, which is screened above the silt-clay lens, has good quality water, and may be an example where the stratigraphy (silt-clay) is continuous enough to retard upward movement of the saline water. In order to determine if this condition exits throughout the study area, it is necessary to examine the stratigraphy of the alluvium.

The stratigraphy of the Quaternary alluvium, in a descending order, is generally (1) sand dunes, (2) a relatively continuous, near-surface silt-clay bed, (3) alternating sequences of fining-upward sandy silt-clay, sand, and gravel lenses (not always present), (4) a basal sand and gravel bed, and (5) bedrock. The stratigraphy in this report is defined in terms of the predominant lithology and its effective permeability. Sand and gravel are classified together (permeable), and silt and clay are combined (relatively impermeable).

Sand Dunes

Sand dunes cover most of the study area. They are not present in southern Pratt County where the near surface silt-clay is exposed. The dune sands consist of fine sand and silt, moderately well-rounded, with minor lenses of medium sand (Layton and Berry, 1973). Topographically, the dunes range from rugged and active to relatively low gentle swells with a stable soil surface (Frye and Leonard, 1952). In the previous studies, the thickness of the sand dunes was measured in terms of the old stratigraphic nomenclature (dune sand, Loveland, and Crete Formations) with no relationship to the lithology and stratigraphy as defined in this study. As a consequence, the previous thickness ranges of 30 to 50 foot high sand dunes may differ from that for sand dunes measured from the near surface silt-clay.

Near Surface Silt-clay

There is one silt-clay bed near the surface that is continuous throughout most of the study area although it is overlain in some areas by the dune sands. The same silt-clay was identified by Layton and Berry (1973), who noted that there is an essentially continuous silt-clay beneath the dune sands in the northern and southeastern parts of Pratt County, and indicated that the origin of this silt-clay is eolian and fluvial.

At the three recharge study sites, the Soil Conservation Service dug trenches 220 cm to 240 cm (7 to 8 feet) deep, and found at least one buried paleosol at each site (Roth and Nettleton, 1988, personal communication). The paleosols had no fluvial cross-bedding, and represent stable conditions with their burial representing later aggradation. Therefore, since the near surface silt-clay was deposited there has been no recent fluvial erosion or deposition, and wind blown sediments have been the major source of material for aggradation. Welch and Hale (1987) noted that there are loess deposits underlying the sand dunes between the Cimarron river and the Arkansas river in southeastern Kearny, southern Finney, and west-central Gray counties, and loess forms a nearly continuous mantle over the land in northwestern, west-central, and southwestern Kansas. The lateral continuity, presence of a buried paleosol, extensive loess deposits in western Kansas, and loess deposits underlying dune sands mentioned previously further support the idea that this silt-clay could be a loess deposit. Radiocarbon dates, and quantitative, statistical, and trace-element geochemical studies on the silt-clays are needed to prove this.

The silt-clay was defined in the natural gamma logs and geologic logs by assuming the top must occur within the upper 10 feet (3 meters) of alluvium below the land surface. If no silt-clay bed was found in the upper 10 feet (3 meters) then it was contoured as not being present, even though a silt-clay bed may be present from 10 to 20 feet (3 to 5 meters) below land surface. In this area it is difficult to prove that stratigraphicly a silt-clay beginning 10 feet (3 meters) below the land surface or lower correlates with the near-surface silt-clay without additional information. The great distance of 6 miles (10 kilometers) between gamma logs also made it difficult to correlate a silt-clay that begins 10 feet (3 meters) below land surface. In addition, a silt-clay begining 10 feet (3 meters) below land surface will have a different hydrogeologic effect on the movement of water. It will have less of an effect on recharge than a silt-clay that occurs in the upper 10 feet (3 meters). A natural recharge study currently underway has found evidence that this near-surface silt-clay serves as an aquitard (Sophocleous, 1987, personal communication).

There are at least 30 individual isolated locations in the study area where a silt-clay bed or lens is not present from the land surface down to 10 feet (3 meters) depth (Table 6). Site 49 is the only site in the

Table 6. Well sites where the near-surface silt-clay is not present and depth to top of first silt-clay is equal or greater than 10 feet (3 meters).

Source of data *	Location	Land surface elevation (feet)	Depth to top of silt-clay (feet)	Thickness of silt-clay (feet)
L	19S 13W 34CC		22	6
F	20S 10W 01AA	1725	16	8
F	20S 10W 01CC	1758	25	56
F	20S 10W 10DD	1805	20	36
L	20S 11W 30DD	1806	61	12
F	21S 08W 11AA	1635	54	3
F	21S 08W 22BB	1639	30	11
F	21S 09W 06BB	1698	30	5
F	21S 09W 36DD	1655	46	25
F	21S 10W 20DD	1734	27	8
S&F	21S 11W 12CCC	1731	10	6
S&F	21S 11W 18AAA	1801	9	8
S&F	21S 13W 21BBB	1906	11	24
L	21S 13W 22BB	1884	16	9
L	22S 11W 05DC	1773	14	19
L	22S 13W 22CC	1897	15	15
S&F	23S 09W 35CCC	1718	12	3
S&F	23S 10W 31AAA	1787	25	7
S&F	25S 10W 14BBB	1748	15	1
S&F	25S 11W 23DDD	1796	111	13
S&F	25S 12W 08BBB	1896	11	4
B	26S 10W 02CD	1709	28	7
S&F	26S 11W 01ABA	1805	28	9
S&F	26S 15W 04BBB	2049	34	15
S&F	27S 11W 29AAA	1771	63	2
S&F	27S 12W 09AAA	1852	36	12
GMD 49	27S 12W 35AAA	1737	10	8
S&F	28S 11W 33CCB	1798	58	3
S&F	28S 12W 14DDD	1834	19	22
S&F	29S 15W 33BBC	2000	25	14

* B Bayne (1974) L Latta (1950)
F Fent (1950) S&F Stullken and Fader (1976)
GMD Observation well network

observation well network that may not have the near surface silt-clay. There is, however, a silt-clay that begins at 10 feet (3 meters) below land surface. This silt-clay could still act as a confining layer on the aquifer, and may correlate with the near-surface silt-clay. Further information is needed to correlate this silt-clay with the near-surface silt-clay and determine its hydrostratigraphic effects.

The isolith map shows the lateral extent and vertical thickness of the near-surface silt-clay bed (Figure 10). The thickest portion of the silt-clay is north of the Arkansas River from T. 28S. to T. 30S. and from R. 11W. to R. 13W., and T. 20S. R. 13W. Here the thickness ranges from 10 to 62 feet (30 to 19 meters). In the rest of the study area the thickness ranges from 0 to 40 feet (0 to 12 meters).

Basal Sand

The basal sand isolith map represents the thickness of silty-clayey sands, sands, and gravels that overlie the subcropping bedrock and extend upward to the first major silt-clay bed that can be identified on the gamma log (Figure 11). These sands and gravels were deposited in a fluvial depositional environment. For easy reference, the elevation of the top of the basal sand is given in Tables 9 and 10 at each well location used in

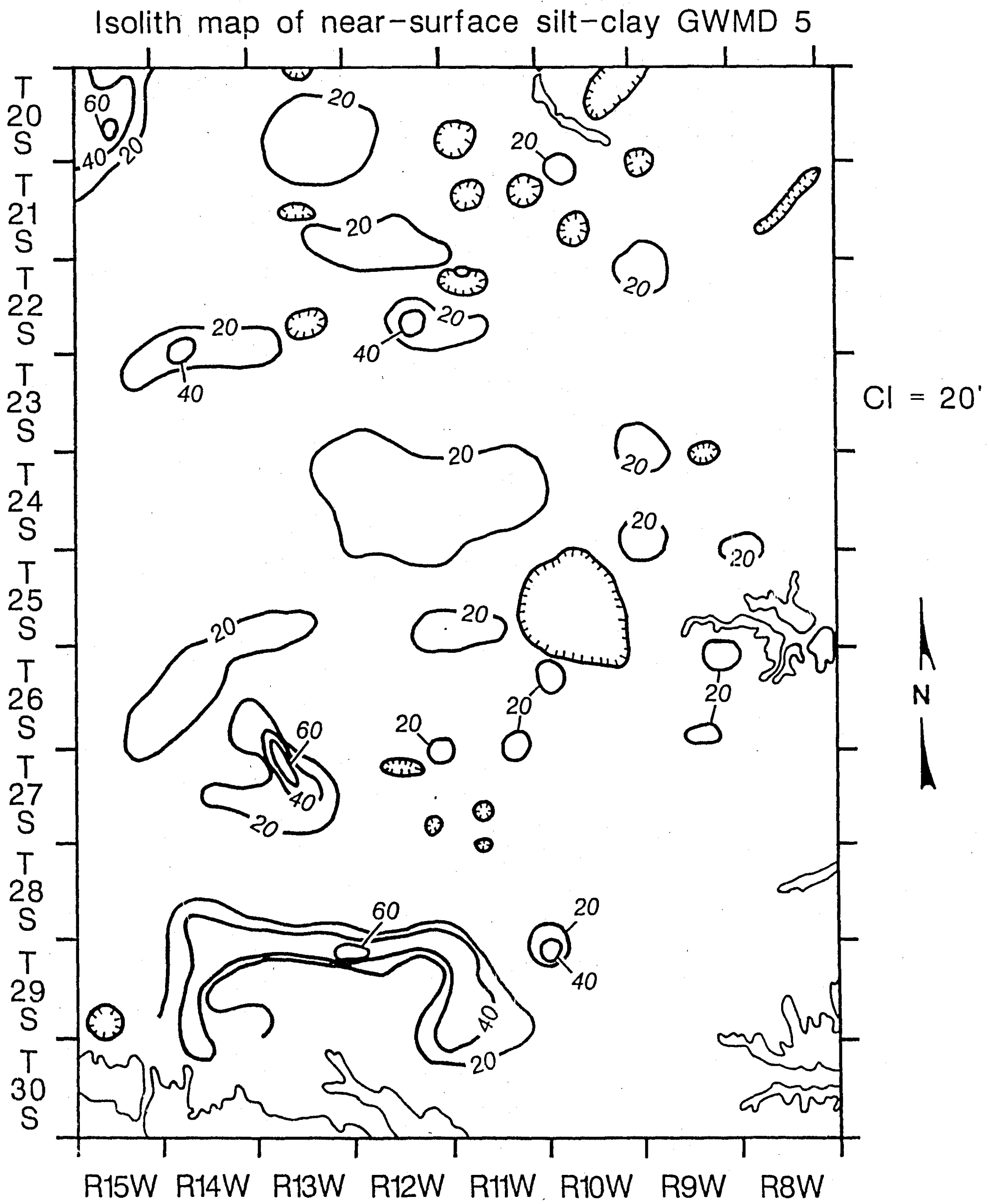


Figure 10. Near-surface silt-clay isolith map.

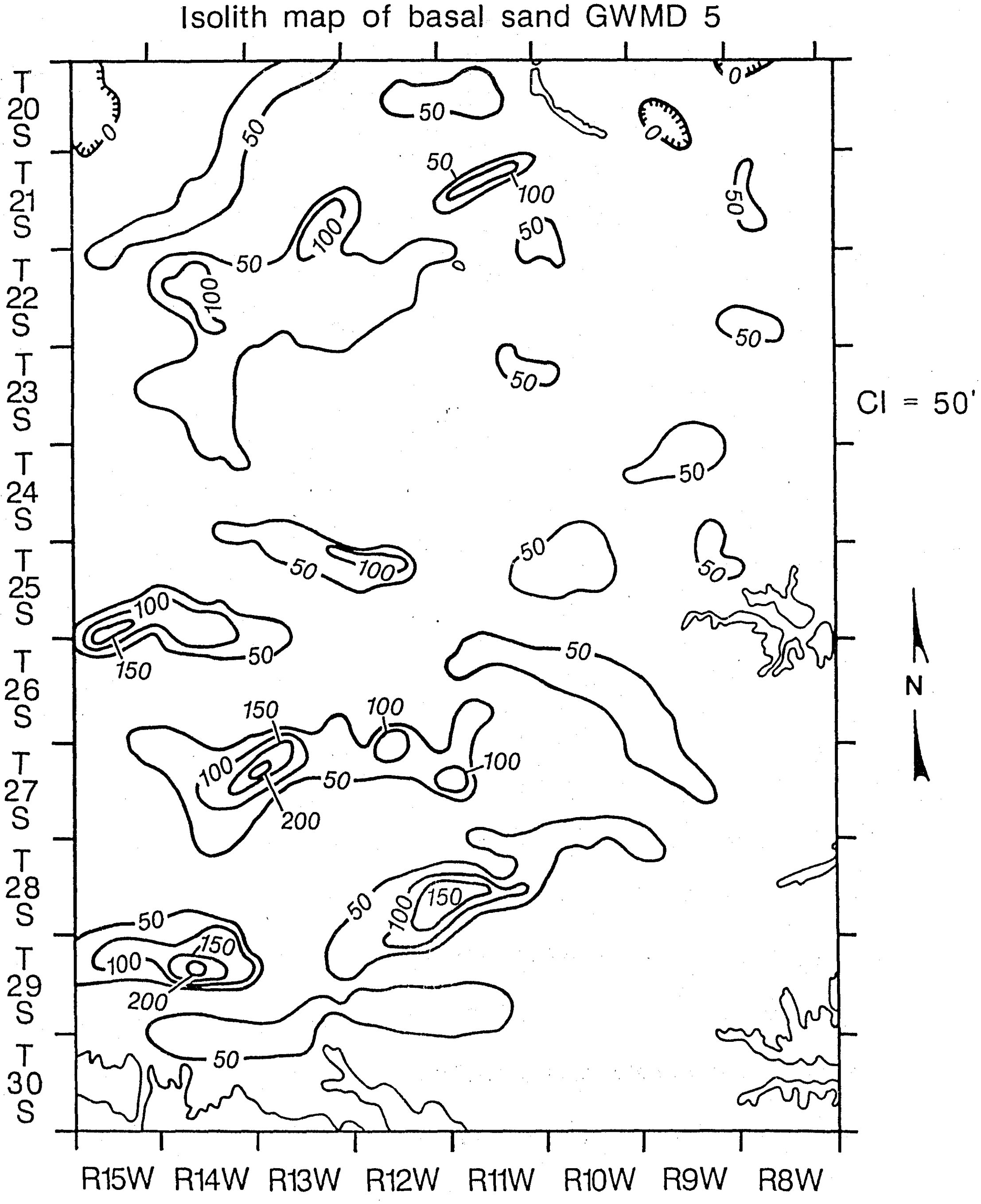


Figure 11. Basal sand isolith map.

this study. The thickness of the basal sand was determined by the extent of the sand and gravel overlying the bedrock to the first major silt-clay. A major silt-clay is defined as a silt-clay that is thicker than 2 feet (0.6 meters) and has at least a 50 cps gamma-ray response. At site 32 a silt-clay with a thickness of 2 feet (0.6 meters) or less was not continuous over enough of an area to significantly influence the flow of ground water. Site 32 will be discussed further in the variable lithology section. In addition, the gamma-ray response of a silt-clay 2 feet (0.6 meters) thick or less will not be recorded at the full cps. The amount of data was found to be insufficient to produce a reliable contour map of the basal sand.

The basal sand generally directly overlies the Cretaceous or Permian bedrock. There are, however, at least 44 locations where there is a silt-clay between the bedrock and the basal sand (Table 7). At these sites the basal sand was mapped from the top of that silt-clay. The silt-clay could be a remnant of a paleosol, overbank deposit, or colluvium based on the topography of the bedrock and geologic log descriptions (Table 8). There is probably a genetic difference between the silt-clays overlying the bedrock and the higher silt-clays, but the origin can not be determined without samples.

The silt-clays that directly overlie the bedrock,

Table 7. Location of silt-clay lenses that directly overlie the bedrock.

Source *	Location	Silt-clay thickness (feet)	
L	19S 15W 33BB	50	Bedrock to surface
F	20S 08W 06BB	43	Bedrock to surface
F	20S 09W 20DD	27	Bedrock to surface
L	20S 11W 30DD	04	
L	20S 15W 04CD	32	Bedrock to surface
L	20S 15W 05AA	43	Bedrock to surface
L	20S 15W 22CC	62	Bedrock to surface
L	20S 15W 28CBB	52	Bedrock to surface
L	20S 15W 31AAA	48	Bedrock to surface
F	21S 08W 16BB	6	
S&F	21S 11W 12CCC	14	
L	21S 11W 20CCD	16	
GMD 16	21S 12W 31CCC	7	
S&F	21S 14W 16BBB	18	
L	21S 14W 20BB	11	
GMD 51	21S 14W 36DDD	25	
B	23S 10W 13AAA	18	
GMD 25	23S 10W 06BBA	13	
GMD 1	23S 12W 12BAA	16	
L	23S 13W 22BB	6	
GMD 9	24S 10W 31CBC	21	
L	24S 14W 31BB	4	
GMD 6	25S 13W 06BBB	3	
S&F	26S 13W 19BBD	1	
S&F	26S 14W 34DDD	8	
S&F	27S 11W 12CBC	11	
S&F	27S 11W 33BBB	3	
S&F	27S 12W 26DDA	7	
S&F	27S 14W 33DDD	3	
S&F	27S 15W 05BBB	22	
S&F	28S 11W 05DDD	1	
S&F	28S 12W 32AAA	1	
S&F	28S 14W 33DDD	9	
S&F	29S 11W 11CCC	15	
S&F	29S 12W 02BBB	10	
S&F	29S 12W 14AAA	9	

Source *	Location	Silt-clay thickness (feet)
S&F	29S 14W 12CCC	1
S&F	29S 14W 22CCC	3
PR	29S 15W 11DDD	23
S&F	29S 15W 18BBB	22

*	
B	Bayne (1974)
F	Fent (1950)
GMD	Observation well network
L	Latta (1950)
S&F	Stullken and Fader (1976)

Table 8. Observation well sites where a silt-clay lens directly overlies the bedrock.

Site	Location	Description
16	21S 12W 31CCC	Floor of flood plain toward side of paleochannel; greenish-grey clay stringers.
51	21S 14W 36DDD	Side of paleochannel, gray clay (sandy) mixed with fine gravel small fragments of yellow sandstone (Dakota drift).
25	23S 10W 06BBA	Side of ridge; weathered red bed.
1	23S 12W 12BAA	Slope of a valley; Siltstone and chalk fragments.
9	24S 10W 31CBC	Flood plain, paleosol, fine grained silt-slightly cemented.
6	25S 13W 06BBB	On ridge, pinkish gray clay with whitish gray stringers (eroded Dakota Formation ?).

where present, range from 1 to 58 feet (0.3 to 17 meters) in thickness. The thickest and most continuous of these silt-clays are north of the Arkansas River (T. 20 S. R. 15 W.) The silt-clays extend from the surface to bedrock in the northwest corner of the study area and have been described as loess deposits (Latta, 1950). This loess may be continuous with the near-surface silt-clay if the near-surface silt-clay is a loess.

The next highest concentration of silt-clays overlying the basal sand is in the southern part of the study area (T. 29 S.) and trends from west to east. They are relatively thick and lie on or near bedrock highs.

At some sites, the first major silt-clay bed that overlies the basal sand is the near-surface silt-clay. The sites where there are no major silt-clays from the bedrock to the near-surface silt-clay are listed in Table 9. Site 37 is unique. It has a thick near-surface silt-clay and a thick basal sand. Site 17 is also fairly "clean" from the bedrock to the near-surface silt-clay. At site 44 the top of the basal sand was placed at a depth of 157 feet (47 meters) since there seems to be a sandy silt-clay and caliche bed from 130 to 157 feet (39 to 47 meters. The sandy silt-clay with caliche may act as an aquitard. The caliche layers may not serve as aquitards depending on their permeability.

Table 9: Well sites where there are no significant silt-clay beds in the phreatic zone (from the bedrock to the surface or near-surface silt-clay bed).

Source of data*	Location	Land surface elev. (feet)	Elev. top of basal sand (feet)	Thickness of basal sand (feet)	Depth to top of basal sand (feet)
L	19S 12W 29DD	1815	1802	42	13
S&F	20S 11W 08CC	1778	1769	84	9
L	20S 11W 12BB	1761	1743	19	18
L	20S 13W 09DD	1862	1844	54	18
L	20S 15W 02DD	1094	1915	06	49
F	21S 08W 20DDD	1637	1637	72	0
S&F	21S 11W 18AAA	1801	1773	180	28
GMD 17	21S 12W 36DDC	1795	1766	85	29
L	21S 13W 24BB	1861	1856	151	5
L	21S 13W 27DB	1880	1855	137	25
L	22S 11W 7BBB	1785	1785	25	0
S&F	22S 11W 07BBB	1785	1783	52	2
L	22S 14W 17BAA	1955	1955	205	0
S&F	23S 09W 35CCC	1718	1703	95	15
S&F	23S 11W 02BBB	1789	1733	64	56
L	23S 13W 28CA	1897	1887	48	10
S&F	24S 09W 23DDD	1636	1634	47	2
S&F	24S 07W 24AAA	1571	1563	23	8
S&F	24S 10W 32CCC	1733	1731	66	2
S&F	25S 09W 12AAA	1657	1652	91	5
S&F	25S 12W 08BBB	1896	1881	142	15
B	26S 08W 25AAA	1618	1594	9	24
S&F	27S 11W 32DDD	1716	1716	92	0
S&F	27S 12W 15BBB	1827	1802	50	25
GMD 37	27S 13W 05CAB	1971	1910	177	61
S&F	27S 13W 05AAA	1962	1943	195	19
S&F	27S 14W 12DDD	1983	1973	242	10
S&F	28S 11W 20AAA	1826	1792	168	34
S&F	28S 12W 14DDD	1834	1793	186	41
S&F	28S 14W 33DDD	2020	1933	140	87

S&F	29S 14W 08DDD	2024	1972	202	52

* B	Bayne (1974)	L	Latta (1950)
F	Fent (1950)	S&F	Stullken and Fader (1976)
GMD	Observation well network		

The top of the basal sand was determined by the first significant silt-clay overlying the basal sand. This gives the impression that there is a second continuous silt-clay that overlies the basal sand. This silt-clay, however, cannot be correlated from site to site. The depth and color of this silt-clay varies from site to site. Considering that the thickness of the sand beds in the study area ranges from 6 to 242 feet (2 to 73 meters), and that the overall thickness of the alluvium ranges from approximately 30 to 242 feet, the silt-clays found between the near-surface silt-clay and the basal sand are probably not continuous.

Geologic logs of irrigation wells near the observation wells were used to determine stratigraphically where the irrigation wells are screened. Some wells are not screened in the basal sand because of water-quality considerations. In Pratt County, 30 out of 40 irrigation wells were screened in the basal sand. In Reno County 4 out 16 irrigation wells, in Rice County, 10 out of 32 irrigation wells, and in Stafford County, 4 out of 10 irrigation wells were screened in the basal sand. This indicates that the sand bed serves as an aquifer for irrigation purposes in some areas.

Variable Lithology Section

After mapping and defining the near-surface silt-clay and the basal sand, there remained a section on most of the logs that could not be correlated. This section contains one or more alternating sequences of gravel, sand, and silt-clay beds. The thickness ranges from approximately 8 to 200 feet (3 to 60 meters) where present. Cross sections were drawn to show the variability in thickness and lithology of the section (Appendix VI). Table 10 lists the number of silt-clay beds between the near-surface silt-clay and basal sand, and the variability in the number of silt-clay beds in this section.

In some areas there is a sand bed in the variable lithology section that can supply water for domestic use and, in some cases, water for irrigation. Cross sections C - C′, E - E′, F - F′, H - H′, I - I′, and J - J′ show a sand bed between the silt-clay that overlies the basal sand and the near-surface silt-clay.

Cross section J - J′ has another silt-clay bed that could be correlated. The silt-clay at site 13 is described as a tan-clay matrix from 76 to 78 feet (22.8 to 23.4 meters) and 2 feet (0.6 meters) thick . At site 44 the silt-clay is an orange silty clay from 84 to 96 feet (25.2 to 28.8 meters) and 12 feet (3.6 meters) thick, and from 96 to 114 feet (28.8 to 34.2 meters) it

Table 10. Sites where there are silt-clay lenses with a thickness greater than 2 feet between the near-surface silt-clay and basal sand.

Source of data *	Location	Number of beds between	Thickness near-surface silt-clay	Elevation of basal sand
L	19S 11W 29BB	1	12	1661
L	19S 13W 27CB	3	5	1724
L	19S 14W 30AD	4	27	1764
F	20S 09W 02CC	2	8	1531
F	20S 09W 10DC	4	33	1550
F	20S 09W 10DD	2	26	1543
L	20S 12W 21BB	2	23	1755
L	20S 14W 05CC	1	11	1850
F	21S 08W 01AA	1	4	1566
F	21S 08W 11CC	1	6	1475
F	21S 08W 16BB	2	6	1604
F	21S 08W 22BB	0	2	1507
B	21S 09W 36DD	1	2	1585
GMD 23	21S 10W 06AAD	1	23	1690
F	21S 10W 11CC	1	8	1673
GMD 18	21S 11W 07BBB	7	18	1616
L	21S 11W 20CCD	1	5	1671
L	21S 11W 24CC	5	4	1621
L	21S 11W 36DD	3	10	1616
F	21S 11W 36DD	3	10	1616
GMD 22	21S 12W 06CCB	5	25	1643
L	21S 12W 25BB	4	14	1643
L	21S 12W 27BB	7	31	1641
GMD 16	21S 12W 31CCC	2	37	1708
GMD 50	21S 13W 06BCC	2	8	1697
L	21S 13W 22BB	1	0	1834
L	21S 14W 20BB	3	11	1792
S&F	21S 14W 16BBB	1	14	1815
GMD 51	21S 14W 36DDD	1	9	1770
B	22S 07W 20DD	3	19	1451
S&F	22S 08W 19DDD	5	11	1542
GMD 31	22S 09W 01ADA	1	14	1599
B	22S 09W 10DDD	3	11	1590
B	22S 09W 20DDD	3	7	1523
GMD 24	22S 10W 01ADB	2	30	1622
GMD 11	22S 10W 06CBB	4	16	1579
S&F	22S 10W 08BBB	5	6	1595
S&F	22S 10W 30DAA	2	3	1625
L	22S 11W 28BC	1	20	1791
L	22S 12W 23CC	2	54	1728
S&F	22S 12W 36BBB	2	24	1720

Source of data *	Location	Number of beds between	Thickness near-surface silt-clay	Elevation of basal sand
L	22S 13W 22CC	2	8	1790
L	22S 14W 32CC	1	42	1884
S&F	23S 08W 16CCC	3	16	1558
GMD 27	23S 09W 01ADA	3	19	1595
GMD 32	23S 09W 25DDD	6	7	1535
GMD 26	23S 10W 01AAA	5	14	1586
GMD 25	23S 10W 06BBA	4	10	1689
B	23S 10W 13AAA	2	10	1665
B	23S 10W 19BCB	1	15	1709
B	23S 10W 25BBB	4	15	1583
GMD 30	23S 10W 36DAA	2	20	1622
S&F	23S 11W 02BBB	2	3	1733
S&F	23S 12W 07CCC	2	2	1697
GMD 5	23S 12W 06BBA	3	6	1730
GMD 1	23S 12W 12BAA	1	15	1700
GMD 2	23S 12W 36ABA	2	10	1757
GMD 52	23S 13W 06BBB	2	20	1742
S&F	23S 13W 08CCB	3	3	1807
L	23S 13W 12AA	1	5	1719
L	23S 13W 22BB	1	3	1855
GMD 3	23S 13W 36DCC	3	23	1797
S&F	23S 14W 30BBB	2	2	1851
GMD 4	23S 14W 36DDC	3	17	1830
S&F	24S 08W 11DDD	2	6	1565
GMD 10	24S 10W 06DCC	7	16	1641
B	24S 10W 12CC	2	5	1670
GMD 9	24S 10W 31CBC	2	9	1715
GMD 29	24S 10W 36AAA	3	21	1591
L	24S 11W 05AA	1	27	1743
L	24S 11W 25DD	3	18	1701
L	24S 11W 28DD	3	24	1690
L	24S 12W 34BB	1	46	1745
GMD 7	24S 13W 36DDD	3	36	1783
L	24S 14W 11AAA	2	10	1810
L	24S 14W 31BB	1	28	1864
L	24S 15W 30CC	3	26	1916
GMD 28	25S 09W 01ADD	1	24	1585
GMD 34	25S 09W 36DDC	1	20	1625
B	25S 10W 12CCC	2	8	1640
L	25S 11W 33AA	2	24	1658
GMD 8	25S 12W 11AAA	4	22	1738
GMD 33	25S 12W 36CBB	2	34	1776
GMD 6	25S 13W 06BCB	1	14	1840
GMD 20	25S 13W 31DDA	3	22	1825
L	25S 13W 33AA	6	27	1770
GMD 19	25S 13W 36DCC	3	11	1777

Source of data *	Location	Number of beds between	Thickness near-surface Silt-clay	Elevation of basal sand
L	25S 15W 33DD	5	10	1818
B	26S 08W 18CC	1	13	1609
GMD 40	26S 09W 31CDD	5	12	1632
GMD 41	26S 09W 35ADA	2	2	1615
B	26S 09W 34AAA	2	24	1555
GMD 39	26S 10W 01AAA	1	12	1649
B	26S 10W 27DDD	1	7	1671
GMD 35	26S 10W 31CCC	5	17	1614
GMD 21	26S 11W 01DDD	2	24	1736
S&F	26S 11W 04BBB	2	7	1762
S&F	26S 11W 09CCC	3	17	1710
S&F	26S 11W 29ADD	2	11	1744
S&F	26S 11W 32DD	3	11	1668
S&F	26S 11W 36DD	3	4	1649
B	26S 11W 36DDD	2	6	1650
PR	26S 11W 35CCC	1	30	1739
PR	26S 12W 34CDD	4	12	1732
GMD 38	26S 12W 36ADD	3	13	1717
S&F	26S 13W 19BBD	5	16	1830
S&F	26S 14W 05AAA	1	22	1919
S&F	26S 14W 09DDD	5	30	1784
S&F	26S 14W 23AAA	3	18	1774
S&F	26S 14W 34DDD	3	18	1825
S&F	27S 11W 12CBC	2	7	1715
S&F	27S 11W 17AAA	5	12	1644
S&F	27S 11W 30CCC	1	6	1638
S&F	27S 11W 32ABA	1	3	1641
PR	27S 11W 32DAA	1	7	1681
S&F	27S 11W 33BBB	2	3	1658
S&F	27S 12W 01BBB	5	23	1698
S&F	27S 12W 05AAA	2	17	1810
GMD 36	27S 12W 06BAA	4	18	1743
S&F	27S 12W 13ADD	2	12	1762
S&F	27S 12W 26DDA	6	10	1666
S&F	27S 12W 36DAA	2	5	1649
S&F	27S 13W 21ACA	5	40	1768
GMD 43	27S 13W 31DDD	3	17	1817
S&F	27S 14W 05AAA	5	15	1824
S&F	27S 14W 21AAA	1	25	1916
S&F	27S 14W 33DDD	2	6	1922
PR	27S 15W 02ABB	3	38	1859
S&F	27S 15W 05BBB	2	12	1898
S&F	27S 15W 06DDD	5	4	1872

Source of data *	Location	Number of beds between	Thickness near-surface silt-clay	Elevation of basal Sand
GMD 15	28S 11W 01AAA	1	15	1649
S&F	28S 11W 05DDD	5	1	1640
S&F	28S 11W 10CCC	1	17	1635
S&F	28S 11W 20AAA	1	4	1792
S&F	28S 12W 10BBB	2	5	1696
S&F	28S 12W 32AAA	4	11	1695
GMD 42	28S 13W 01CBA	5	19	1679
PR	28S 13W 26DCB	7	15	1722
S&F	28S 14W 28AAA	1	29	1804
S&F	28S 14W 32AAA	3	54	1841
S&F	28S 14W 33DDD	1	50	1933
GMD 45	29S 11W 01DAD	1	45	1678
GMD 46	29S 11W 06AAA	4	45	1659
S&F	29S 11W 11CCC	4	6	1693
S&F	29S 11W 12DDD	2	6	1662
S&F	29S 11W 16BBB	1	25	1710
PR	29S 11W 21CCC	1	67	1726
GMD 12	29S 11W 36ACC	3	18	1657
S&F	29S 12W 02BBB	2	45	1792
S&F	29S 12W 14AAA	4	7	1705
S&F	29S 12W 17AAA	4	19	1719
GMD 48	29S 12W 36DCC	3	46	1715
GMD 47	29S 13W 12ABB	4	60	1778
S&F	29S 13W 12CCC	3	10	1779
S&F	29S 13W 16BBC	4	6	1746
GMD 44	29S 13W 35ABB	5	11	1733
GMD 14	29S 14W 12ABB	2	41	1798
S&F	29S 14W 12CCC	1	12	1889
S&F	29S 14W 22CCC	5	1	1808
S&F	29S 14W 32DDD	1	48	1915
GMD 13	29S 14W 36AAA	2	29	1775
PR	29S 15W 11DDD	1	17	1925
S&F	29S 15W 17AAA	1	9	1977
S&F	29S 15W 18BBB	1	4	2012

*	
B	Bayne (1974)
F	Fent (1950)
GMD	Observation well network
L	Latta (1950)
S&F	Stullken and Fader (1976)

is tan with orange-tinged sandy clay and 18 feet (5.4 meters) thick. At site 48 the silt-clay is a tan clay from 76.5 to 90 feet (22.95 to 27 meters) and 13.5 feet (4.05 meters) thick. At site 12 it is only described as a thin clay lenses. From the gamma logs, the thickness of the silt-clay is 8 feet (2.4 meters) thick at site 13, 7 feet (2.1 meters) thick at site 44, 7 feet (2.1 meters) thick at site 48, and 6 feet (1.6 meters) thick at site 13. There is a considerable discrepancy between the thickness values indicated on the geologic logs and the natural gamma-logs. Considering the amount of error possible in geologic logs, the natural gamma-log thicknesses are probably more accurate. Without samples or additional information, it is difficult to try and correlate this particular silt-clay. It is, therefore, considered as part of the variable lithology section. Cross section J - J′ does show that there are instances where there is another sand bed that overlies a silt-clay.

Site 29 has a silt-clay at 121 feet that overlies the basal sand. This silt-clay may be continuous enough to serve as a local aquitard and confine the saline water in the basal sand.

Gamma logs were run on all four wells at site 32 (23-9W 25DDD) to examine stratigraphic changes over a small area. The wells are spaced approximately 10 feet

(3 meters) apart. At this spacing, most silt-clay lenses in the variable lithology section can be traced from one well to the next well with only minor variation (Figure 12). It is interesting to note that the thickness of the near-surface silt-clay is nearly constant when viewed at this spatial scale. The silt-clay in well 1 (20 feet or 6 meters depth) does not correlate with the well 3 log, but is observed in the log for well 2 (20 feet or 6 meters depth), and in well 4 (20 feet or 6 meters depth). The cross section shows that a silt-clay with a thickness of 2 feet (0.6 meters) or less may not be continuous over an area of 40 feet (12 meters). For example, at well 2 there is an "extra" clay lens at a depth of 90 feet (27 meters) that is not found in well 1 or well 3. From these logs it can be stated that on a very small, local scale the silt-clays are generally continuous, and the stratigraphy at each site is relatively constant.

Bedrock

The Tertiary Ogallala Formation has been described in the study area by Fent (1950a) and Fader and Stullken (1978). The Ogallala crops out in Reno and Rice counties and is found on well logs in Kiowa and Pratt counties. Stullken and Fader (1976) described the physical character of the Ogallala Formation as being similar to the Pleistocene deposits. Since the Tertiary Ogallala Formation was deposited and subsequently eroded

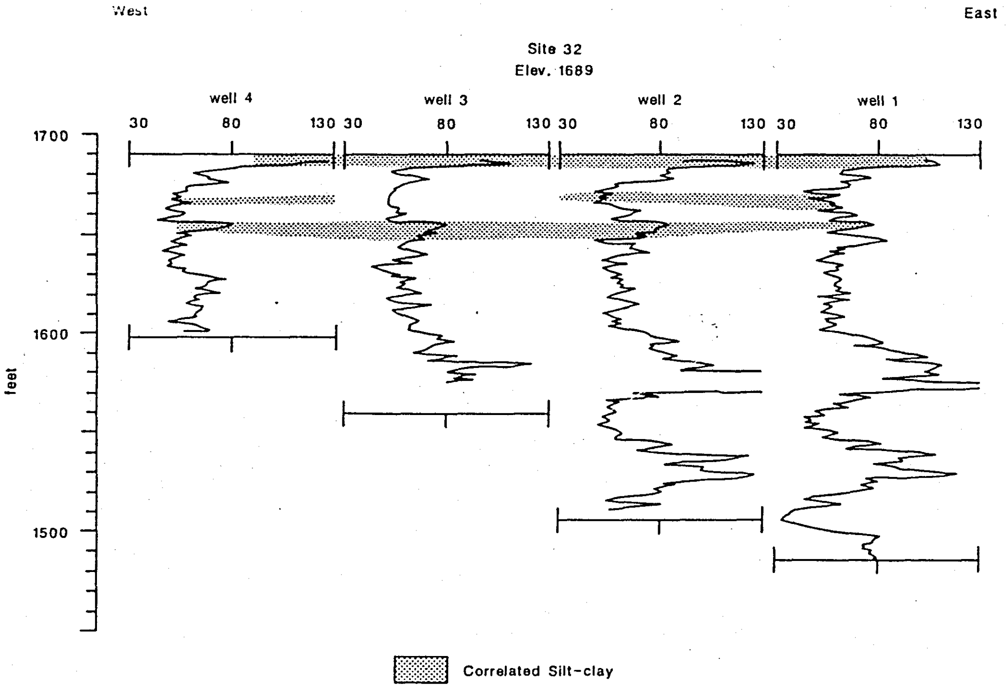


Figure 12. Cross section of gamma logs at Site 32.

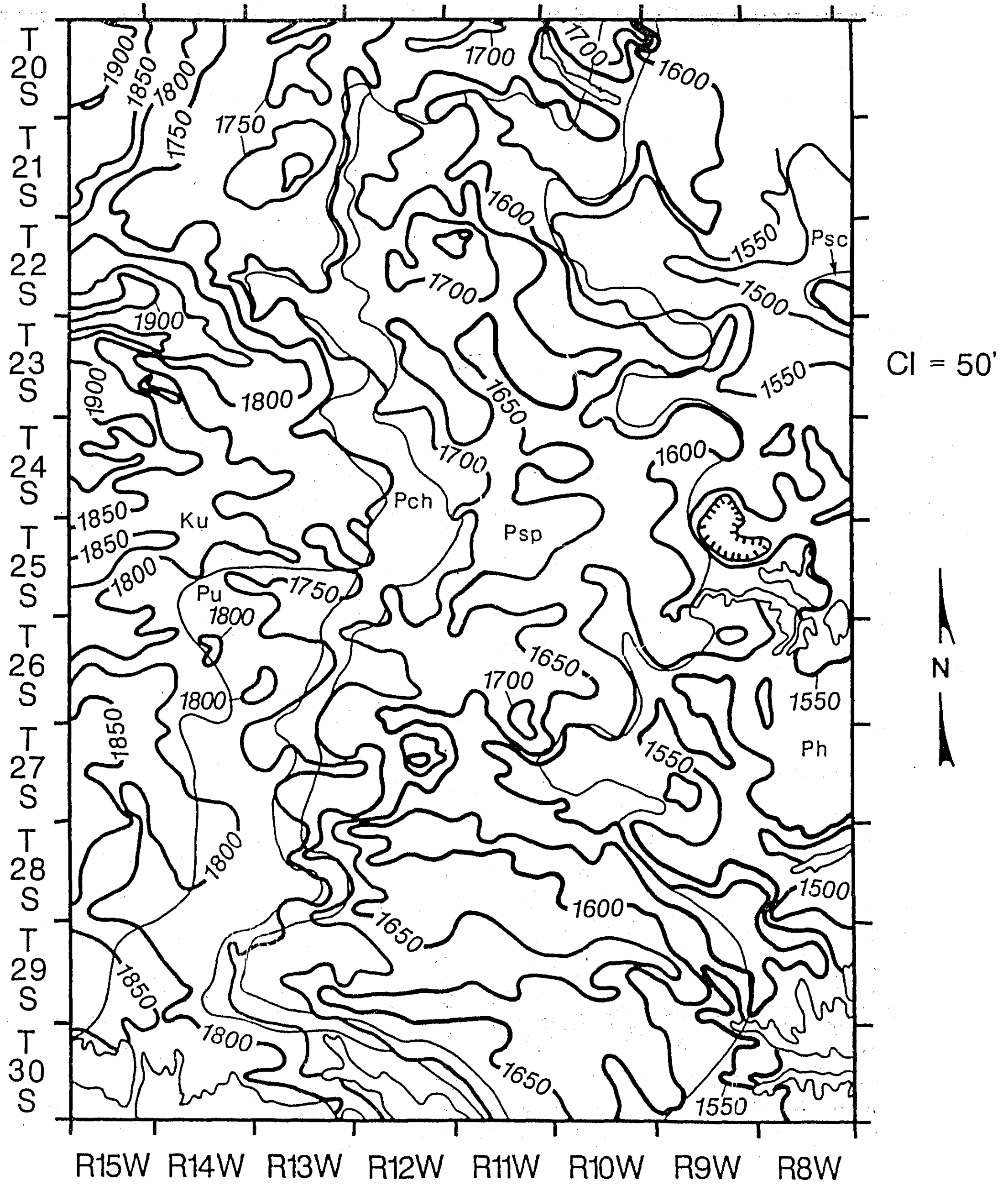
from most of the study area, the isolated erosional remnants of the Ogallala are difficult to distinguish from the Pleistocene alluvium. The Ogallala, therefore, is considered to be part of the Pleistocene hydrologic unit for the purposes of this study and the consolidated rocks that underlie the alluvium are considered to be bedrock. A generalized stratigraphic section of the geologic units and their water-bearing properties is provided in Table 11.

Prior to the deposition of the Pleistocene alluvium, the upper Cretaceous rocks and upper portion of the Permian were subaerialy exposed. Erosional processes during the Tertiary and early Pleistocene produced a gently, easterly "dipping" topography with broad valleys in the bedrock (Figure 13). At some point in time, the paleochannels or paleovalleys were cut into the bedrock (Figure 14). Without age control on the overlying sediments, it is impossible to determine when these periods of downcutting occurred. The only statement that can be made with certainty is that it happened some time during the Tertiary and/or Quaternary and was affected by the glacial events. Because the sediments are Tertiary and Quaternary, and the glacial events represent changes in climate.

The general paleotopography and paleochannels on the bedrock surface reflect one of the primary factors

Table 11. Generalized columnar section of geologic units and their water-bearing properties (from Stulken and Fader, 1976).

System	Geologic unit	Maximum Thickness (feet)	Physical Character	Remarks
QUATERNARY	Alluvium	360	Stream-laid deposits of late Quaternary age ranging from clay to gravel. Occurs along principal stream valleys.	Comprises principal aquifer. Water generally is of good chemical quality, but may be of 2/ poor chemical quality in the northeastern part of the area and in the deep valleys in the bedrock surface of the southeastern part of the area. Yields as much as 2,000 gpm to wells.
	Undifferentiated Pleistocene deposits		Unconsolidated deposits of sand and gravel with interbedded lenses of clay, silt, and caliche. These deposits are in contact with the Lower Cretaceous and Permian rocks where the Ogallala Formation is absent.	
TERTIARY	Ogallala Formation (Pliocene deposits)	65	Unconsolidated deposits of clay, silt and fine sand with interbedded caliche. Deposits of Pliocene age crop out in Reno and Kingman Counties and are noted in well logs in Kiowa and Pratt Counties.	The quantity of water contributed by the Ogallala Formation is unknown. Where present and saturated, these deposits are considered to be a part of the same hydrologic unit as the undifferentiated Pleistocene deposits.
CRETACEOUS	Undifferentiated Lower Cretaceous rocks	380	Upper unit (Dakota Formation)--brown to gray, fine- to medium-grained sandstone interbedded with gray sandy shale and varicolored shale. Middle unit (Kiowa Formation)--dark-gray to black shale interbedded with tan and gray sandstone. Lower unit (Cheyenne Sandstone)--gray and brown, fine- to medium-grained sandstone interbedded with dark-gray shale.	Water generally of poor chemical quality. Yields 10 to 100 gpm to wells locally in the western part of the area.
PERMIAN	Undifferentiated Permian rocks	350	Interbedded reddish shale, siltstone, and sandstone with some beds of dolomite and anhydrite. Includes in descending order; Whitehorse Formation, Dog Creek Formation, Blaine Formation and Flower-pot Shale.	Water generally of poor chemical quality. May yield as much as 10 gpm to wells.
	Cedar Hills Sandstone	200	Reddish shale, siltstone, silty shale and sandstone.	Sandstone may contribute highly mineralized water to the principal aquifer where the two units are in contact.
	Salt Plain Formation	300	Reddish-brown sandy siltstone, and fine-grained sandstone.	May contribute highly mineralized water to the principal aquifer where the two units are in contact.
	Harper Sandstone	250	Brownish-red siltstone and silty shale with a few thin beds of silty sandstone. Kingman sandstone member is near the top of the formation.	Water may be of poor chemical quality. May yield no water or as much as 100 gpm to wells in eastern part of the area.



Subcropping bedrock contour map GWMD 5
modified from Fader and Stullken, 1978

Figure 13. Contour map of the subcropping bedrock.

Subcropping bedrock contour map GWMD 5
modified from Fader and Stullken, 1978

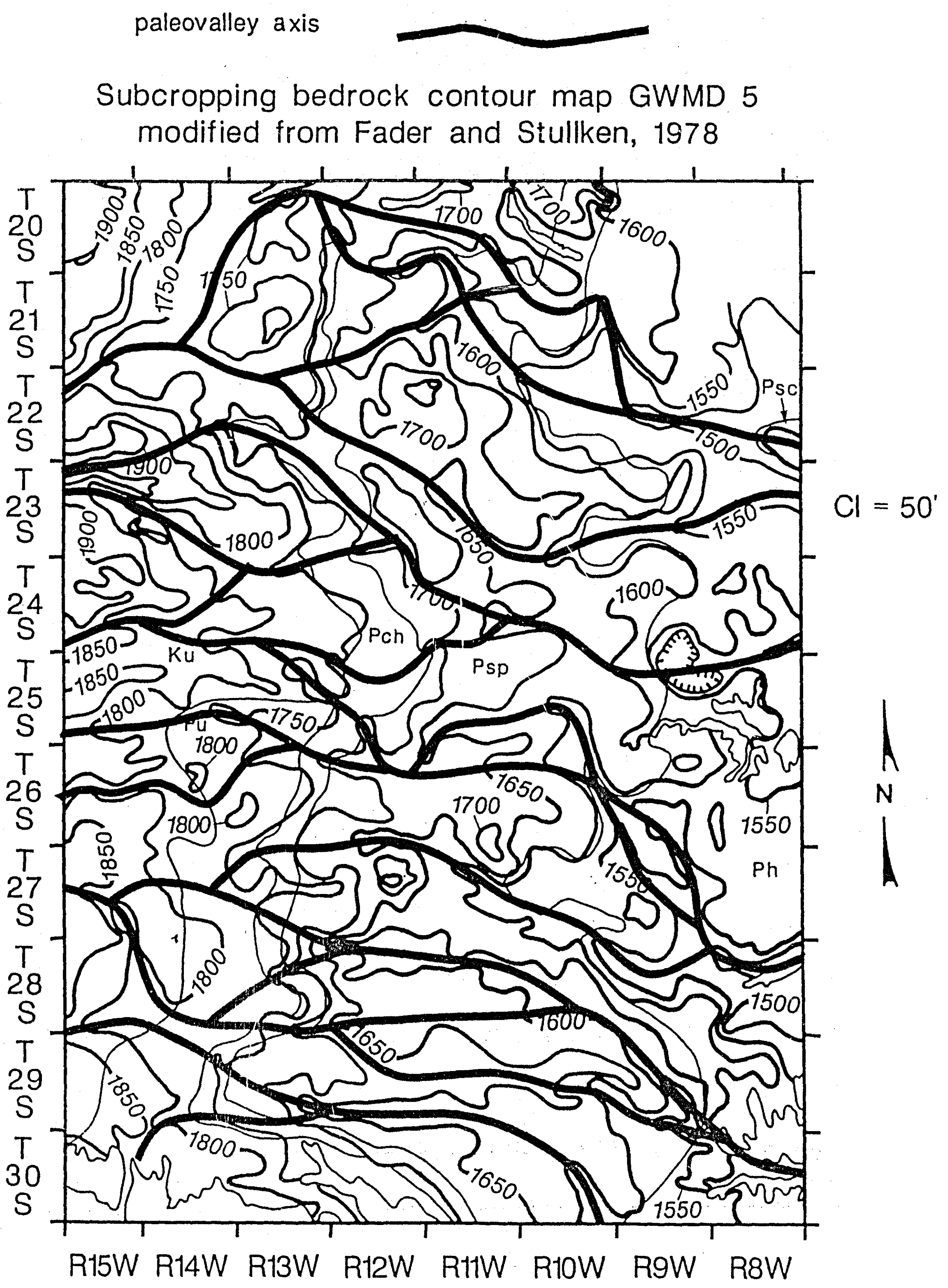


Figure 14. Axis of paleovalleys.

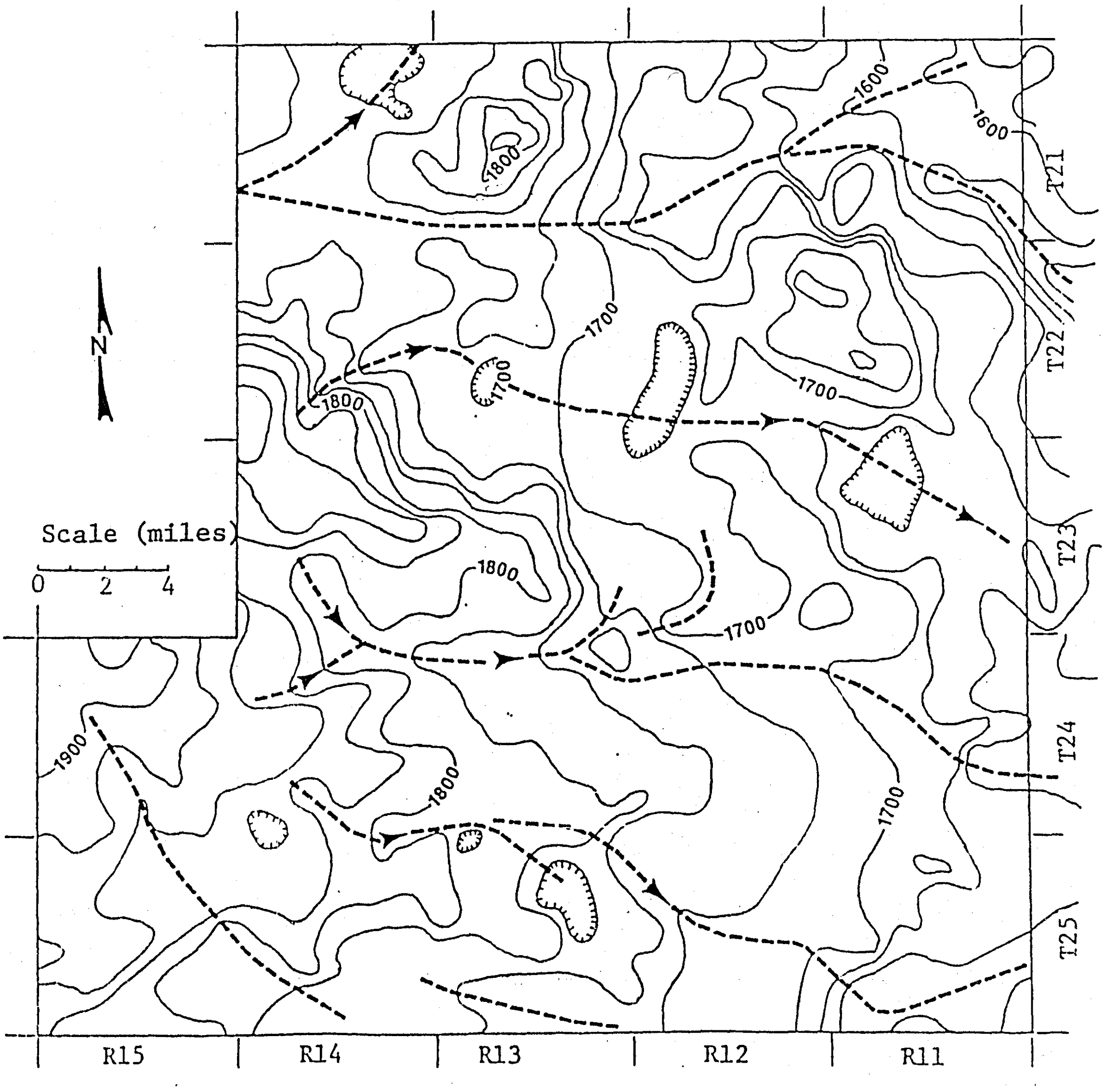
controlling the deposition of the alluvium. This influenced the deposition of a continuous basal sand, continous near-surface silt-clay, and a variable lithology section between. Some of these valleys have been identified in previous studies as paleochannels. Bayne (1956) described three channels in Reno County. Cobb (1980) noted several channels in the study area (Figure 15). The evidence for paleochannels and fluvial deposition are (1) the pattern of contour lines of the bedrock surface, (2) lows or valleys filled with sand and gravel, and (3) thicker basal sands in the valleys. Some of the valleys are well defined in an accepted fluvial pattern, but others seem to diverge and then later converge, forming an anabranching pattern.

DEPOSITION OF THE ALLUVIUM

Currently, the Arkansas River channel is "perched" on alluvium at a higher elevation than any of the neighboring rivers to the north or south. Smith (1940) thought that the volume of sediment carried down from the Rocky Mountains, crustal warping, and impervious bedrock floor contributed to the perched nature of the river. Fent (1950a) believed that the Pleistocene drainage patterns indicated a northeastward migration of the Arkansas River. This migration was the result of successive stream captures of tributaries to the north by

Figure 15. Paleovalleys as interpred by Cobb (1980).

- - - - - - - - ➤- - - - - - - - - - - Inferred drainage and direction of flow



the southern trunk of the Arkansas River.

The following factors were examined as influences on the mechanisms of the alluvial deposition and the resulting stratigraphy and topography: (1) paleotopography and impervious nature of the bedrock, (2) large volumes of sediment and streamflow, and (3) climate and vegetation. The information presented in this paper and previous studies was used to generate a depositional hypothesis based on these factors. However, without samples of the sediments it is difficult to validate the hypothesis.

Bedrock Paleotopography

The low relief and gently sloping topography combined with a relatively impervious bedrock of consolidated limestone, shale and sandstone probably influenced the size and shape of the Arkansas River channel. This resulted in a shallow, broad river channel similar to the Arkansas River channel described in 1852 (Mead, 1896). At that time, the river channel was aggrading and ranged from 800 to 1,200 feet (240 to 360 meters) wide with well-defined banks that rose only slightly above the water level. Since 1852, man has had an impact on the Arkansas River. It has proceeded to narrow and downcut its channel (Spray, 1986). A shallow river channel can be easily and frequently breached during a flood, with consequent deposition of sediments on the flood plain. This would allow large amounts of detrital sediments to be deposited over a large area and could make it difficult to differentiate point bar and overbank deposits.

Wolman and Leopold (1957) argued that it is often difficult to distinguish between point bar and overbank deposits in the field. Without cores and having well cuttings from only three wells, point bar and overbank deposits become impossible to differentiate in the study area. The similar lithologies of both types of deposits increase the problem of differentiation. Because the lithologies are similar and the point bar and overbank deposits are probably contemporary, hydrologically they are connected. An impervious bedrock for the river channel bottom, combined with the shallow channel and large amounts of sediment, would reduce the transporting erosive strength of the river. This would allow the river to aggrade. As the channel aggraded with sand and gravel, increasing amounts of water would be lost to the alluvium through infiltration, allowing further deposition of more sediment. Now, the shallow channel is influenced by stream-flow loss into the alluvium (Spray, 1986).

The flood waters were originally contained in the valleys. This is supported by the fact that most of the thick basal sand deposits are in the paleovalleys. During floods, the water and sediments were probably carried in more than one valley. This would explain the anabranching pattern of the paleovalley. A modern example of this would be the Mississippi and Atchafalaya Rivers (Schumm, 1977). The anabranching pattern of the modern channels and of the paleovalleys in this study area supports the theory that the Arkansas River captured streams to the north as its own channel aggraded. The anabranching channels could, therefore, represent separate (in time) but related channels.

While the river was aggrading in the valleys, paleosols formed and loess deposits accumulated on the exposed bedrock. This is supported by the location and description of the silt-clays that directly overlie the bedrock and underlie the basal sand. Eventually, the valleys aggraded to the point where the flood waters could spread over the tops of the hills and ridges and erode some of the paleosols and deposit sands and gravels. The variations in the thickness of the basal sand are due to local cut, fill, and stream movement. Even with more information it will still be difficult to identify individual fluvial facies associated with one specific time.

The paleo-gradient in the southern part of the study area is approximately 8.3 feet/mile (2.5

meters/kilometer), and the gradient in the northern part is approximately 7 feet/mile) (2.1 meters/kilometer. The present stream gradient is approximately 6 feet/mile (1.8 meters/kilometer) (Smith, 1940). A high paleochannel gradient in the south with a northward decrease in gradient would support the theory of Fent (1950b) that there was a northward migration of the Arkansas River. Initially, the Arkansas River flowed across the southern portion of the study area where the gradient was the highest. As the valley aggraded, the stream gradient declined until a channel to the north had a higher gradient than the stream. This established the conditions to allow avulsion to occur. The avulsions probably occurred during floods when the river system is most likely to change.

The stratigraphy, however, does not fully support this idea. If this theory was completely true then one would expect to find the oldest sediments in the southern part of the study area and the youngest sediments in the northern part. Even without dates on the volcanic ashes and caliches, the number and extent of caliche beds would follow the same depositional pattern. One would find more caliche beds in the southern part of the study area and progressively fewer caliche beds as one proceeds north. As the stream moved north, the southern part of the area would become part of the more stable flood plain with deposits of loess accumulating and paleosols forming, which would eventually result in the formation of a calcic horizon (caliche). This assumes that the caliches in the area actually represent paleosol calcic horizons.

Table 4 indicates that the number of caliche deposits at each site varies in a relatively random pattern with no definite north to south trend and there is no increase in the number of caliche deposits proceeding northward. There may, however, be a west to east trend, with the highest number of caliche deposits occurring as clusters on bedrock highs, trending from west to east. In addition, not all the caliche deposits may represent paleosols. If they are paleosols, then lack of a north-south trend would support the theory that some of the channel deposits were contemporary, or at least contemporary during times of major deposition (major floods). More data and work on the caliche deposits is needed to verify this.

A more continuous silt-clay bed overlying the basal sand would also be expected in the southern part of the area as the result of loess accumulation. A continuous silt-clay bed is not evident in the southern part of the study area below the near-surface silt-clay bed, i.e., loess.

The only major area with a continous silt-clay that extends from the surface to bedrock is in the northwest corner of the study area. The sediments have been described as loess deposits. If the near-surface silt-clay is a loess, then this loess may be continuous with the near-surface silt-clay except where a river or creek has cut down through the silt-clay

The thickness of the basal sand seems to be controlled by the bedrock topography. The basal sand tends to be thicker in the paleochannels. In the channels, the basal sand ranges in thickness from 8 to 242 feet (2.4 to 72.6 meters), and the average thickness is 101 feet (30.3 meters). The shapes of the natural gamma-log curves at some of the study sites indicate a fining-upward sequence similar to the fluvial sequence described by Serra and Sulpice (1975). They described this type of fining-upward sequence from a point bar deposit, and showed that shapes on the gamma-ray log could be correlated with grain-size trends, and, based upon sedimentological information, inferences could be drawn about the depositional environment. This particular sequence could indicate an alluvial/fluvial channel or a transgressive sand. Most transgressive sands are deposited along continental margins. During the time when the alluvium was deposited, the study area was not a continental margin. A transgressive sand, therefore, is not a likely depositional environment for these alluvial sediments.

Twenty of the gamma logs show some type of fining-upward sequence in the basal sand. Site 43, for example, shows a fining-upward sequence possibly indicating fluvial cycles similar to the gamma log of a point bar described by Serra and Sulpice (1975). The fining-upward sequence is expected if the basal sand is of fluvial origin and was deposited in paleochannels.

In this study, the sedimentological information (grain size of the sands and gravels) supports a fluvial depositional environment. Authors of past studies have stated that this alluvium was mainly deposited by fluvial processes, and it does not represent a transgressive sand (Bayne, 1956; Fent, 1950; Latta, 1950; Layton and Berry, 1973; and Stullken and Fader, 1960).

Wolman and Leopold (1957) commented that in situations where (1) there is constant frequency of overbank flooding, (2) the entire valley is being aggraded at a constant rate, and (3) the channel bed and flood plain are rising uniformly, it is difficult to differentiate overbank deposits from point-bar deposits. It would also be difficult to differentiate the different ages of the deposits in the aggrading section. A modern example is the Nile River. They found indications that both the bed and the flood plain of the Nile River were being aggraded at a rate of 3 to 4 feet (0.9 to 1.2 feet) in 1,000 years. It can be inferred then that sufficient time has elapsed to have permitted the current alluvium to aggrade 40 to 280 feet (12 to 84 meters). The findings of Wolman and Leopold (1957) would explain the deposition of the basal sand and the difficulty involved in interpreting, correlating, and dating the stratigraphy, especially the variable lithology section.

Volume of Sediments and Streamflow

The large volume of sediment and the impervious nature of the bedrock could have reduced the ability of the Arkansas Rivers to erode and led to the aggadation. This would explain the large volume of arkosic sands and gravels and paucity of silt-clay beds in the study area. The assumption of large volumes of sediments is not without foundation. Richards (1982) commented that an excessive sediment load combined with a water flow spread over a wide area, and subsequent loss of streamflow due to infiltration into the alluvial sediments previously deposited would allow aggradation during floods. The streamflow discharges on the Arkansas River do show a transmission loss between Syracuse and Garden City, Kansas (Jordan, 1977). This same flow loss was evident, between Syracuse and Great Bend, Kansas, during the June 1965 flood in the Arkansas River Basin (Table 12). The 1965 flood is probably the closest modern analog to the streamflow discharges that deposited the alluvium in the

Table 12. Transmission loss between pairs of gauging stations on the Arkansas River basin (from Snipes, 1974).

Date (cfs)	Location	Discharge (cfs)	Flow loss (cfs)
1951	Garden City to Dodge City	33,500 19,700	13,800
1965	Syracuse to Garden City	174,000 130,000	44,000
	Garden City to Dodge City	130,000 82,000	48,000
	Dodge City to Kinsley	82,000 49,800	32,200
	Kinsley to Great Bend	49,800	22,000

(cfs) cubic feet per second

area. This flood resulted from extremely large amounts of precipitation falling over a short period of time in the Arkansas River drainage basin. The flood did not contain the additional volume of water that would be associated with the glacial events. The size and magnitude of this flood, therefore, is lower than would have occurred in the past. The John Martin Dam held the entire flood runoff from upstream. This had a significant impact on the peak discharge down stream. Without the reservoir the peak discharge at Lamar, Colorado would have been 209,000 cubic feet per second (cfs) (672 meters cubed per second) instead of the actual 73,800 cfs (221 meters cubed per second) (U.S. Army Corps of Engineers, 1966). Even with John Martin Dam, the U.S. Army Corps of Engineers estimated that 230,000 acres of land were flooded between John Martin Dam and Great Bend. That would cover approximately 21% of the study area.

Climate and Vegetation

The fact that there is only one continuous silt-clay bed in the study area could indicate that there has been a definite change in the depositional environment. This change in climate is supported by the reappearance of branchiate snails and an increase in abundance and types of all gastropod fauna during Kansan time (Frye and Leonard, 1957). The evidence indicates a moist climate with prairie vegetation dominant and belts of trees and shrubs along valleys. There was a distinct climatic change that followed, however, and the moist conditions gave way to increasing aridity, arriving at the present semi-arid climate. Some studies have placed the continuous silt-clay at the end of the last major glacial event to recent time. The resultant climatic change resulted in decreased discharge and thus carried decreased amounts of coarse grained sediments in the Arkansas River. This has allowed loess deposits to accumulate and pedogenesis to occur in the near surface clay and the overlying sand dunes. It is also conceivable that the stream parameters, stream width, etc. reached an equilibrium allowing most of the study area to stabilize and encouraged development of at the least one soil profile in the near-surface silt-clay.

CHANGES IN SILT-CLAY HYDRAULIC CONDUCTIVITY

The continuous near-surface silt-clay bed may affect recharge and thus the position of the contact of freshwater and saline water in the area. In addition, changes in the freshwater-saltwater contact could affect the permeability of silt-clay lenses below the near surface silt-clay bed. A study by Goldenberg et al. (1983) involving the seawater-freshwater interface in coastal aquifers with a small percentage of clay showed that if the aquifer material is exposed to seawater and then to freshwater, the hydraulic conductivity of the system decreases by one or more orders of magnitude almost instantaneously. Another study by Goldenberg et al. (1984) found that even small amounts of montmorillonite can produce large decreases in hydraulic conductivity while small amounts of illite and kaolinite have little effect. Since montmorillonite is the dominant clay mineral in the study area, if saline water and then freshwater comes in contact with a silt-clay bed, its hydraulic conductivity could be significantly reduced. A reduction in hydraulic conductivity in silt-clay lenses could further impede the recharge of the aquifer. However, reduced permeability of a silt-clay bed bear the freshwater saltwater interface could also decrease the amount of upconing saline water due to the pumping stress of a well.

CONCLUSION

The unconsolidated sediments in the Great Bend Prairie are fluvial deposits, caliche deposits (associated with soil formation), and eolian and volcanic-ash deposits. During times of non-deposition, soil formation and erosional processes have dominated. The climatic changes associated with the glacial advances and retreats in the upper Mississippi Valley and Colorado have significantly influenced the depositional environment.

The sources for the alluvium are: the Rocky Mountains to the west, erosion of the Ogallala, Niobrara, and Dakota Formations in western Kansas and eastern Colorado, loess deposits from the glacial events to the north and west, and volcanic-ash deposits. The bulk of the fluvial deposits are believed to have been transported by the Arkansas River. Large amounts of sediment-laden water flowed down the Arkansas River and sediments were subsequently deposited along the river.

The gamma logs from the observation wells indicate that the silt-clay beds are generally not continuous. Each natural gamma-ray well log tells an individual depositional history that relates to a fluvial system and its facies environments.

A near-surface silt-clay and a basal sand are correlatable over the entire study area. The silt-clay bed occurs near the surface underlying the sand dunes and ranges in thickness from 1 to 40 feet (.3 to 12 meters). The basal sand ranges in thickness from 8 to 242 feet (2.4 to 72.6 meters). Between these two correlatable beds is a section with alternating sand, gravel, and silt-clay beds (variable lithology) that can not be correlated between well sites. At some sites, the lowest silt-clay in this section can serve as a confining layer and an aquitard between the freshwater aquifer and underlying saline water.

The basal sand overlies the bedrock and serves as an aquifer in some areas. The irrigation wells that are screened in this basal sand need to be identified, and recorded. In those areas where the basal sand supplies water for irrigation and saline waters are present in the bedrock, there are no barriers to prevent the upconing of saline water. This could present problems during times when the water table is low and there is a heavy pumping demand on the aquifer. Under these conditions, saline water may upcone into the freshwater portion of the aquifer and adversely affect irrigation water quality. To minimize the amount of saline water upconed and potential crop and land damage, several precautions should be taken:

(1) determine which irrigation wells are screened in the basal sand and classify them as high risk wells,

(2) frequently monitor the observation wells and high risk wells for signs of increased salinity, especially during times of high demand on the aquifer and low water levels (i.e. specific conductance readings), and

(3) if there is an increase in salinity, the irrigation wells should reduce or stop pumping until the high demand on the aquifer is over.

This should only be necessary during times of extreme drought. Upconing saline water could not only cause damage to crops and soils if accidentally used for irrigation, but also affect recharge in the aquifer by reducing the permeability of silt-clay beds. Both of the effects could have long term economic effects.

REFERENCES

Bayne, C.K., 1956, Geology and ground-water resources of Reno County, Kansas: Kansas Geological Survey, Bulletin 120, 130 p.

Bayne, C.K., and Ward, J.R., 1974, Geology and hydrogeology of Rice County, central Kansas: Kansas Geological Survey, Bulletin 206, part 3, 17 p.

Blake, W.P., 1902, The caliche of southern Arizona: an example of deposition by the vadose circulation: American Inst. Mining Metal. Petroleum Engineers Trans., v. 31, p. 220-226.

Bouyoucos, G.J., 1927, The hydrometer as a new and rapid method for determining the colloidal content of soils: Soil Science, v 23, no 4, p. 319.

Cobb, P.M., 1980, The distribution and mechanisms of salt water intrusion in the fresh water aquifer and in Rattlesnake Creek, Stafford County, Kansas: M.S. thesis, University of Kansas, Lawrence, 176 p.

Doveton, J.H., 1986, Log analysis of subsurface geology, concepts and computer methods: John Wiley & Sons, Inc., New York, 273 p.

Fader, S.W., and Stullken, L.E., 1978, Geohydrology of the Great Bend Prairie, south-central Kansas: Kansas Geological Survey, Irrigation Series 4, 19 p.

Fent, O.S., 1950a, Geology and groundwater resources of Rice County, Kansas: Kansas Geological Survey, Bulletin 85, 142 p.

Fent, O.S., 1950b, Pleistocene drainage history of central Kansas: Kansas Academy of Science Transactions, v. 53, no. 1, p. 81-90.

Folk, R.L., 1980, Petrology of sedimentary rocks: Hemphill Publishing Co., 185 p.

Frye, J.C., and Fent, O.S., 1947, The late Pleistocene loesses of central Kansas: Kansas Geological Survey Bull. 70, pt. 3, p. 29 -52.

Frye, J.C. and Leonard, A.B., 1952, Pleistocene Geology of Kansas: Kansas Geological Survey Bull. 99, 230 p.

Frye, J.C., and Leonard, A.B., 1957, Ecological interpretations of Pliocene and Pleistocene stratigraphy in the Great Plains region: American Journal of Science, v. 255, no 1, 11 p.

Frye, J.C., Swineford, A., and Leonard, A.B., 1948, Correlation of Pleistocene deposits of the Central Great Plains with the glacial section: Journal of Geology, v. 56, no. 6, p. 501-525.

Fund, M., 1984, Water in Kansas: A primer: Kansas Rural Center, p.96.

Geil, S.A., 1987, Significance of the age and identity of a volcanic ash near DeSoto, Kansas, with respect to the enclosing terrace deposits: M.S. thesis, University of Kansas, Lawrence, 167 p.

Goldenberg, L.C., Magaritz, M. and Mandel, S., 1983, Experimental investigation on irreversible changes of hydraulic conductivity in the seawater-freshwater interface in coastal aquifers: Water Resour. Res., v. 19, p. 77-85.

Goldenberg, L.C., Margaritz, M., Amiel, A.J., and Mandel S., 1984, Changes in hydraulic conductivity of laboratory sand-clay mixtures caused by seawater-freshwater interface, Journal of Hydrology, v. 70, p. 329-336.

Jordan, P.R., 1977, Streamflow transmission losses in western Kansas: Proc. of the Amer. Scl. of Civil Eng., Jour. of Hydraulics Div., v. 103, n. HY8, Paper 13156, p. 905-919.

Keys, W.S., 1968, Well logging in ground-water hydrology: Ground Water, vol. 6, no. 1, p. 10-18.

Keys, W.S. and MacCary, L.M., 1985, Application of borehole geophysics to water-resources investigations: Water Resources Inv., U.S.G.S Pub., Chapter E1, Book 2, 126 p.

Krumbein, W.C., 1954, The tetrahedron as a facies mapping device: Journal of Sedimentary Petrology, v. 24, no. 1, p. 3-19.

Latta, B.F., 1950, Geology and ground-water resources of Barton and Stafford Counties, Kansas: Kansas Geological Survey, Bulletin 88, 228 p.

Layton, D.W., and Berry, D. W., 1973, Geology and ground-water resources of Pratt County, south-central Kansas: Kansas Geological Survey, Bulletin 205, 33 p.

Mead, J.R., 1896, A dying river: Transactions Kansas Academy of Science, v. 14, p. 111-112.

Merriam, D.F., 1958, Preliminary regional structural contour map on top of the Stone Corral Formation (Permian) in Kansas: Kansas Geological Survey Oil and Gas Survey Inv. n. 17, 1 pl.

Merriam, D.F., 1963, The geological history of Kansas: Kansas Geological Survey, Bulletin 162, 317 p.

Norris, S.E., 1972, The use of gamma logs in determining the character of unconsolidated sediments and well construction features: Ground Water, vol. 10, no. 6, p. 14-21.

Reeves, C.C. Jr., 1970, Origin, classification, and geologic history of caliche on the southern high plains, Texas and eastern New Mexico: Journal of Geology, V. 78, p. 352 -362.

Richards, K., 1982, Rivers forms and process in alluvial channels: Methuen, London and New York, 361 p.

Richmond, G.M., 1986, Stratigraphy and correlation of glacial deposits of the Rocky Mountains, the Colorado Plateau and the ranges of the Great Basin; in Quaternary Glaciations in the Northern Hemisphere, v 5., V. Sibrava, D.Q. Bowen, and G.M. Richmond, eds: Pergamon Press, p. 129-144.

Rider, M.H., 1986, The geological interpretation of well logs: Halstead Press, John Wiley and Sons, New York, 171 p.

Rosner, M.L., 1986, Correlation of the stratigraphy of the Quaternary Alluvium in the Great Bend Prairie, Kansas: unpublished report, 26 p.

Schumm, S.A., 1977, The fluvial system: Wiley-Interscience, New York, 338 p.

Serra, O., Baldwin, J., and Quirein, J., 1980, Theory, Interpretation and practical applications of natural gamma-ray spectroscopy: Trans. Soc. Prof. Well Log Analysts Ann., Logging Symp., Paper Q, 30 p.

Serra, O. and Sulpice, L., 1975, Sedimentological analysis of sand-shale series from well logs: SPWLA 16th Ann. Symp. Trans., Paper W, p. 1-23.

Smith, H.T.U., 1940, Geological studies in southwestern Kansas: Kansas Geological Survey, Bul. 34, 241 p.

Snipes, R.R., 1974, Floods of June 1965 in Arkansas River Basin, Colorado, Kansas, and New Mexico: Geological Survey Water-supply Paper 1850-D, 97 p.

Spray, K.L., 1986, Impact of surface-water and groundwater withdrawl on discharge and channel morphology along the Arkansas River, Lakin to Dodge City, Kansas: M.S. thesis, University of Kansas, Lawrence, 102 p.

Stullken, L.E., and Fader, S.W., 1976, Hydrogeologic data from the Great Bend Prairie, south-central Kansas: Kansas Geological Survey, Basic Data Series, Ground-Water release no. 5, 50 p.

U.S. Army Corps of Engineers, 1966, Flood report Arkansas River basin, Flood of June 1965, Colorado, Kansas and New Mexico: U.S. Army Corps of Engineers, Albuquerque, N. Mex., 105 p.

Welch, J.E., and Hale, J.M., 1987, Pleistocene loess in Kansas-status, present problems, and future consideration: in, Quaternary environments of Kansas, Guidebook Series 5, W. C. Johnson, ed., Kansas Geological Survey, p. 67-82.

Wentworth, C.K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, p. 377-392.

Wolman, M.G., and Leopold, L.B., 1957, River flood plains: some observations on their formation: U.S.G.S. Professional Paper 282-C, 109 p.

APPENDIX I.

Gamma Logs From The Observation Wells

▨ Screened interval

The approximate length of the screened interval is indicated by the thickness of the shaded symbol.

Sp C - Specific conductance, umho/cm at 25° C.

TDS - Total-dissolved-solids, concentration, mg/L

< 500 mg/L TDS, recommended for drinking water
> 2,000 - 3,000 mg/L TDS, to salty to drink
35,000 mg/L TDS, seawater

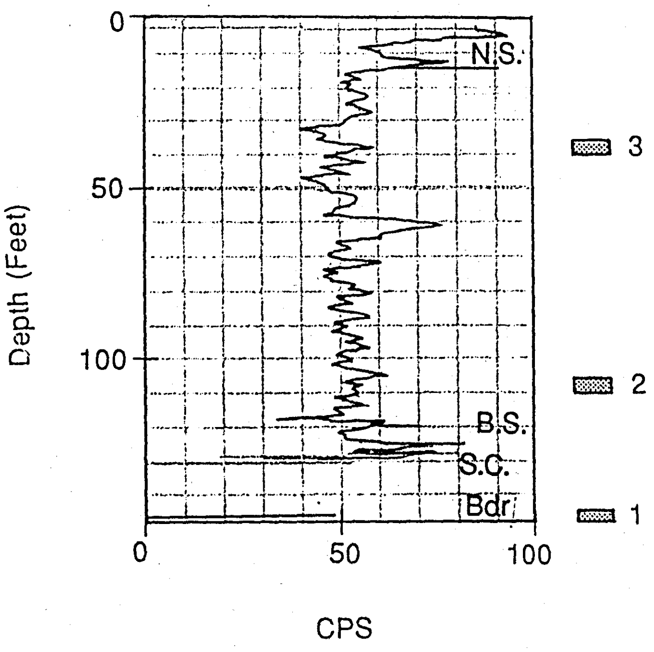
N.S.	Near surface silt-clay
B.S.	Basal Sand
S.C.	Silt-clay
Bdr.	Bedrock

Note: It was not possible to log to the bottom of every deep well. Therefore, there are screened intervals indicated below the gamma log.

Site 1
Location: 23S 12W 12BAAA
County: Stafford

Well	1	2	3
Sp C	36900	7000	413
TDS	24163	3856	253

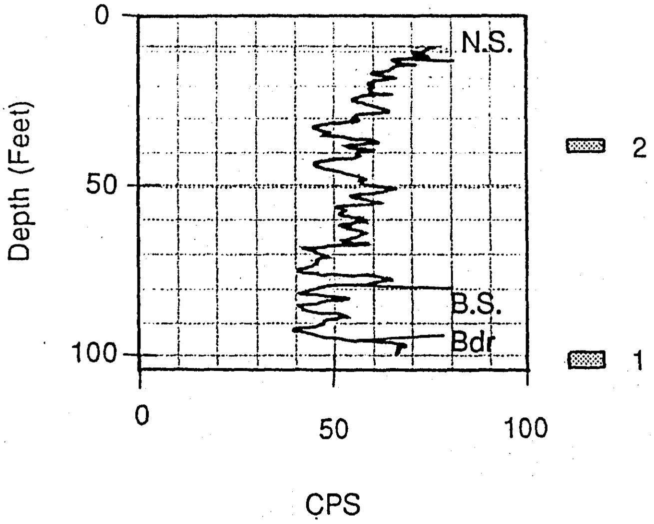
Natural Gamma Log
Ground Surface Elevation: 1827



Site 2
Location: 23S 12W 36ABAB
County: Stafford

Well	1	2
Sp C	2630	875
TDS	1445	508

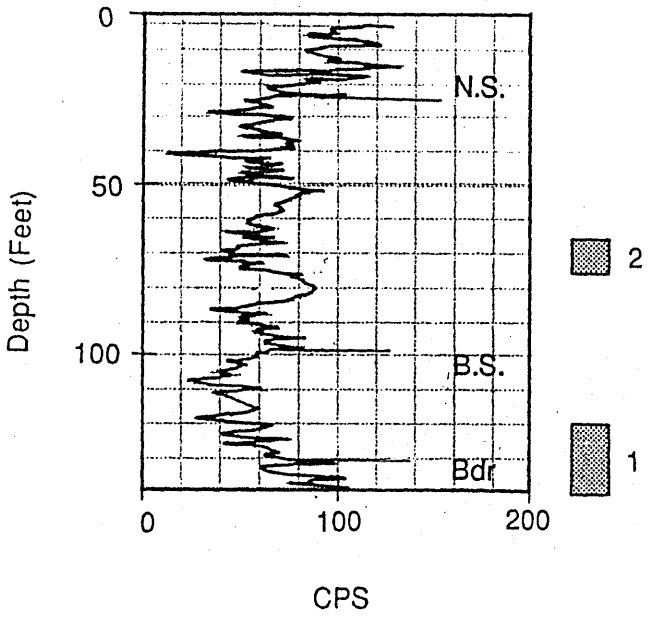
Natural Gamma Log
Ground Surface Elevation: 1837



Site 3
Location: 23S 13W 36DCCC
County: Stafford

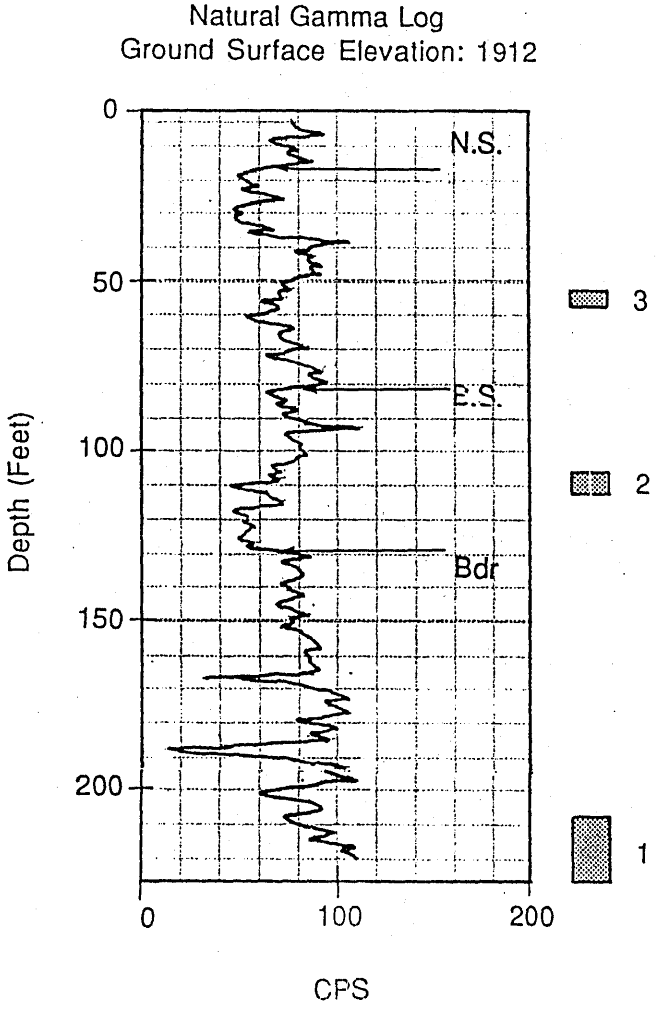
Well	1	2
Sp C	1660	1590
TDS	580	889

Natural Gamma Log
Ground Surface Elevation: 1898



Site 4
Location: 23S 14W 36DDCD
County: Stafford

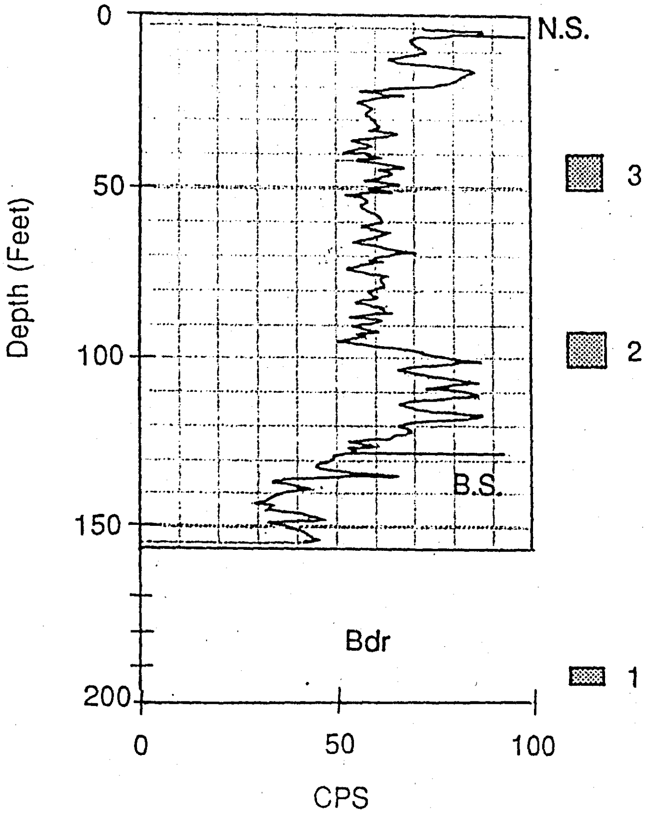
Well	1	2	3
Sp C	77600	3370	942
TDS	53294	1960	518



Site 5
Location: 23S 12W 06BBBA
County: Stafford

Well	1	2	3
Sp C	85200	55700	795
TDS	74613	37751	445

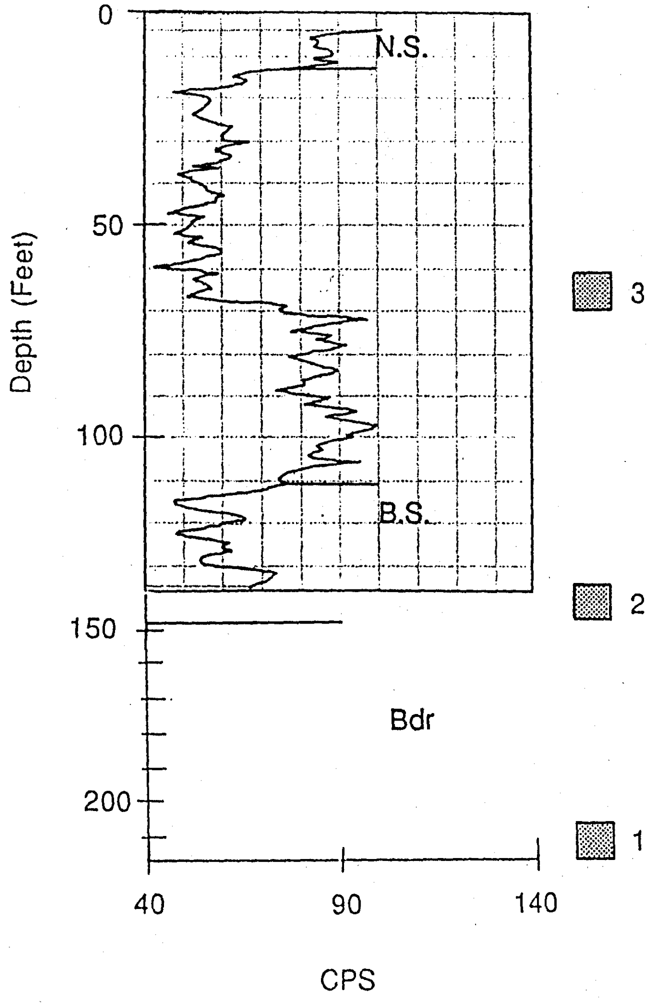
Natural Gamma Log
Ground Surface Elevation: 1855



Site 6
Location: 25S 13W 06BCBC
County: Stafford

Well	1	2	3
Sp C	98900	5010	1330
TDS	74252	3082	693

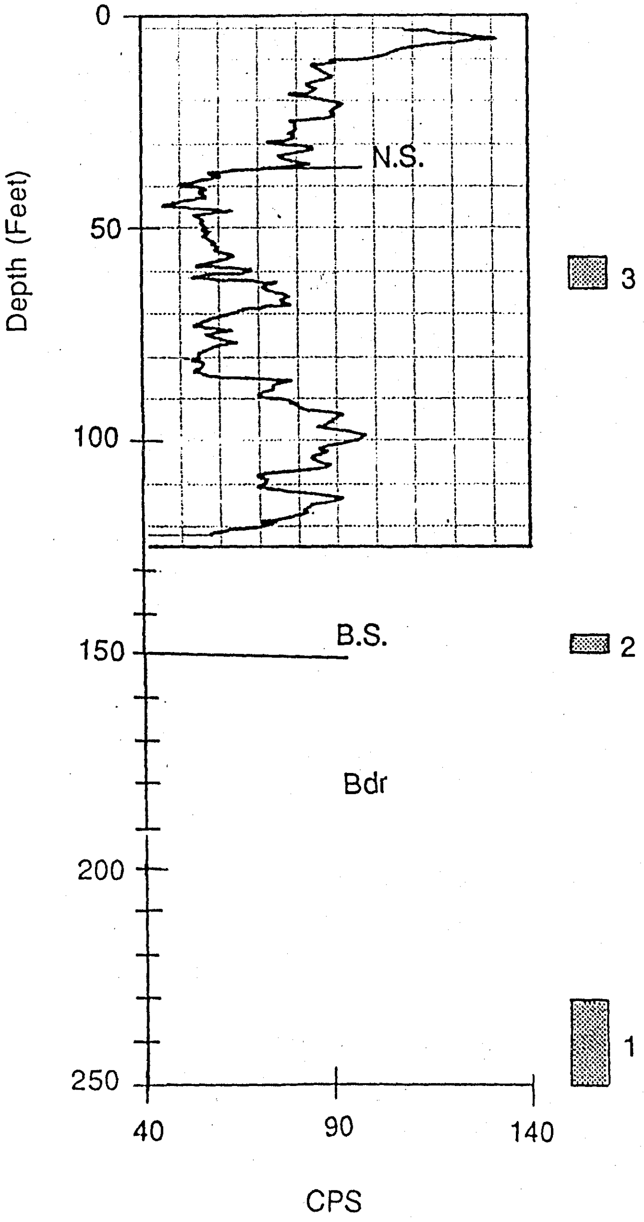
Natural Gamma Log
Ground Surface Elevation: 1950



Site 7
Location: 24S 13W 36DDDD
County: Stafford

Well	1	2	3
Sp C	18900	991	699
TDS	11787	568	413

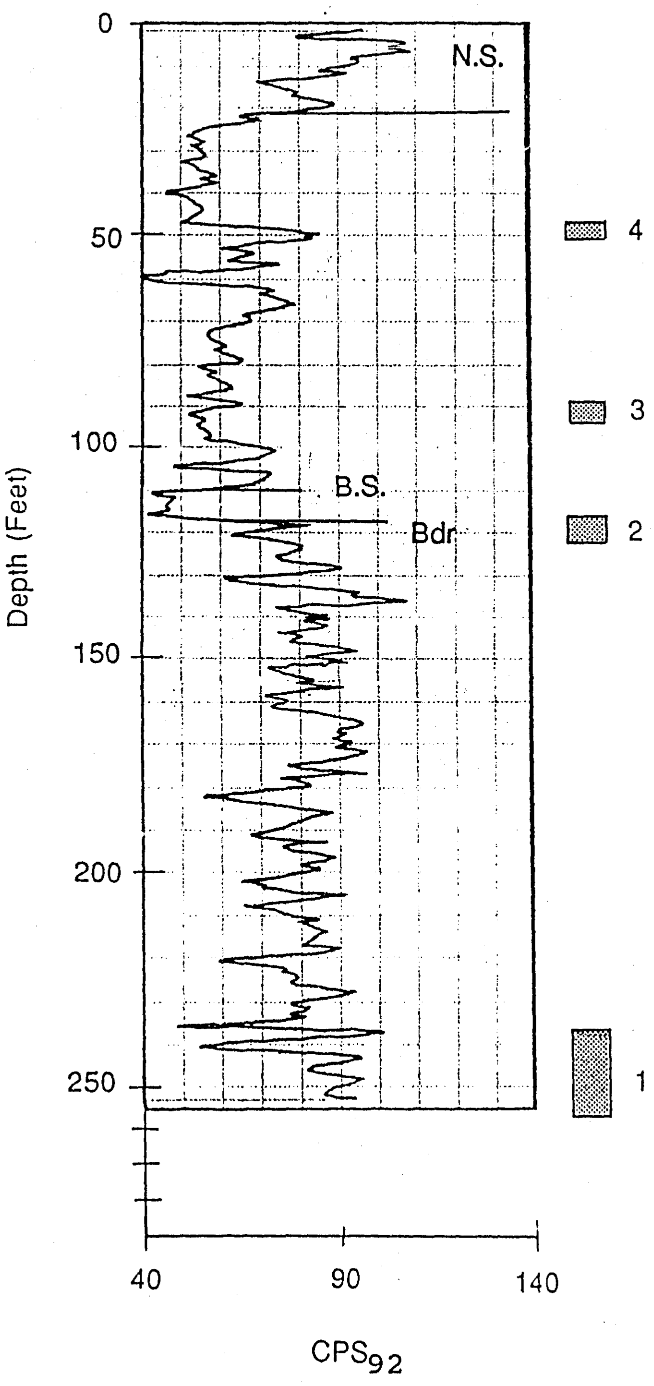
Natural Gamma Log
Ground Surface Elevation: 1906



Site 8
Location: 25S 12W 11AAAD
County: Stafford

Well	1	2	3
Sp C	106000	1420	1280
TDS	89345	793	710

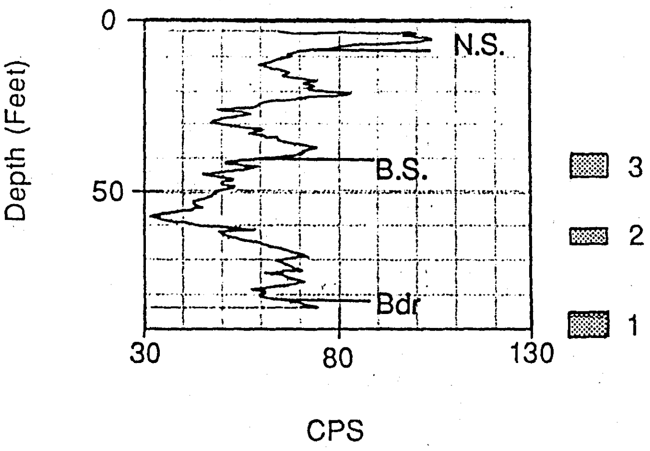
Natural Gamma Log
Ground Surface Elevation: 1848



Site 9
Location: 24S 10W 31CBCB
County: Reno

Well	1	2	3
Sp C	10700	5040	3190
TDS	6261	2917	1783

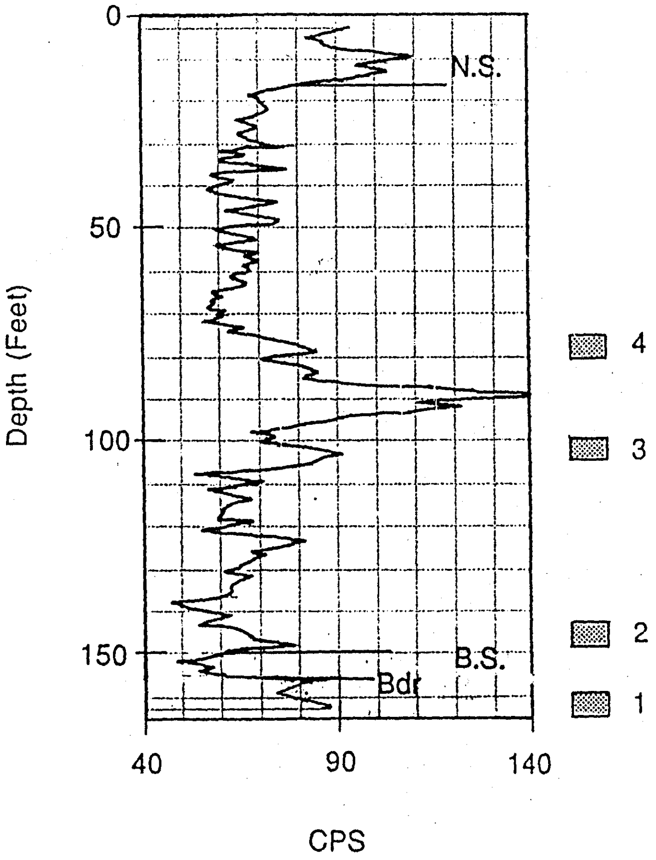
Natural Gamma Log
Ground Surface Elevation: 1755



Site 10
Location: 24S 10W 06DCCC
County: Reno

Well	1	2	3	4
Sp C	6230	4900	2410	971
TDS	3451	2766	1341	532

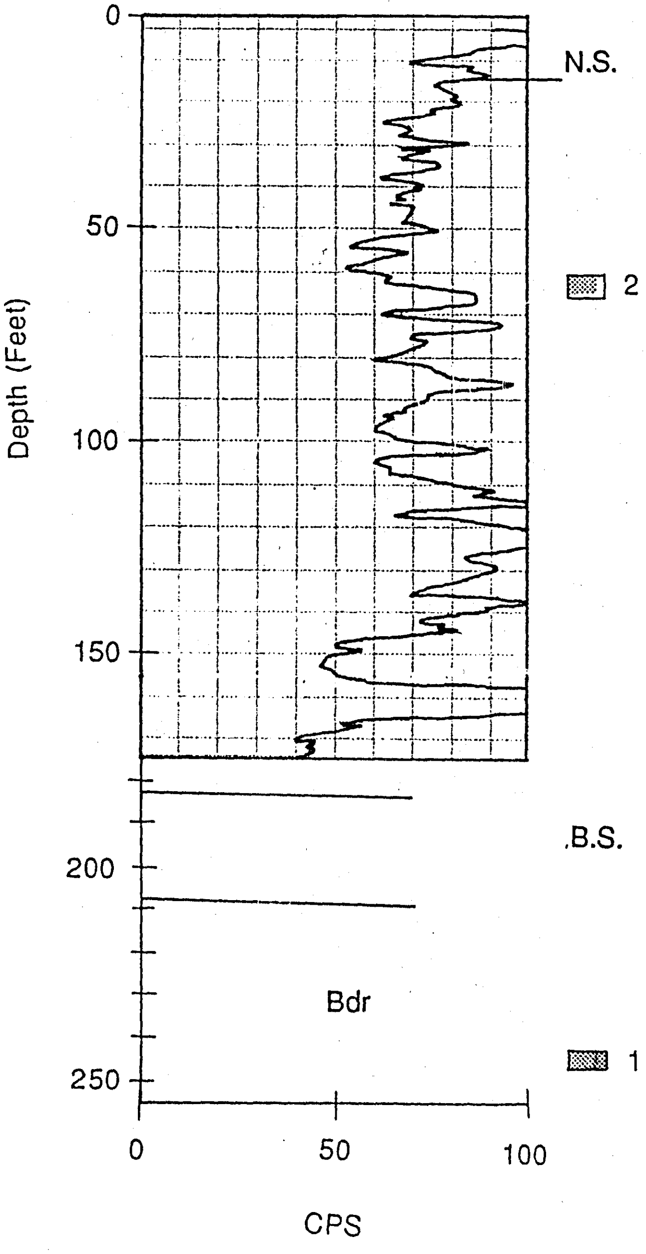
Natural Gamma Log
Ground Surface Elevation: 1790



Site 11
Location: 22S 10W 06CBBB
County: Reno

Well	1	2
Sp C	14000	3900
TDS	8242	2165

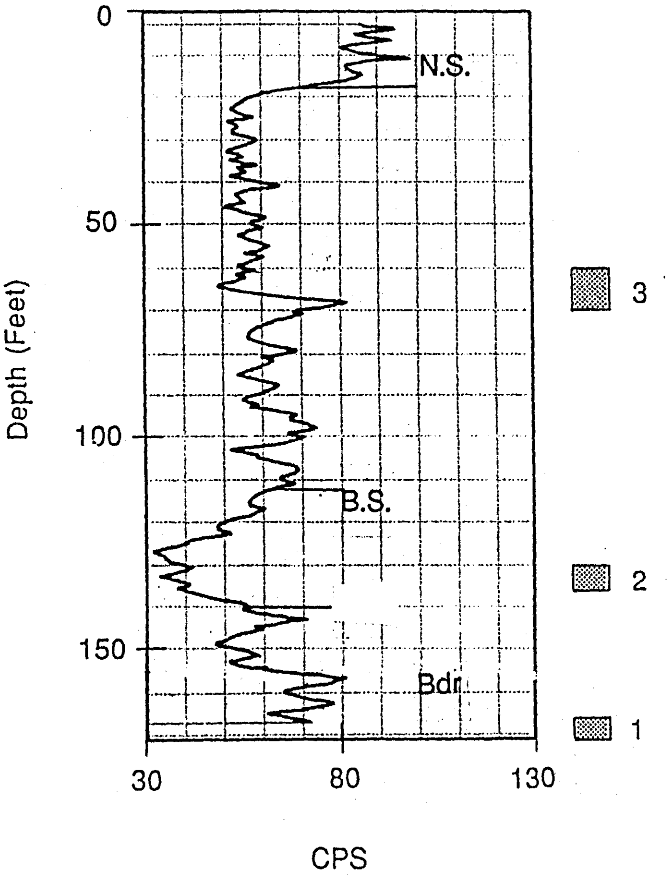
Natural Gamma Log
Ground Surface Elevation: 1763



Site 12
Location: 29S 11W 36ACCC
County: Pratt

Well	1	2	3
Sp C	335	320	455
TDS	188	205	283

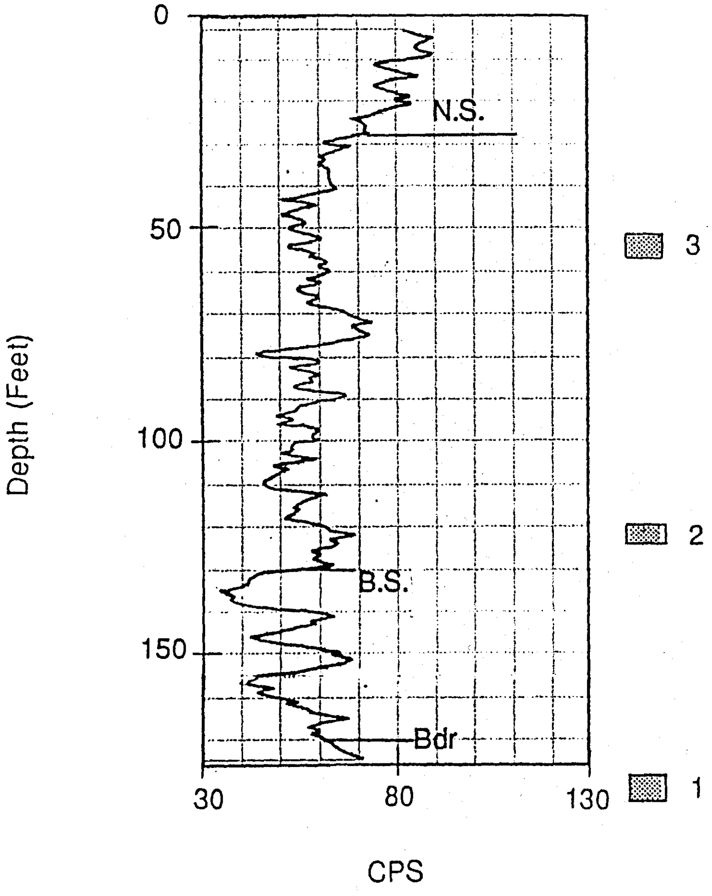
Natural Gamma Log
Ground Surface Elevation: 1770



Site 13
Location: 29S 14W 36AAAD
County: Pratt

Well	1	2	3
Sp C	443	395	404
TDS	266	252	245

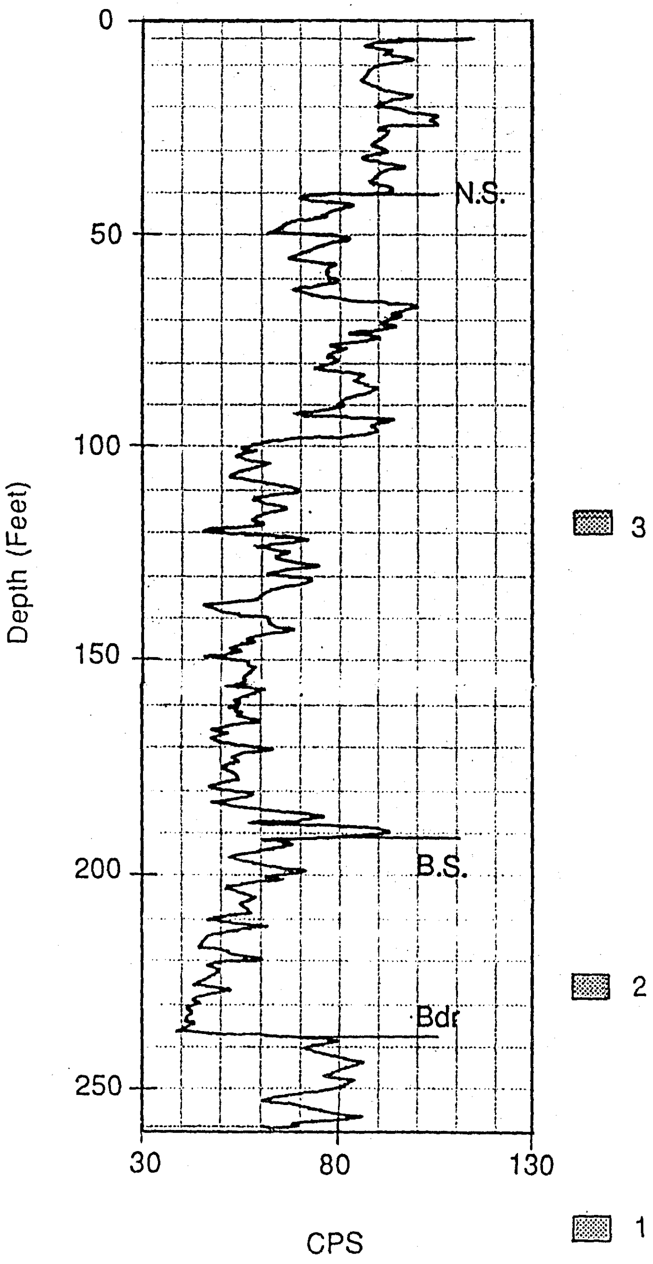
Natural Gamma Log
Ground Surface Elevation: 1905



Site 14
Location: 29S 14W 12ABBB
County: Pratt

Well	1	2	3
Sp C	330	395	640
TDS	218	248	366

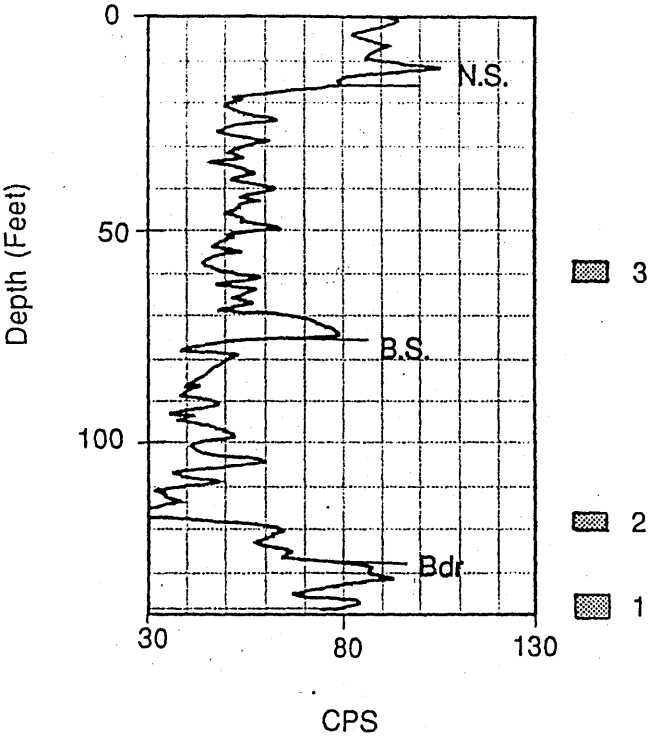
Natural Gamma Log
Ground Surface Elevation: 1989



Site 15
Location: 28S 11W 01AAAD
County: Pratt

Well	1	2	3
Sp C	2100	1400	461
TDS	1158	761	278

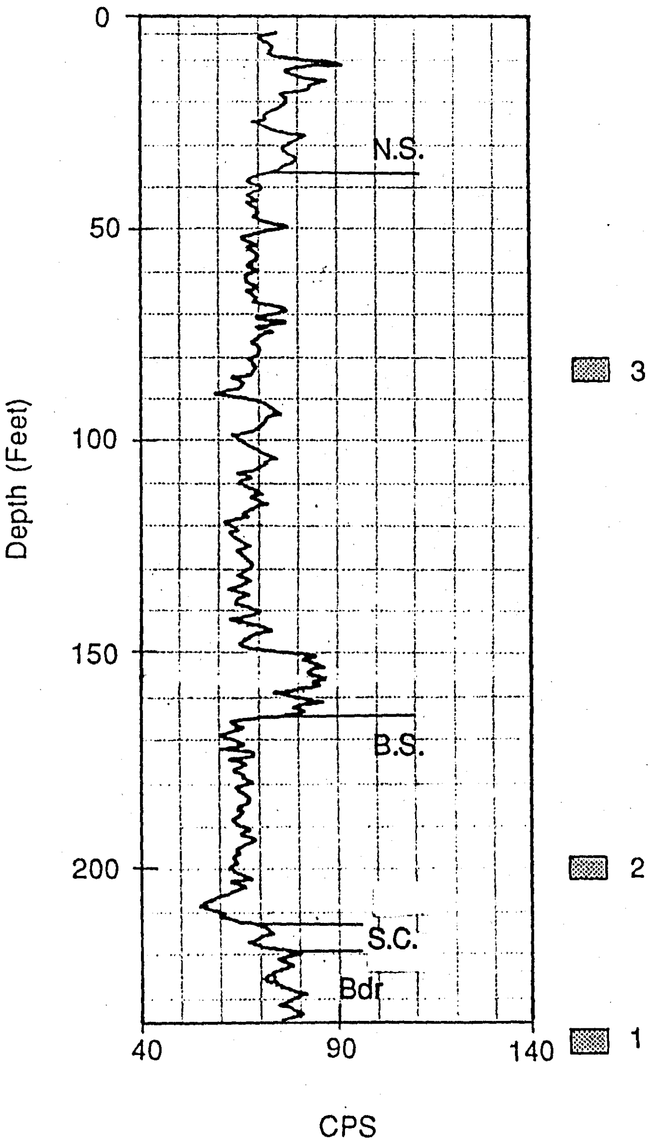
Natural Gamma Log
Ground Surface Elevation: 1725



Site 16
Location: 21S 12W 31CCCB
County: Stafford

Well	1	2	3
Sp C	88500	79100	500
TDS	64019	56623	293

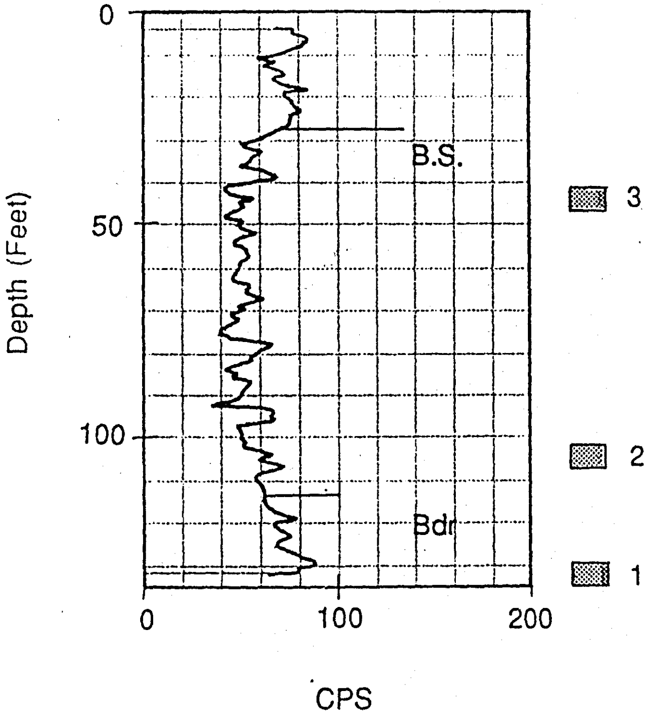
Natural Gamma Log
Ground Surface Elevation: 1873



Site 17
Location: 21S 12W 36DDCC
County: Stafford

Well	1	2	3
Sp C	28900	26000	685
TDS	18670	16143	407

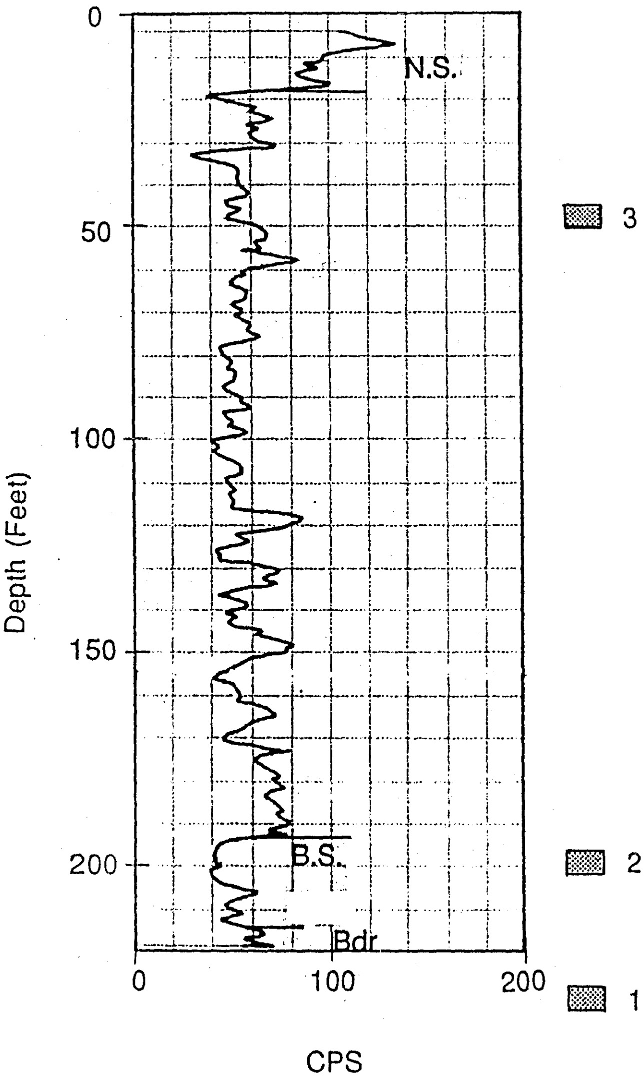
Natural Gamma Log
Ground Surface Elevation: 1795



Site 18
Location: 21S 11W 07BBBA
County: Stafford

Well	1	2	3
Sp C	35200	30900	665
TDS	23553	19624	343

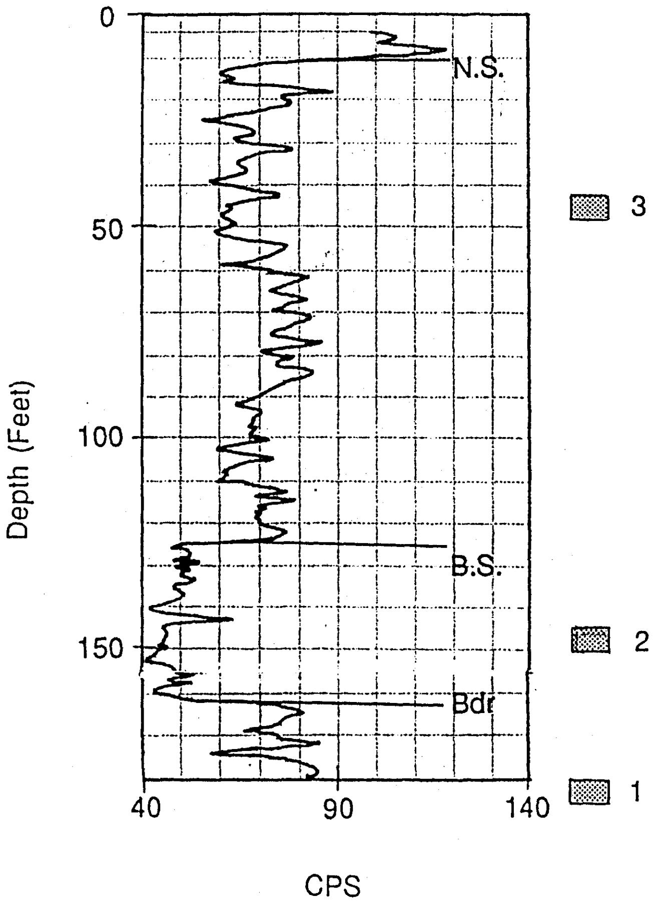
Natural Gamma Log
Ground Surface Elevation: 1810



Site 19
Location: 25S 13W 36DCCC
County: Stafford

Well	1	2	3
Sp C	995	1390	455
TDS	560	770	282

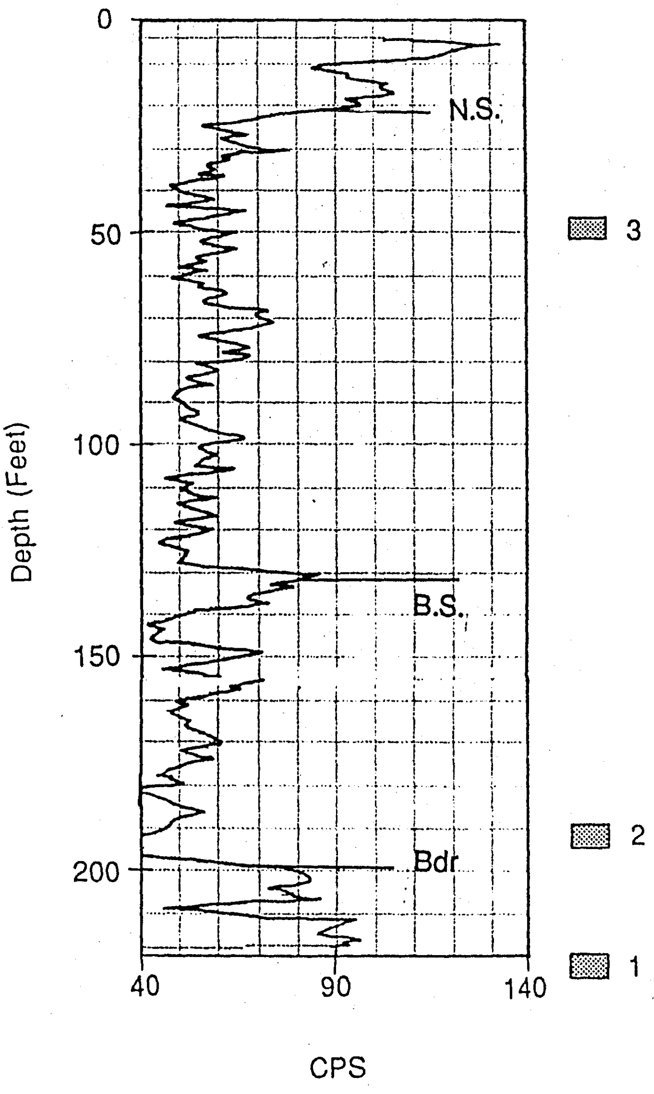
Natural Gamma Log
Ground Surface Elevation: 1902



Site 20
Location: 25S 13W 31DDAA
County: Stafford

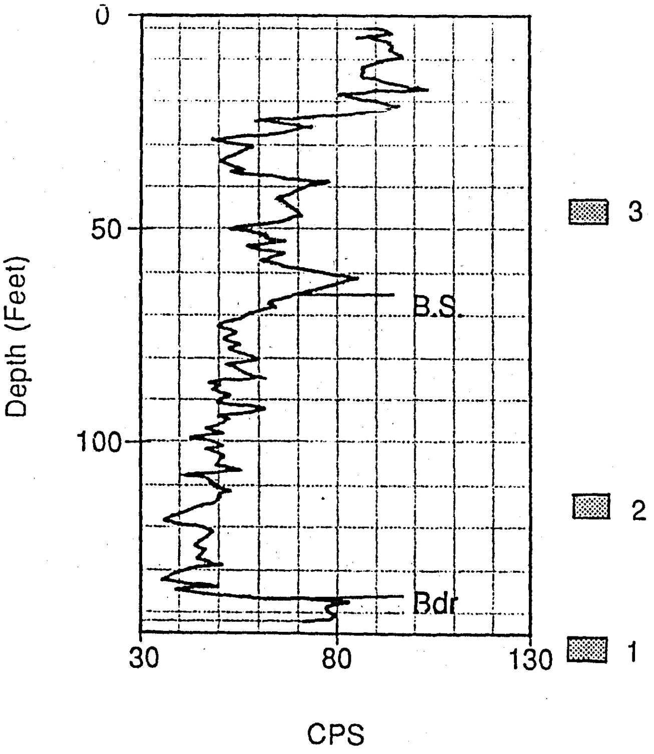
Well	1	2	3
Sp C	17400	1220	471
TDS	11361	675	281

Natural Gamma Log
Ground Surface Elevation: 1960



Site 21
Location: 26S 11W 01DDDA
County: Pratt

Well	1	2	3
Sp C	35100	8020	590
TDS	23265	4513	344

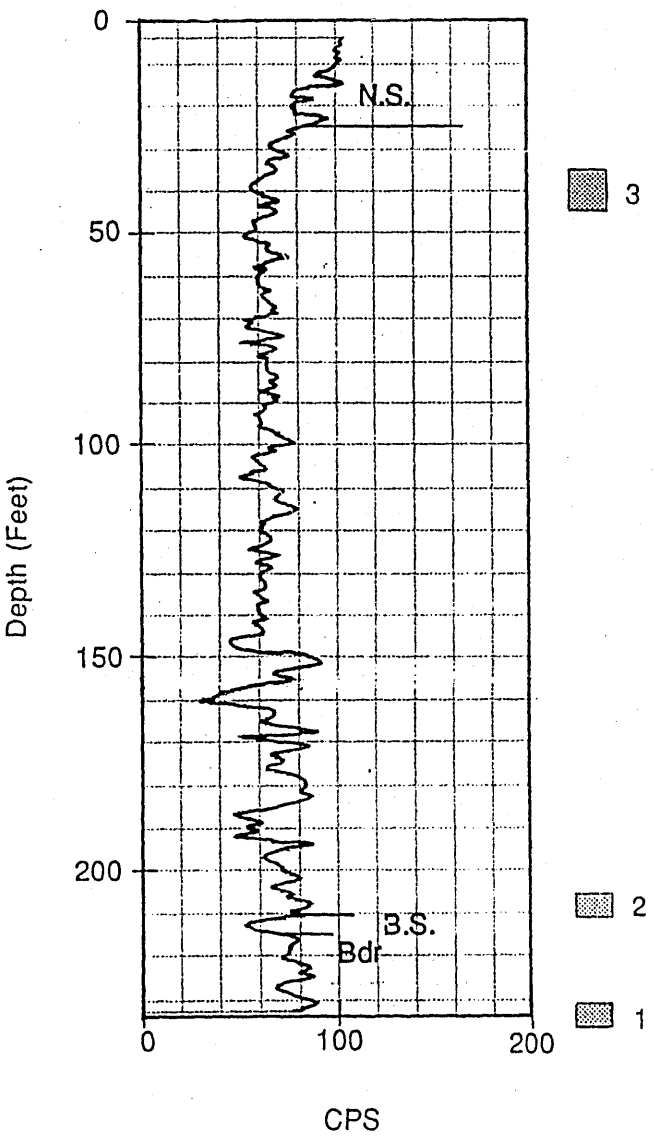


Natural Gamma Log
Ground Surface Elevation: 1801

Site 22
Location: 21S 12W 06CCBC
County: Stafford

Well	1	2	3
Sp C	82600	68900	459
TDS	61451	48685	286

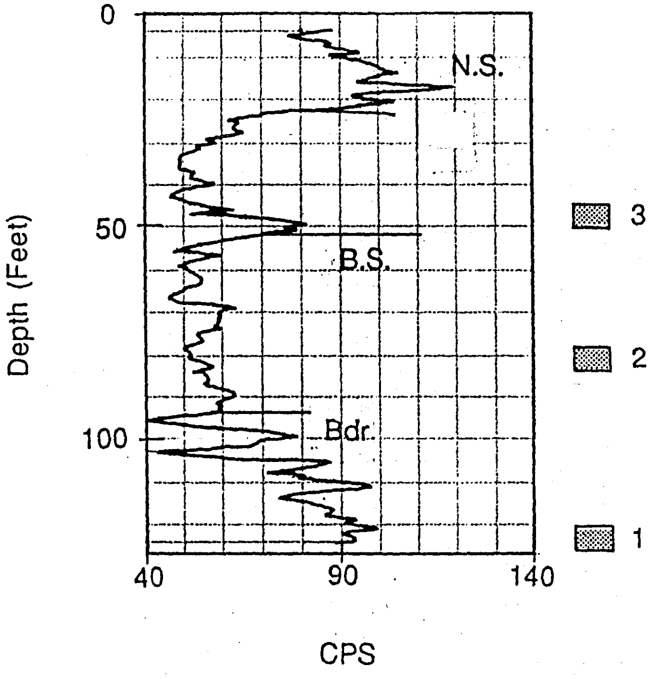
Natural Gamma Log
Ground Surface Elevation: 1855



Site 23
Location: 21S 10W 06AADD
County: Rice

Well	1	2	3
Sp C	21300	935	895
TDS	13361	526	503

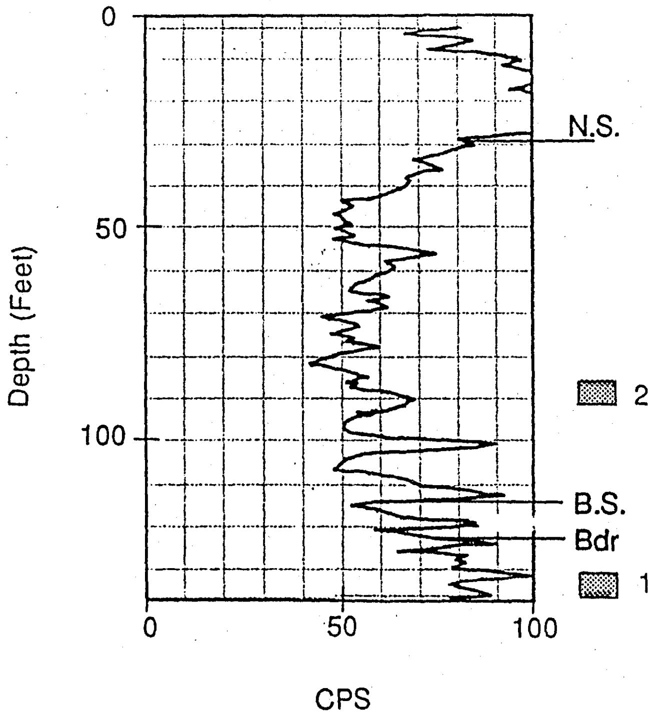
Natural Gamma Log
Ground Surface Elevation: 1743



Site 24
Location: 22S 10W 01ADBC
County: Reno

Well	1	2
Sp C	6310	1260
TDS	3450	710

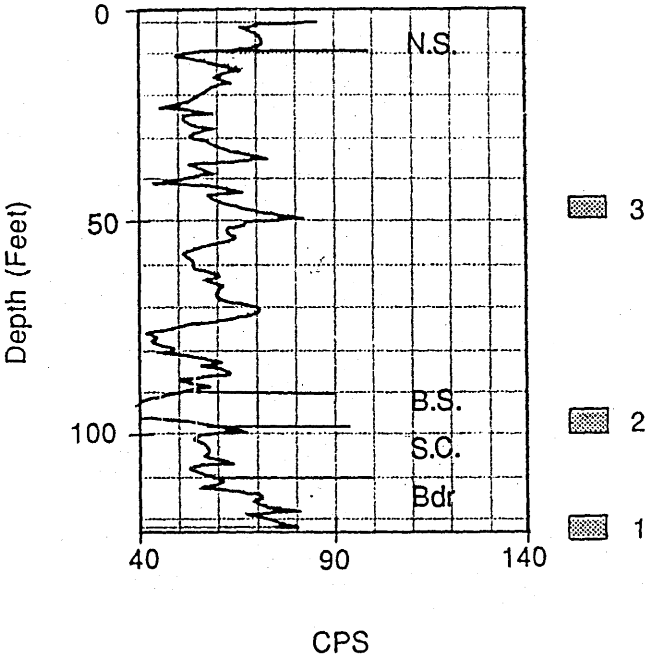
Natural Gamma Log
Ground Surface Elevation: 1736



Site 25
Location: 23S 10W 06 BBAB
County: Reno

Well	1	2	3
Sp C	40800	66100	61500
TDS	31101	44071	41150

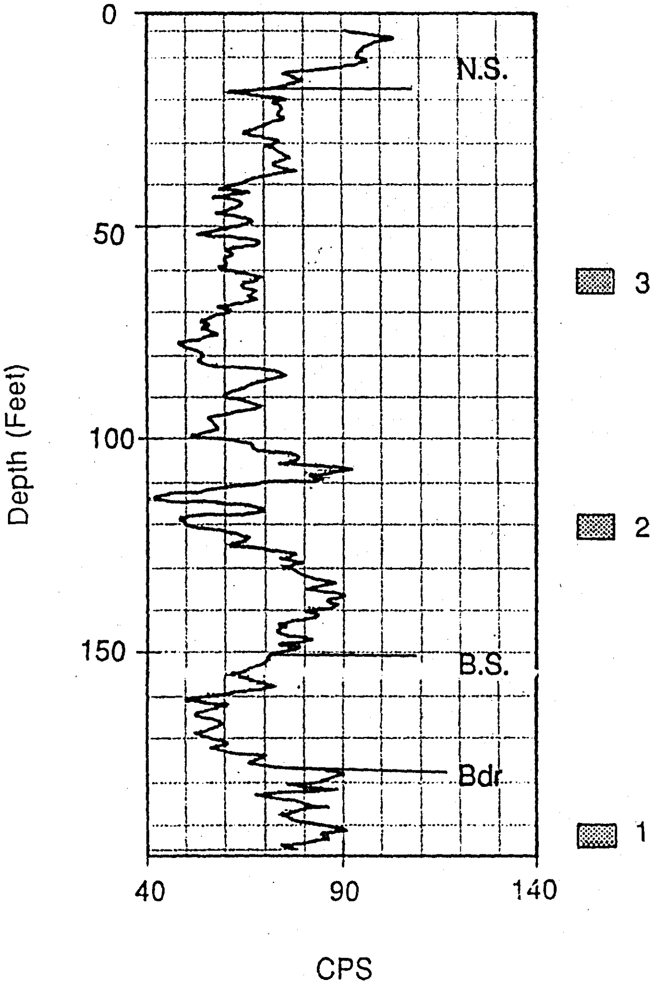
Natural Gamma Log
Ground Surface Elevation: 1780



Site 26
Location: 23S 10W 01AAAA
County: Reno

Well	1	2	3
Sp C	37100	34500	3170
TDS	24856	22847	1721

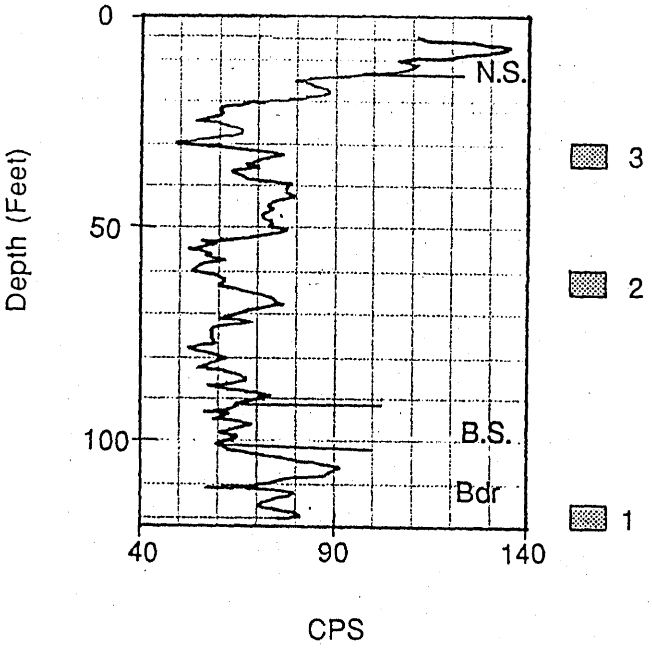
Natural Gamma Log
Ground Surface Elevation: 1738



Site 27
Location: 23S 09W 01ADAA
County: Reno

Well	1	2	3
Sp C	6510	2800	2590
TDS	3631	1580	1572

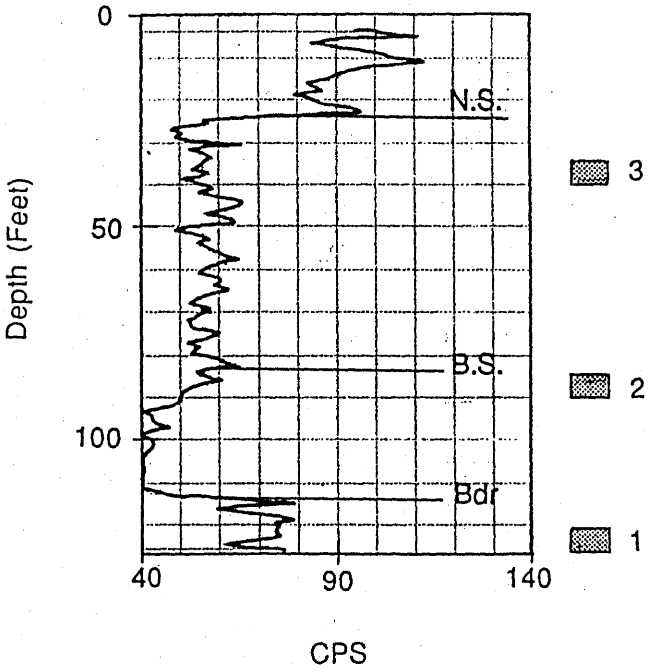
Natural Gamma Log
Ground Surface Elevation: 1685



Site 28
Location: 25S 09W 01ADDA
County: Reno

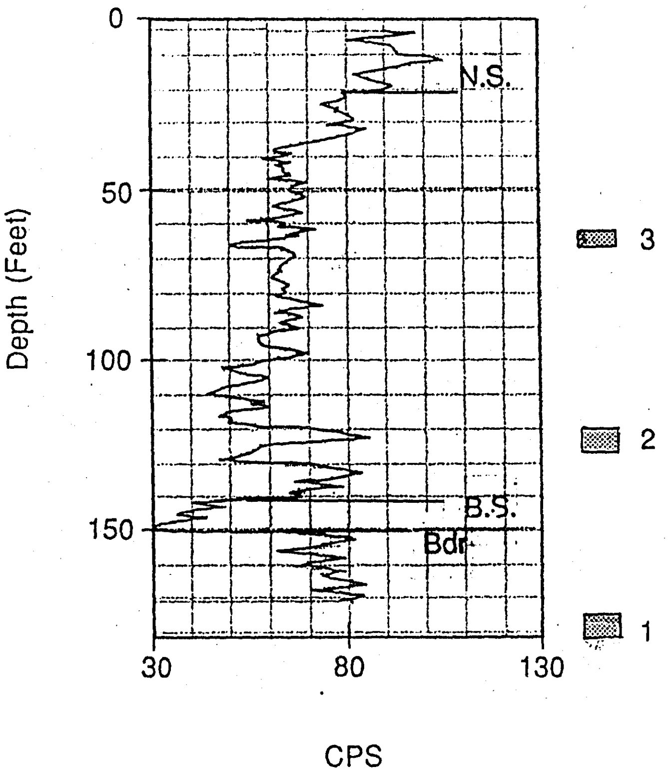
Well	1	2	3
Sp C	3580	758	275
TDS	2042	424	197

Natural Gamma Log
Ground Surface Elevation: 1668



Site 29
Location: 24S 10W 36AAAA
County: Reno

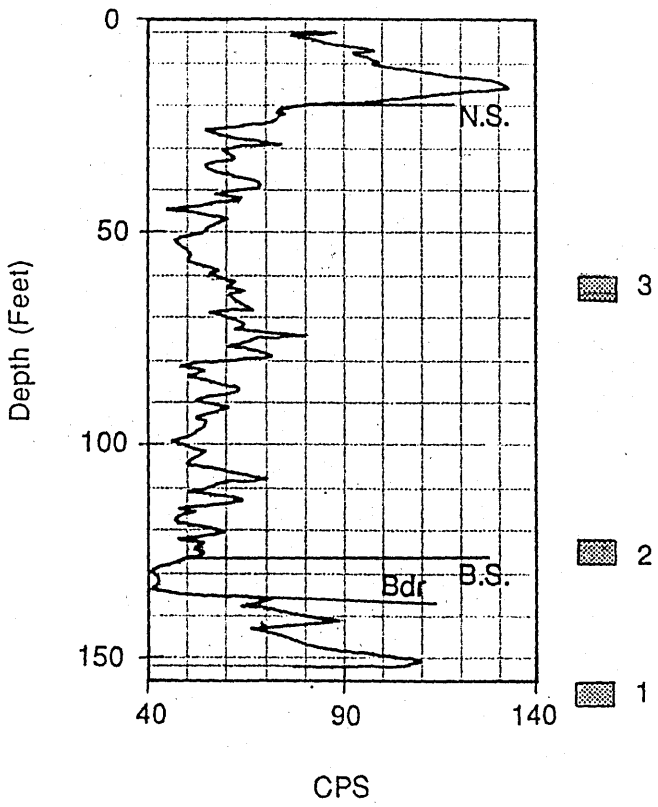
Well	1	2	3
Sp C	60000	1500	372
TDS	43070	818	246


Natural Gamma Log
Ground Surface Elevation: 1731

Site 30
Location: 23S 10W 36DAAA
County: Reno

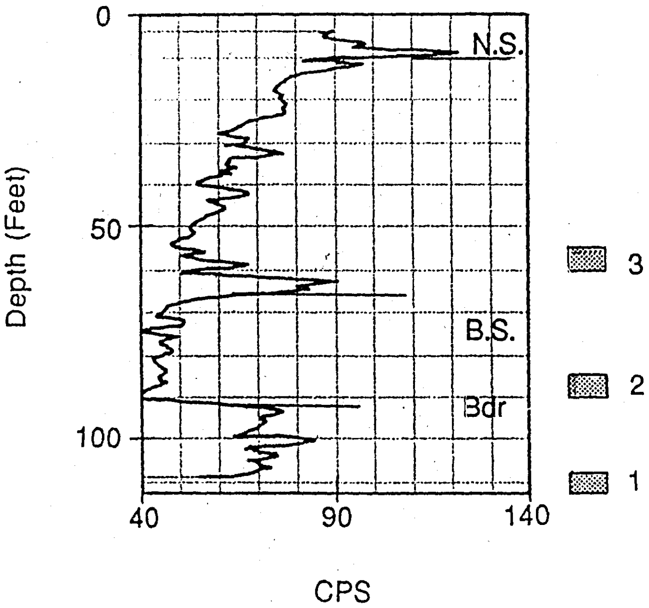
Well	1	2	3
Sp C	8000	1710	381
TDS	4436	932	243

Natural Gamma Log
Ground Surface Elevation: 1750



Site 31
Location: 22S 09W 01ADAA
County: Reno

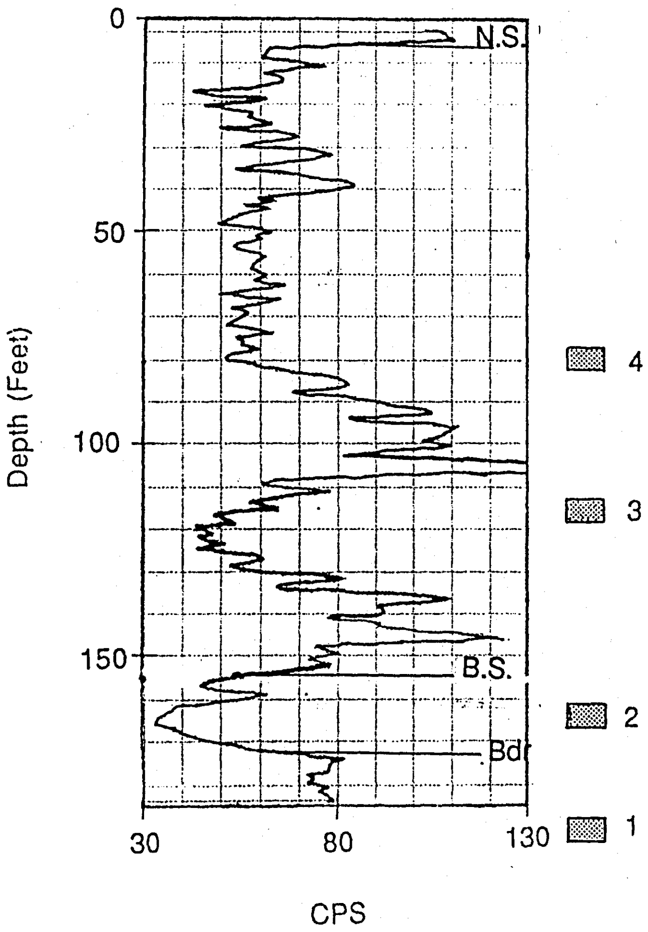
Well	1	2	3
Sp C	6520	2350	1590
TDS	3660	1229	894


Natural Gamma Log
Ground Surface Elevation: 1665

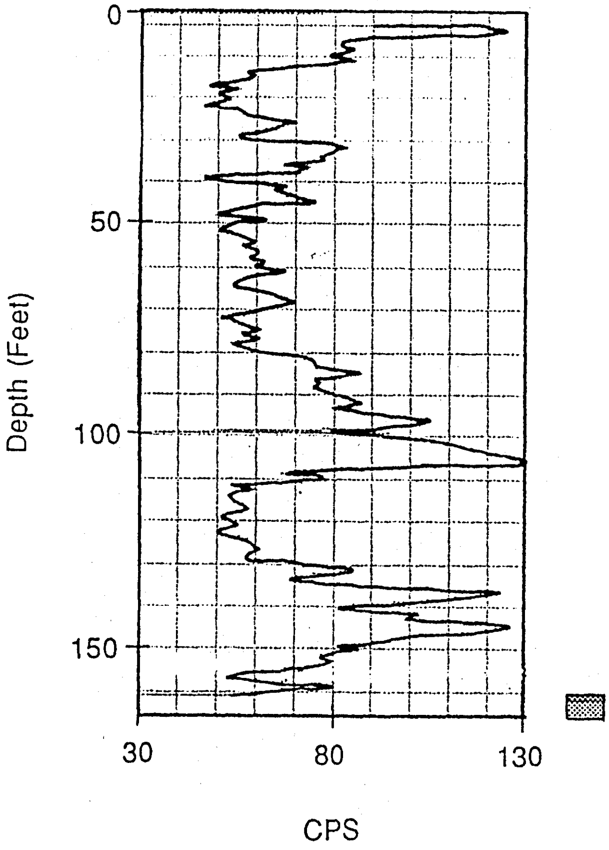
Site 32
Location: 23S 09W 25DDDD
County: Reno

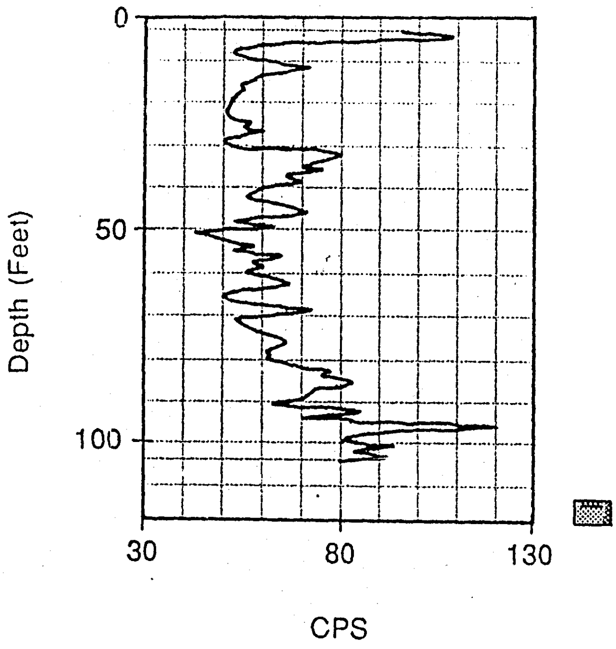
Well	1	2	3	4
Sp C	7150	5300	5700	2020
TDS	4280	3138	3186	1072

Natural Gamma Log
Ground Surface Elevation: 1689



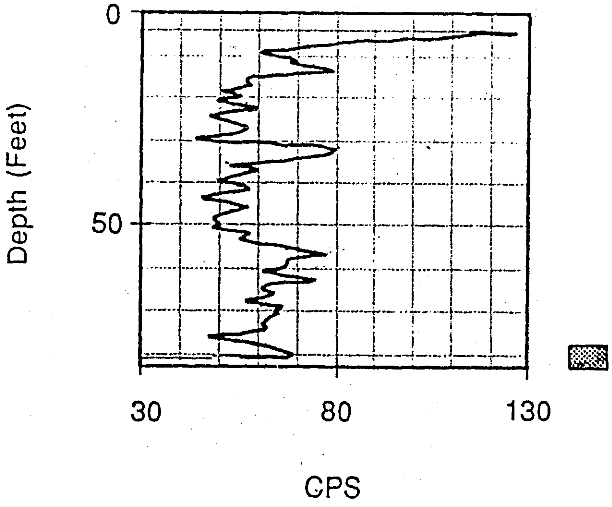
Site 32
Well 2





Site 32
Well 3

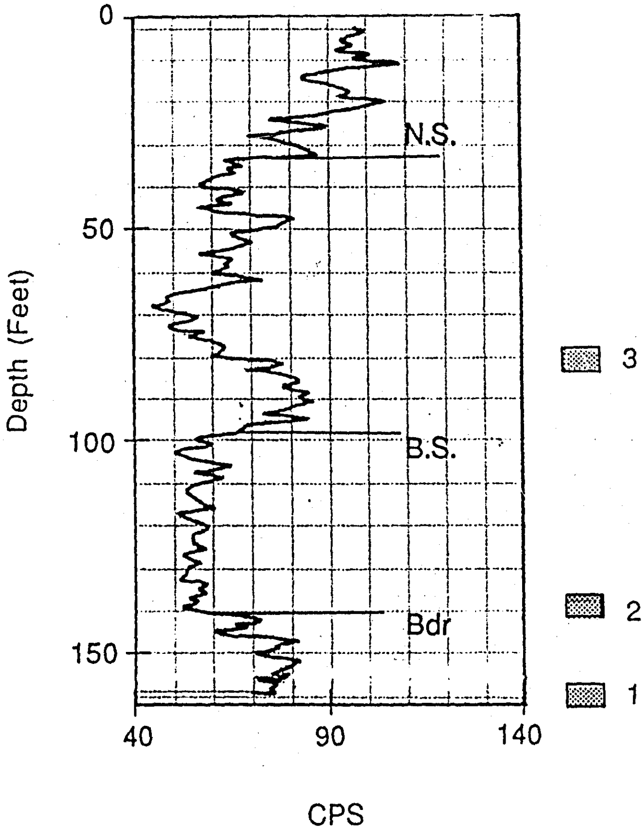
Site 32
Well 4



Site 33
Location: 25S 12W 36CBBA
County: Stafford

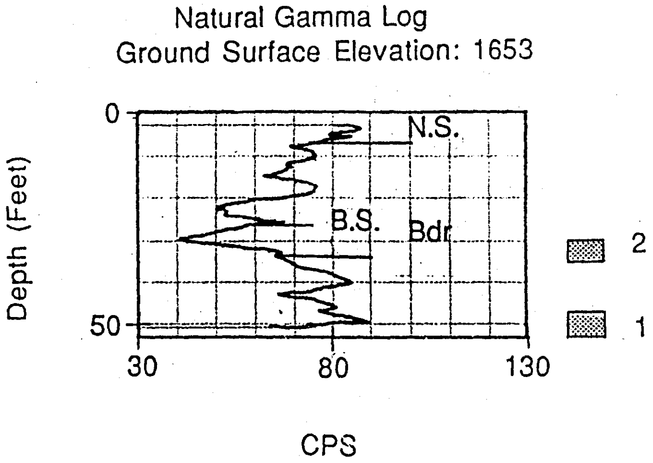
Well	1	2	3
Sp C	4250	1980	471
TDS	2260	1071	294

Natural Gamma Log
Ground Surface Elevation: 1872



Site 34
Location: 25S 09W 36DDCC
County: Reno

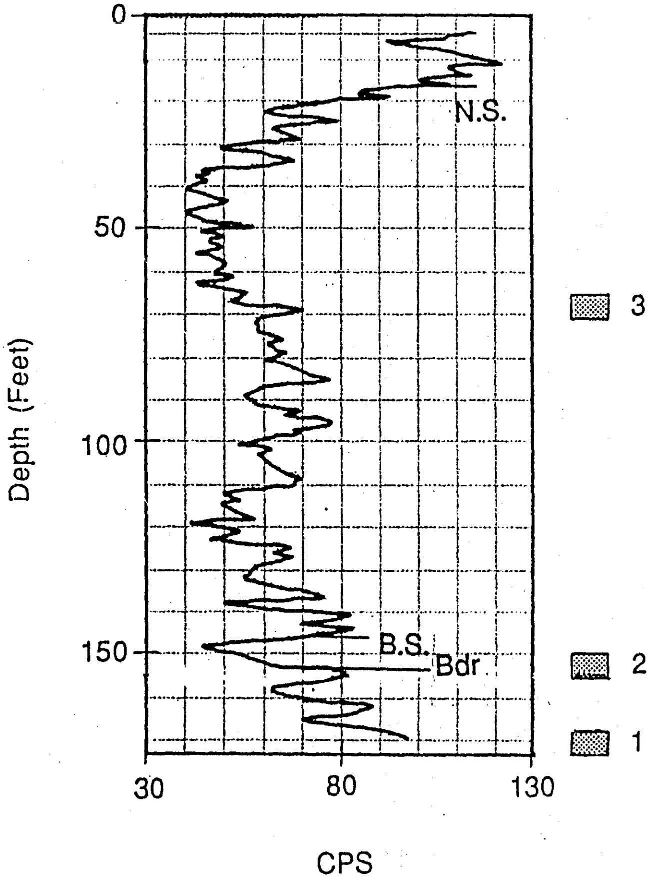
Well	1	2
Sp C	379	388
TDS	253	224



Site 35
Location: 26S 10W 31CCCB
County: Reno

Well	1	2	3
Sp C	21400	2670	440
TDS	13245	1476	276

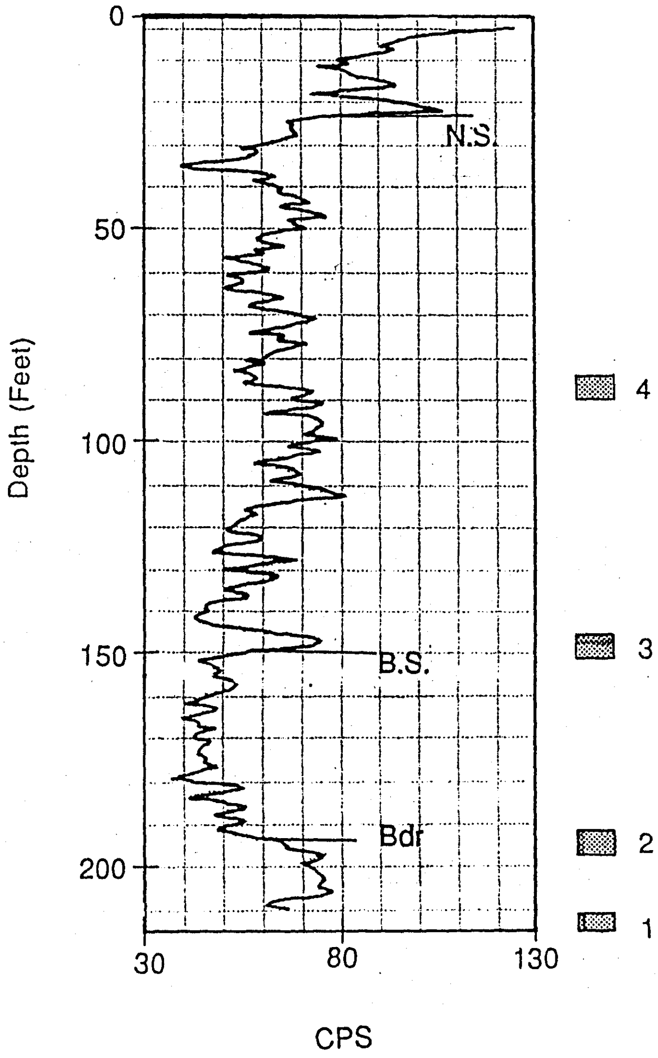
Natural Gamma Log
Ground Surface Elevation: 1760



Site 36
Location: 27S 12W 06BAAB
County: Pratt

Well	1	2	3
Sp C	56800	46600	921
TDS	40027	30754	508

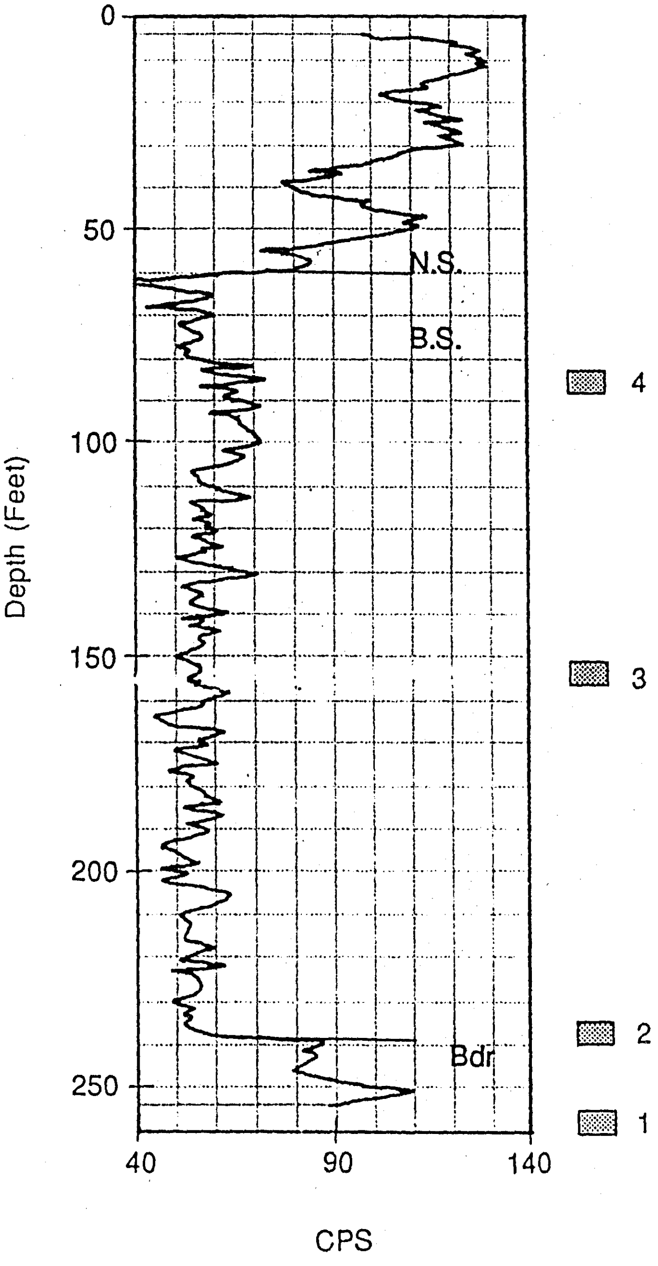
Natural Gamma Log
Ground Surface Elevation: 1892



Site 37
Location: 27S 13W 05CABB
County: Pratt

Well	1	2	3	4
Sp C	7700		385	411
TDS	4311		240	265

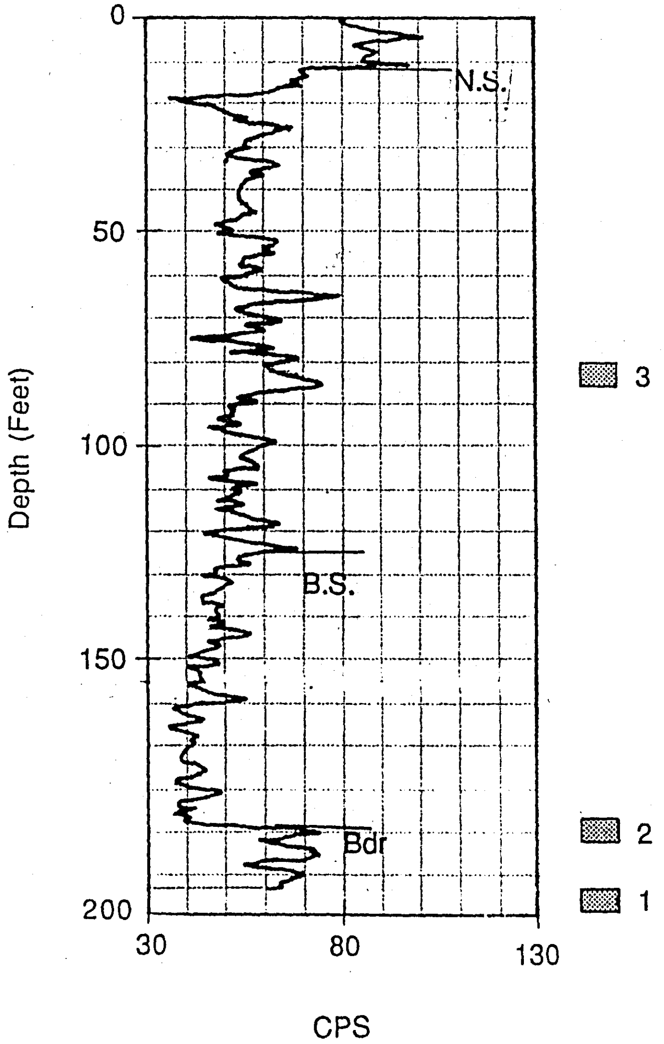
Natural Gamma Log
Ground Surface Elevation: 1971



Site 38
Location: 26S 12W 36ADDA
County: Pratt

Well	1	2	3
Sp C	6910	6620	335
TDS	3680	3556	219

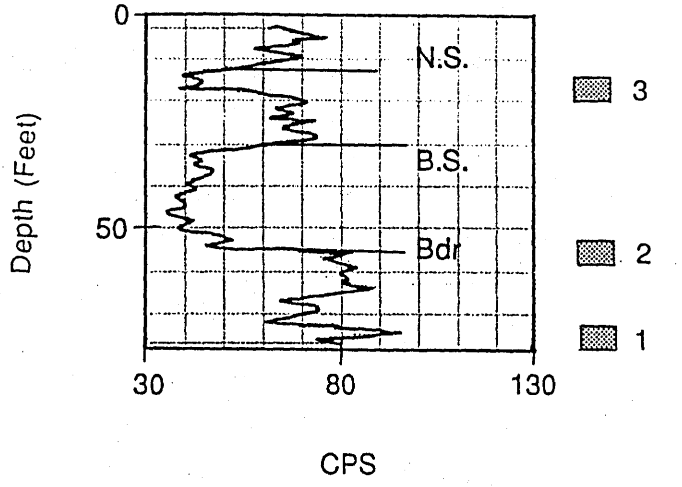
Natural Gamma Log
Ground Surface Elevation: 1844



Site 39
Location: 26S 10W 01AAAA
County: Reno

Well	1	2	3
Sp C	36300	930	710
TDS	23395	520	440

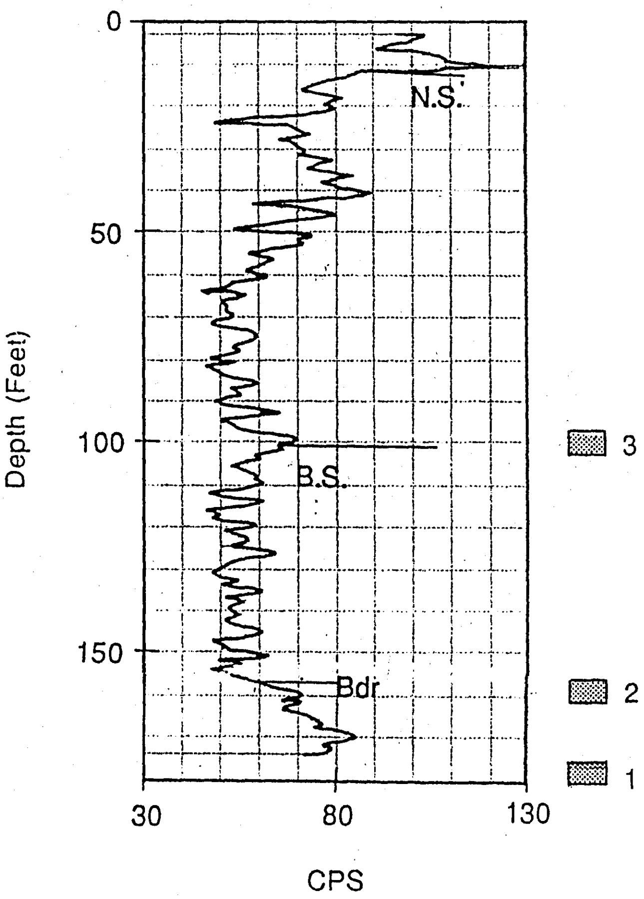
Natural Gamma Log
Ground Surface Elevation: 1679



Site 40
Location: 26S 09W 31CDDD
County: Reno

Well	1	2	3
Sp C	2720	1610	448
TDS	1498	850	284

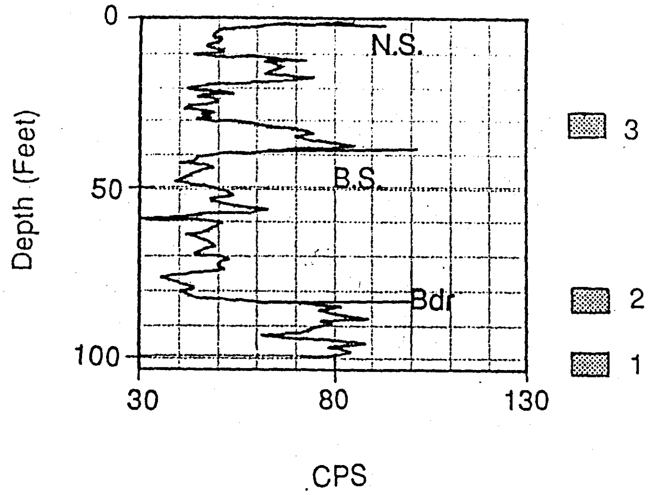
Natural Gamma Log
Ground Surface Elevation: 1735



Site 41
Location: 26S 09W 35ADAD
County: Reno

Well	1	2	3
Sp C	5460	879	328
TDS	3101	498	227

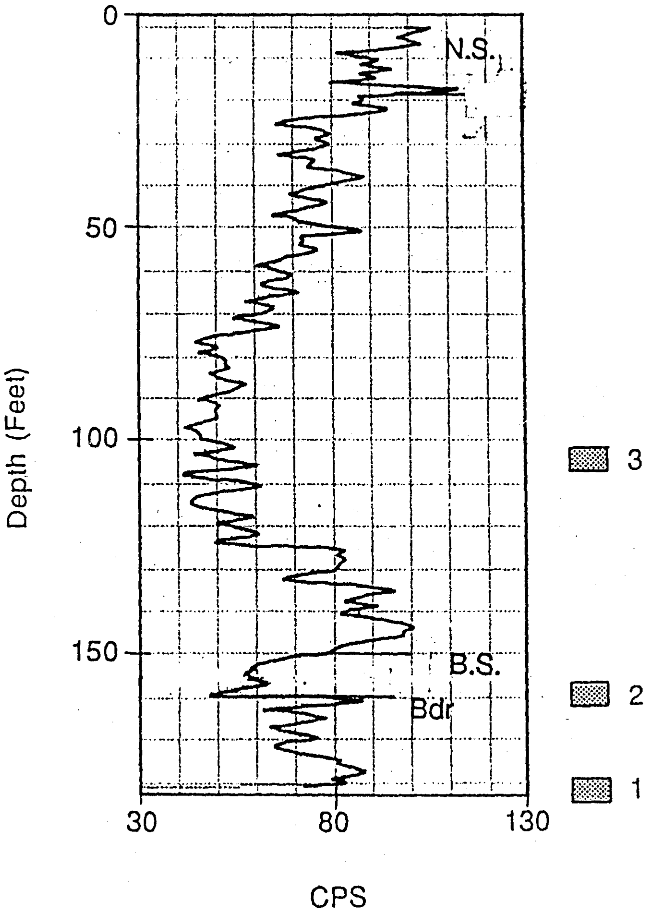
Natural Gamma Log
Ground Surface Elevation: 1654



Site 42
Location: 28S 13W 01CBAA
County: Pratt

Well	1	2	3
Sp C	15500	14200	650
TDS	9567	8745	387

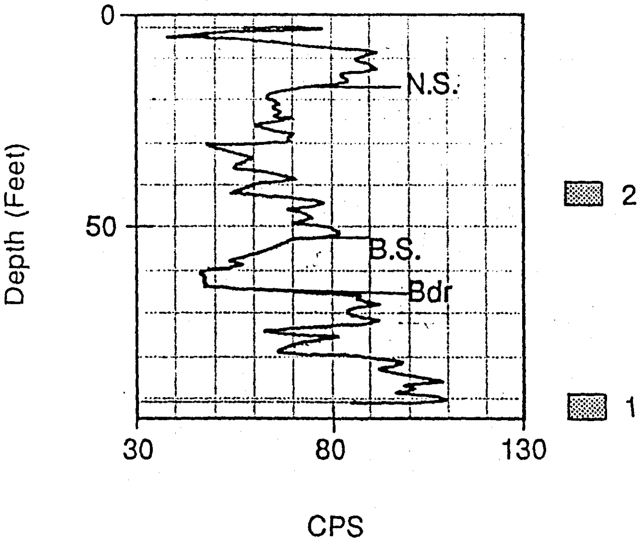
Natural Gamma Log
Ground Surface Elevation: 1829



Site 43
Location: 27S 13W 31DDDD
County: Pratt

Well	1	2
Sp C	7500	421
TDS	4146	265

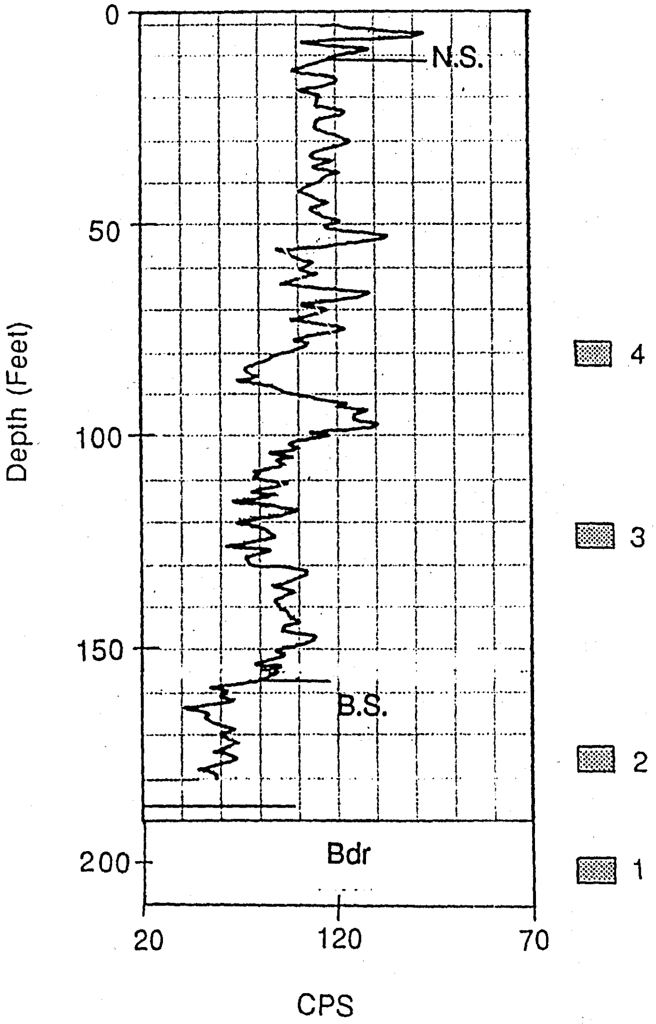
Natural Gamma Log
Ground Surface Elevation: 1872



Site 44
Location: 29S 13W 35ABBA
County: Pratt

Well	1	2	3
Sp C	238	400	374
TDS	155	242	222

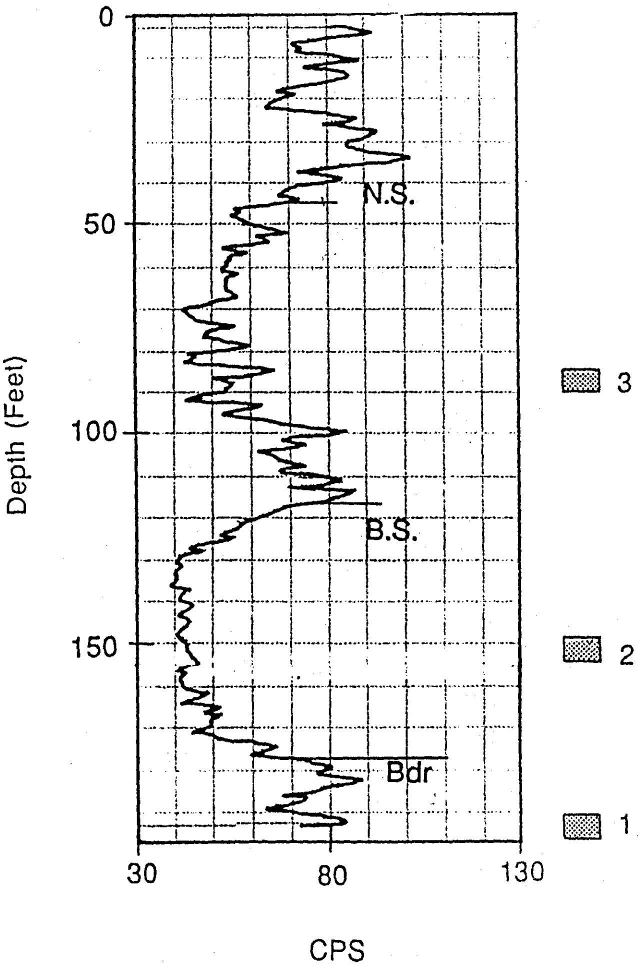
Natural Gamma Log
Ground Surface Elevation: 1891



Site 45
Location: 29S 11W 01DADA
County: Pratt

Well	1	2	3
Sp C	653	477	450
TDS	379	297	283

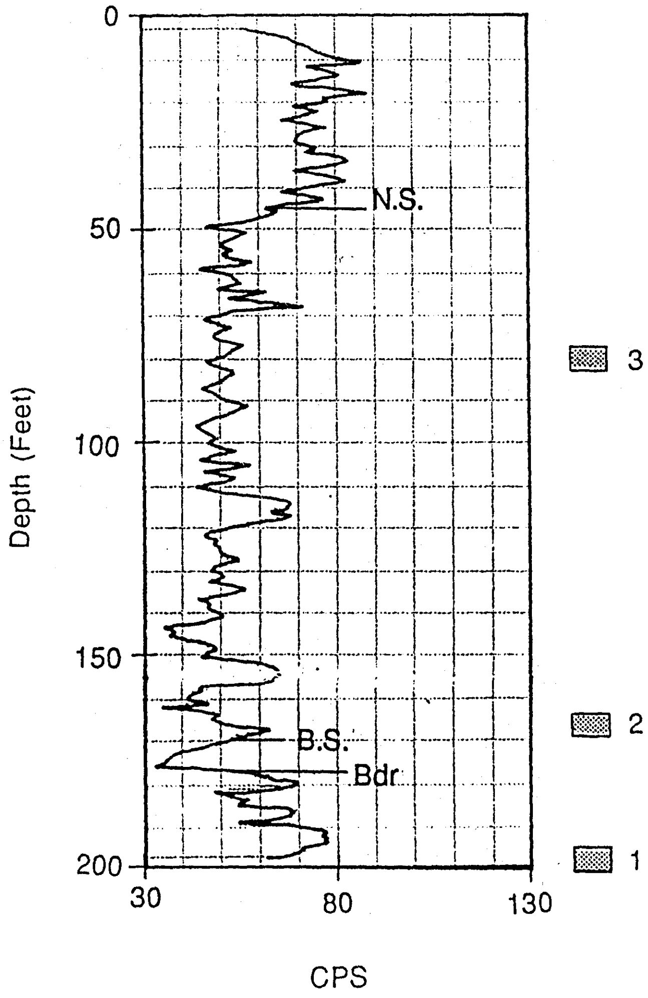
Natural Gamma Log
Ground Surface Elevation: 1795



Site 46
Location: 29S 11W 06AAAB
County: Pratt

Well	1	2	3
Sp C	1460	610	471
TDS	798	361	292

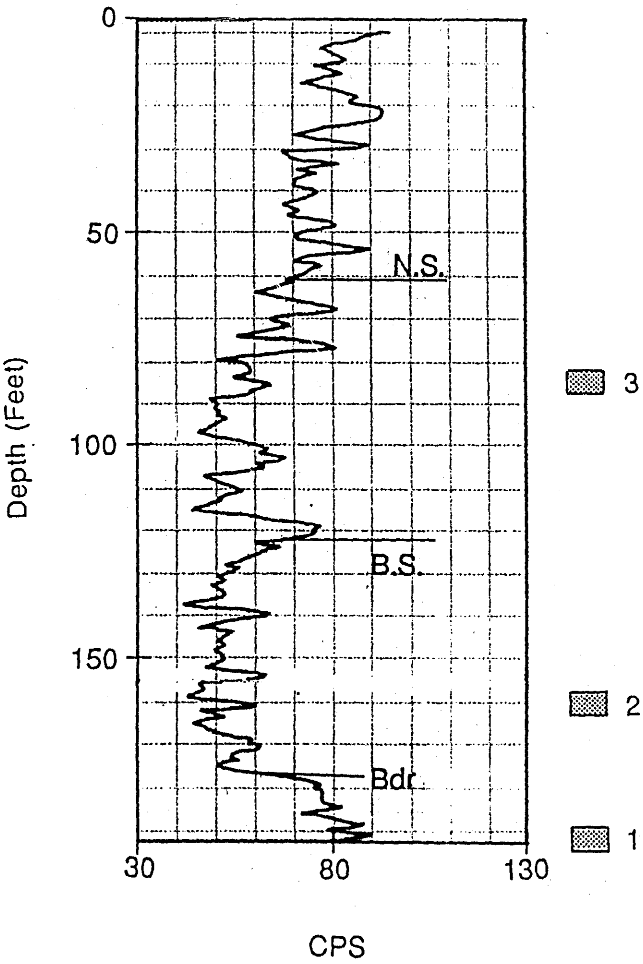
Natural Gamma Log
Ground Surface Elevation: 1830



Site 47
Location: 29S 13W 12ABBA
County: Pratt

Well	1	2	3
Sp C	510	470	409
TDS		292	257

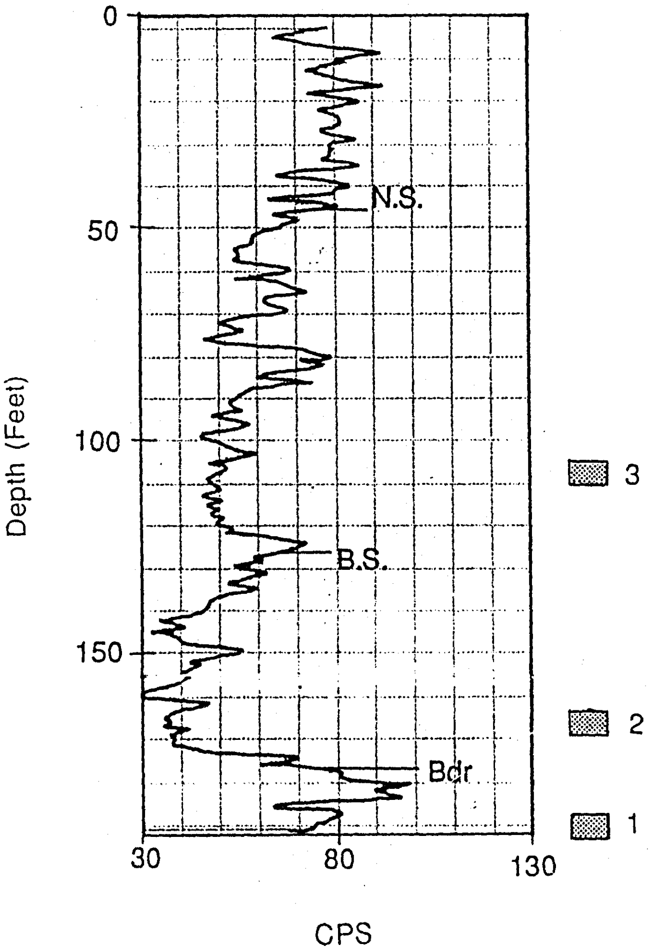
Natural Gamma Log
Ground Surface Elevation: 1900



Site 48
Location: 29S 12W 36DCCD
County: Pratt

Well	1	2	3
Sp C	384	374	361
TDS	246	239	259

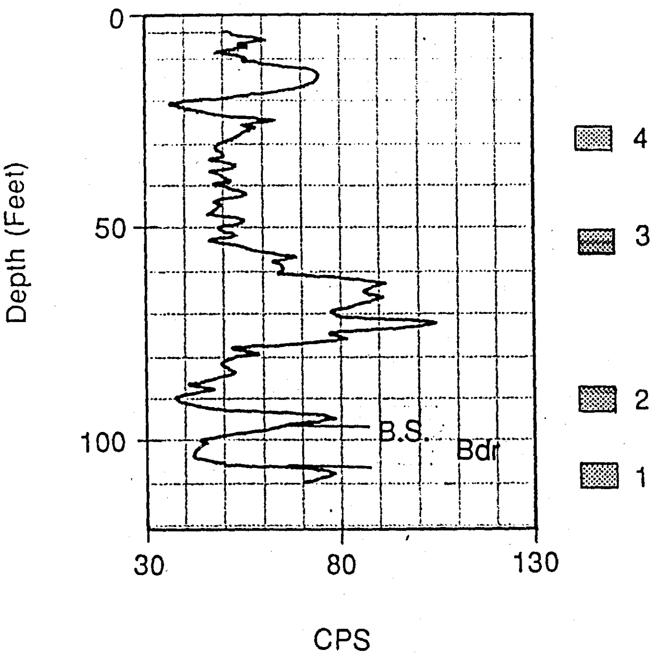
Natural Gamma Log
Ground Surface Elevation: 1842



Site 49
Location: 27S 12W 35AAAA
County: Pratt

Well	1	2	3
Sp C	84800	3830	519
TDS	60894	2098	299

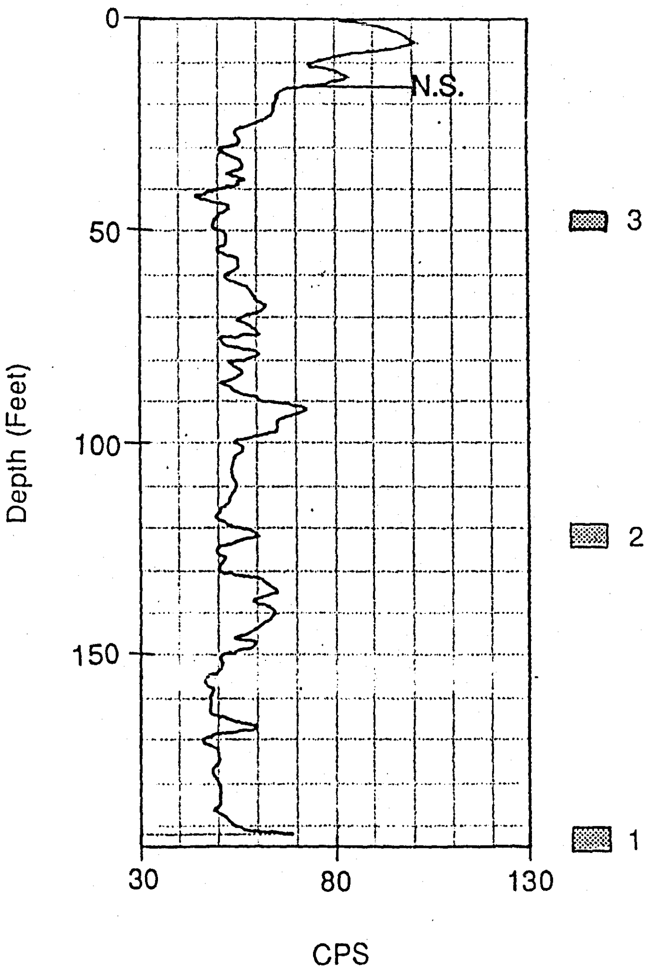
Natural Gamma Log
Ground Surface Elevation: 1737



Site 50
Location: 21S 13W 06BCCC
County: Stafford

Well	1	2	3
Sp C	1040	600	600
TDS			360

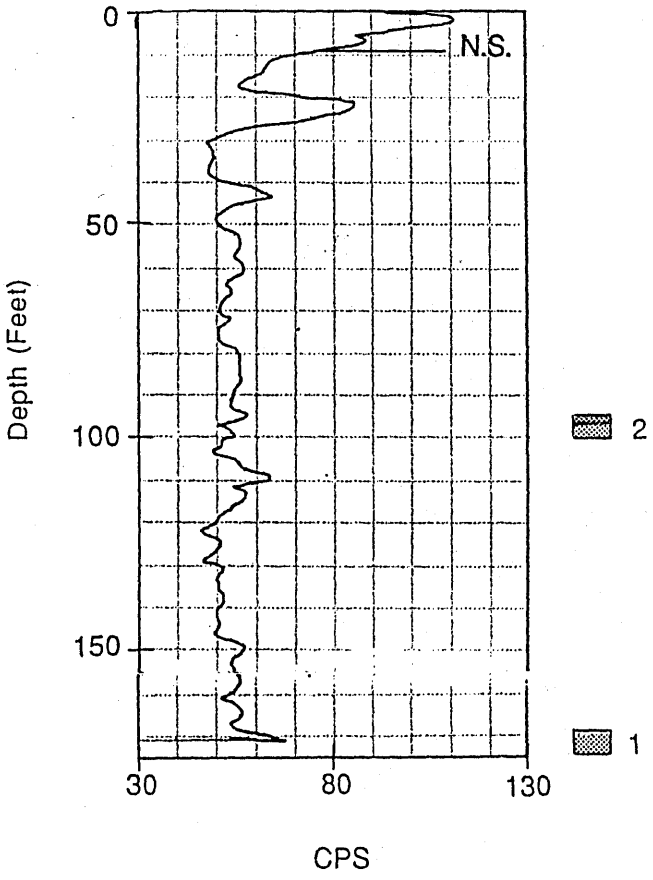
Natural Gamma Log
Ground Surface Elevation: 1912



Site 51
Location: 21S 14W 36DDDA
County: Stafford

Well	1	2
Sp C	4980	500
TDS	2813	303

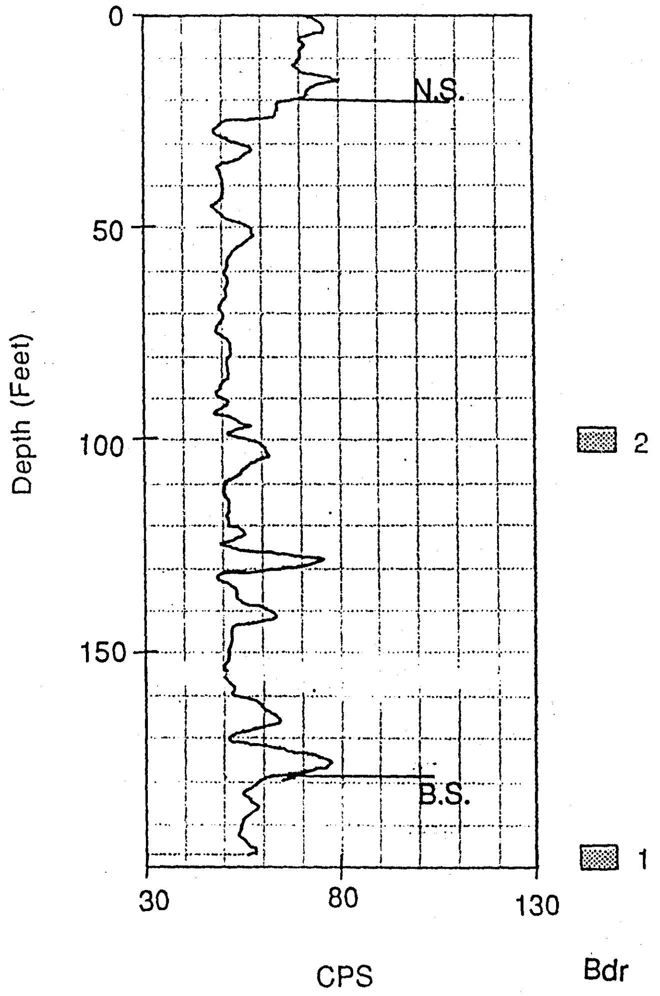
Natural Gamma Log
Ground Surface Elevation: 1915



Site 52
Location: 21S 13W 06BBBC
County: Stafford

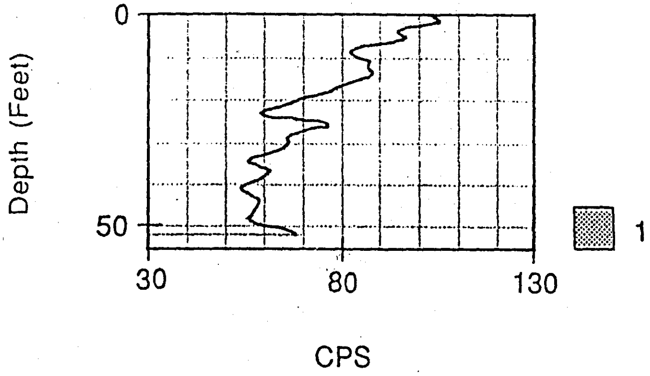
Well	1	2
Sp C	940	440
TDS	514	264

Natural Gamma Log
Ground Surface Elevation: 1920



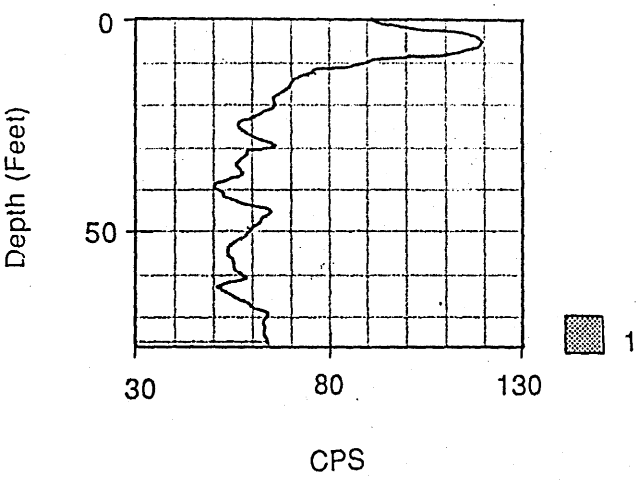
Site PN
Location: 23S 15W 14ABB
County: Pawnee

Natural Gamma Log
Ground Surface Elevation: 1994



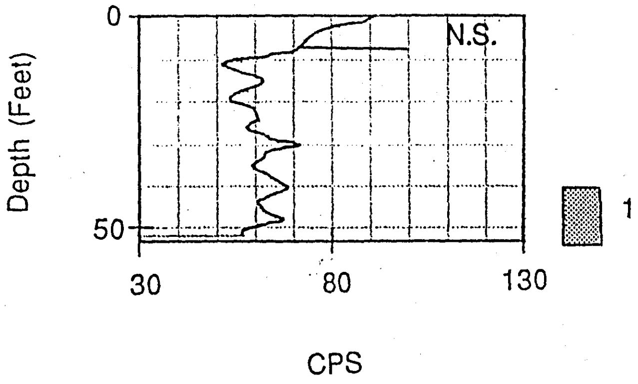
Site PR
Location: 26S 14W 11ADA
County: Pratt

Natural Gamma Log
Ground Surface Elevation: 1975



Site SF
Location: 23S 12W 36BBAC
County: Stafford

Natural Gamma Log
Ground Surface Elevation: 1847



APPENDIX II.

Well Numbering System

The well sites in this report are numbered according to the Bureau of Land Management system of land subdivision (Fig. 16). The first set of numbers gives the township. The second set of numbers indicates the range of east or west of the principal meridian. The third set of numbers gives the section. The 160 acre tract, 40 acre tract, and 10 acre tract are designated a, b, c, and d in a counterclockwise direction, beginning in the northeast quadrant.

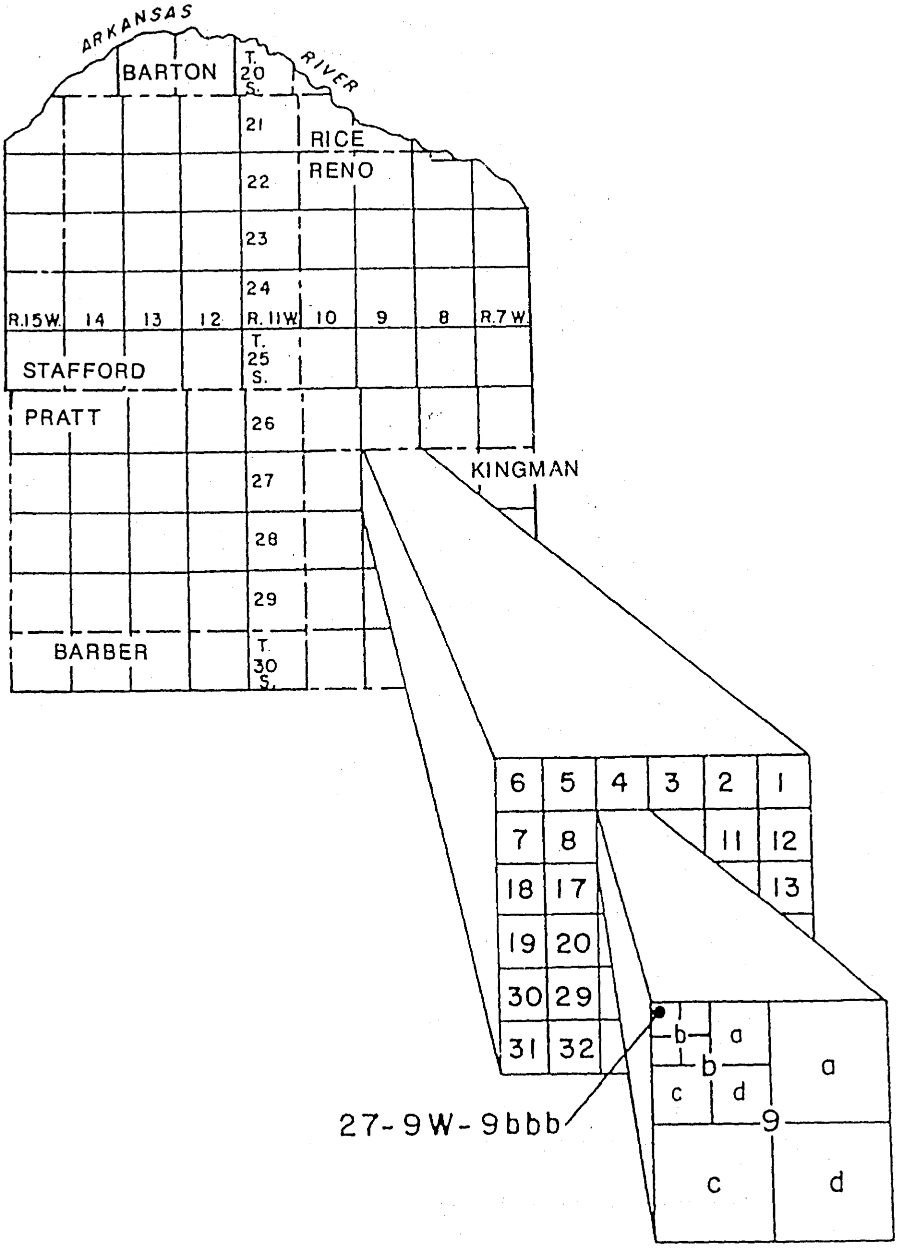


Figure 16. Bureau of Land Managements system of land subdivisions.

APPENDIX III.

Method of Grain Size Analysis

The grain-size distributions of the samples collected during the drilling of three wells to monitor natural recharge were determined using a hydrometer and sieves. The strata that was predominantly silt-clay was analyzed by hydrometer, and the sandy strata was sieved.

Hydrometer Analysis of Fine-grained Particles

Samples whose predominate grain size was less than 0.25 mm (fine sand) were analyzed using a hydrometer method. The hydrometer method of grain-size analysis is based on Stoke's law. Stokes law simply states that spheres of different sizes fall at different velocities in a fluid. It has been experimentally determined by Bouyoucos (1927) that sand-size particles settle out of a column of water within the first 40 seconds, the silt size portion settles out within 6 hours and 52 minutes, and the remaining fraction in the column is clay-size particles. As the particles settle out of the suspension the density of the remaining fluid decreases. The hydrometer measures the density of the suspension in grams per liter (g/L), which can then be mathematically correlated to percent of each grain size present in a sample.

Sample Preparation

Each sample was dried, then the large aggregates were ground using a mortar and pestle. Next, a carefully weighed 50 g sample was transferred into a 250 mL beaker, and 100 mL of 5% sodium hexametaphosphate (Calgon) was added as a dispersing agent. The contents were then mixed well and placed on a mechanical shaker overnight. This allowed the dispersant to mix well with all the particles in the sample and disaggregate the silt-clay particles. The next day the contents were quantitatively transferred to the dispersing cup of a milk-shake mixer and distilled water was added. This was then mixed for two minutes and then transferred quantitatively into a 1000 mL cylinder. The cylinder was filled to the 1000 mL mark with distilled water. The suspension was mixed well with a plunger until uniform. Forty seconds after the plunger was removed the hydrometer was read. The hydrometer was again read approximately six hours after the initial reading.

A blank with 100 mL of Calgon and 880 mL of distilled water in a 1000 mL cylinder was run to correct for the effects of temperature and density of the dispersing solution.

The temperature of the solution was recorded and 0.36 units were added for every degree above 20^{o} C.

Calculations

The percent sand, silt, and clay were calculated using the following formulas:

(1). %clay = corrected hydrometer reading at 6 hrs x 100/wt of sample

(2). %silt = corrected hydrometer reading at 40 sec x (100/50g) -%clay

(3). %sand = 100 - %silt - %clay

Sieve Analysis of Coarse-Grained Particles

The samples with a predominate grain size coarser than 0.0625 mm were sieved following the procedure outlined by Folk (1980). The samples were disaggregated by careful grinding with a mortar and pestle. A 100 g of each sample was sieved for 15 minutes. A Ro-Tap machine was used to keep the shaking constant. The sieve screen sizes were chosen to separate the different grain sizes according to Wentworths size class (Wentworth, 1922). A one phi (phi = -log2 (diameter in mm)) interval was used to determine a general trend for the sediments. The screen size went from -1.25 phi (2.38 mm, granule gravel) to 4. phi (0.0625 mm, very fine sand) with a one phi interval. The pan, therefore, contained any silt-clay particles.

There was concern about the accuracy of using well cutting samples for grain-size analysis. The possibility of uphole contamination and the presence of drilling mud could invalidate the grain-size analysis. An attempt was made to minimize this problem by picking out the cuttings that were definitely uphole contamination and careful washing to remove the drilling mud and not remove the silt-clay portion. To further check the size analysis, the cumulative percent was calculated and graphed. If the samples were not representative of the changing lithologies then the statistics would indicate that by showing no trends. In addition, the grain-size analysis would not match the gamma logs. The grain-size analysis did match the logs, and there were trends in the median grain size typical of a fluvial depositional environment.

APPENDIX IV

Gamma Log Analysis

Natural gamma-ray logs measure the amount of gamma radiation emitted by all the sediments in the samples being tested. Silt-clay (shale) has a medium to high intensity of radioactivity and sand (sandstone) or limestone (caliche) have a low radioactive intensity. Therefore, the lower gamma-ray intensities represent lithologies containing very little silt-clay. This allows gamma logs to be used to differentiate strata that have a high silt-clay content from strata that have a low silt-clay content. The percentage silt-clay in the strata can then be related to effective porosity/permeability. Strata that have a high silt-clay percentage have a low effective porosity/permeability when compared to the total porosity (Keys, 1968). The effective porosity/permeability of strata influences the direction of groundwater flow, hydraulic conductivity, and transmissivity. Therefore, the lithology and effective permeability can be indirectly determined from gamma logs. These parameters are important for determining the movement of saline water or a contaminant plume.

Gamma logs can be important in hydrogeologic studies involving unconsolidated sediments where the wells are cased because they can be made in a cased or uncased well and provide the best method to obtain lithologic information. Information that can be provided from a gamma log are (1) depth and stratigraphy of beds drilled through, (2) lateral correlation of stratigraphy from well to well, and (3) selection of the most favorable interval for screening a well to give the highest yield (Norris, 1972).

In the past, interpretation of gamma logs has been more of an art than a science (Keys and MacCary, 1985). Log interpretation has been based on knowledge of the local geology, drillers logs, and sample cuttings. The empirical log interpretation method relied upon the drawing of a "shale baseline" (Doveton, 1986). This baseline was drawn at the best estimate for a "normal shale" reading. The term "normal shale" is used here in contrast to a uranium-rich "hot shale". In addition, a "clean formation line" was drawn roughly coincident with the lowest reading that occured in the clean units of interest. As a result, log analysis has been empirically qualitative. Numerous studies have examined log shapes and correlated them with grain-size and facies changes (Rider, 1986). Serra and Sulpice (1975) examined gamma log shapes and grain size curve relationships in a fluvial point bar sequence (Figure 17). Their results showed a close relationship between grain size and the gamma-ray log. A decrease in grain size correlated with an increase in the gamma log response. In a fluvial

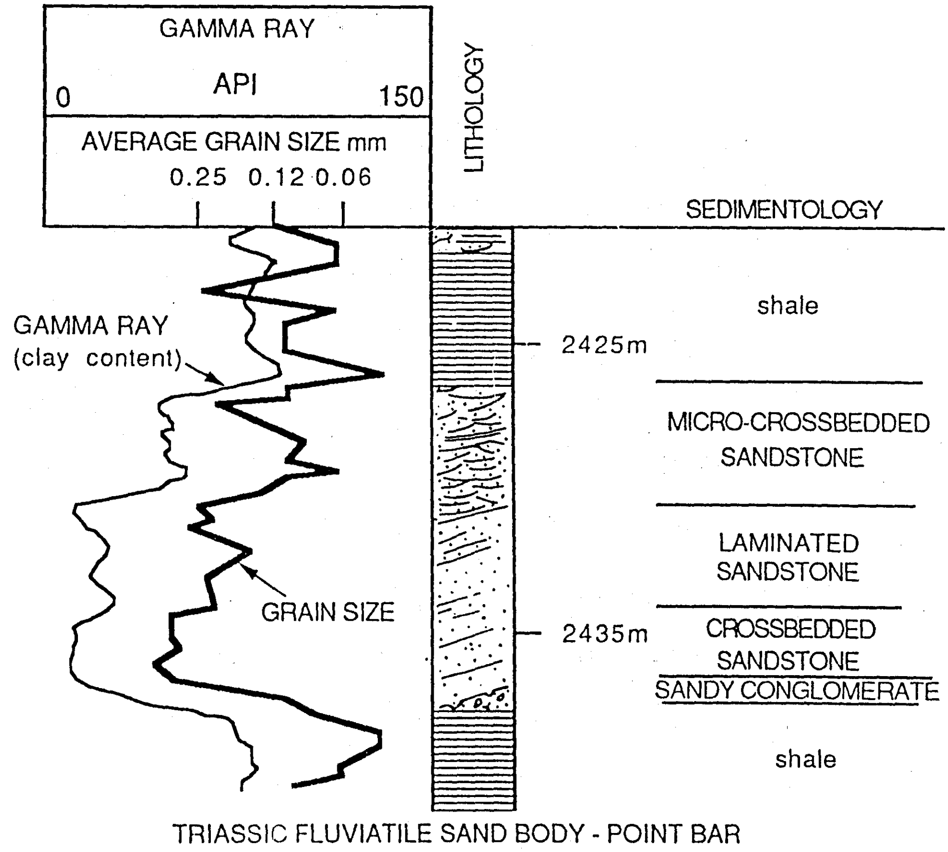


Figure 17. Correlation of a grain size curve to a gamma-ray curve (from Serra and Sulpice, 1975).

system, a fining upward sequence would be represented by a bell-shaped gamma log curve. This indicates that there is a correlation between facies and log shapes. A quantitative approach to log analysis has never been fully applied because natural gamma-ray response is not unique. Specific values of natural gamma ray intensity do not necessarily apply to individual beds or geologic units over a large area (Norris, 1972). However, the emission of natural gamma rays is a stochastic process, and radiation counts are a statistical quantity (Doveton, 1986). Since stochastic processes and statistics are involved, it leads one to consider what would happen if certain variables are kept constant? Can enough limitations be placed on the variables that would allow a quantitative interpretation to be applied? What would happen if samples were taken and analyzed in terms of grain size (sand vs. silt-clay), and then those values used to determine the "clean formation" line and "normal shale" line? This part of the study tried to answer the previous questions. It was found that grain size analysis can be applied to gamma logs if properly confined within certain valid assumptions. If the assumptions prove to not be valid or are not constant, then this approach will not work. For each area that this method is applied to, the assumptions and constants must be re-evaluated, and the grain-size to natural gamma log correlation must be re-done. This procedure needs to be repeated at different areas and tested to see if it will work outside of this particular study area. The assumptions used for this study were the following:

1. The radioactive elements are contained in the silt-clay size portion of the alluvium. Thorium-bearing minerals concentrate in the silty fraction of a shale, and uranium is fixed by absorption upon clays (Serra et al. 1980).

2. The radioactive element potassium, which is in feldspar, also needs to be accounted for. In all the samples examined the feldspar percent was relatively constant. This indicates that the potassium effect is uniform throughout the study area, and permitted the potassium radiation to be considered as a constant.

3. The silt-clays have a relatively similar radioactive count, due to similar origin, source, and depositional environment.

4. Limestone and sand have approximately the same low gamma ray response, and are difficult to tell apart if they occur together in the same log. In this study area there are no limestone beds present. Therefore, any low gamma-ray response is due to sand, gravel, and caliche.

5. The depositional environment is all non-marine and predominately fluvial. There are no limestone beds

present in the study area. Limestones and sand have the approximately the same low gamma ray response, and are difficult to tell apart if they occur together in the same log.

6. Beds with a thickness of less than twice the radius of investigation will not be recorded at the full cps. Because most of the radiation originates within a radial distance of about 1 foot (0.3 meters) from the well (Keys and MacCary, 1985). This means that a silt-clay lens with a thickness of 2 feet (0.6 meters) or less will probably not be recorded at the full counts per second (cps). In this area, a silt-clay that is 2 feet (0.6 meters) thick or less will not be continuous over enough of an area to significantly effect the regional ground-water flow.

7. Casing will shift or suppress the log response (Keys and MacCary, 1985). Therefore, it is important that all the wells are cased with the same type and thickness of pipe. All the wells in this study were cased with 5 inch (12.7 centimeter) pvc pipe.

8. Any changes in bore-hole diameter, gravel pack, grout, and drilling mud may cause a shift in the cps recording. Therefore, with proper drilling and completion methods these may be considered to be constant. These were not constant during the drilling life of the project and did influence the natural gamma

response.

The gamma logger used for this project was a Mount Sopris, model 2 (McCullough, personal communication, 1987). It has a scintillation crystal used with a photoelectric tube that emits light when struck by a gamma photon. The light is amplified by a photomultiplier and converted into electrical pulses. The frequency of the pulses is a measure of the radiation intensity (Norris, 1972). The detector is contained in a watertight probe that was lowered into the borehole on the end of a 2-conductor cable. The signal from the probe is recorded at the surface in terms of depth by a strip-chart recorder which is mechanically connected to the reel that the logging cable is wound on. The distance the pen moves across the recorder chart for a given radiation intensity is controlled by the size of the scintillation crystal. A time constant circuit averages the random pulses from the natural gamma radiation over a given time interval, which smoothes the input signal. A short time constant gives a quick instrument response and allows a relatively fast logging speed and detection of relatively thin beds. The drawback with a short time constant is it may produce a ragged appearing log that is difficult to interpret. A longer time constant requires a slower logging speed and results in a relatively smooth log. The best time constant and logging speed that gives the desired information must be determined for a particular study area. In this study, each well was logged using 2 sec for the time constant (total count) with an uphole speed of 10 ft/min (3 meters), with cps and depth recorded on the gamma log.

The lithologic variability in the study area was compensated for by obtaining well cuttings from Pratt, Pawnee, and Stafford Counties. This gave a broad sampling of lithologies in the study area. Well cuttings were collected approximately every 2 feet (0.3 meters), rinsed well, and as much uphole contamination as possible was removed. Next, hydrometer and sieve grain size analysis were run on the well cutting. The finer samples were analyzed using the hydrometer method described by Bouyoucos (1927), and the larger grained samples were analyzed by the sieve method outlined by Folk (1980).

The Pawnee and Pratt County wells were used to get a range of cps that correlated to a range of grain size (Figure 18 and 19). These ranges were then tested on the Stafford Co. well log (Figure 20). If the cps vs grain size ranges were too small, then the grain size values would occur outside of the cps ranges. If the cps ranges were too large, then the grain size ranges would overlap. The silt to clay ratio, and silt-clay bed thickness affected the cps. A higher percentage of silt resulted in a lower cps. This is shown in the Pratt well at 30

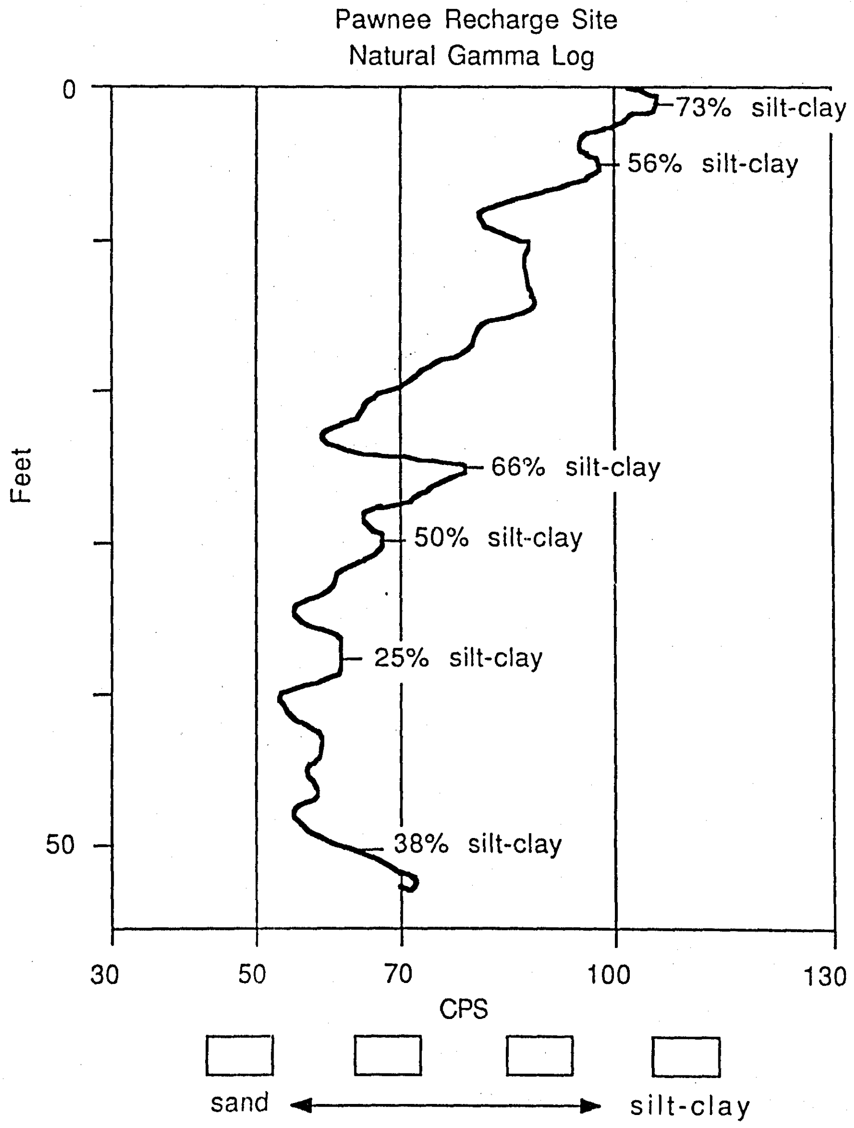


Figure 18. Pawnee recharge site natural gamma log.

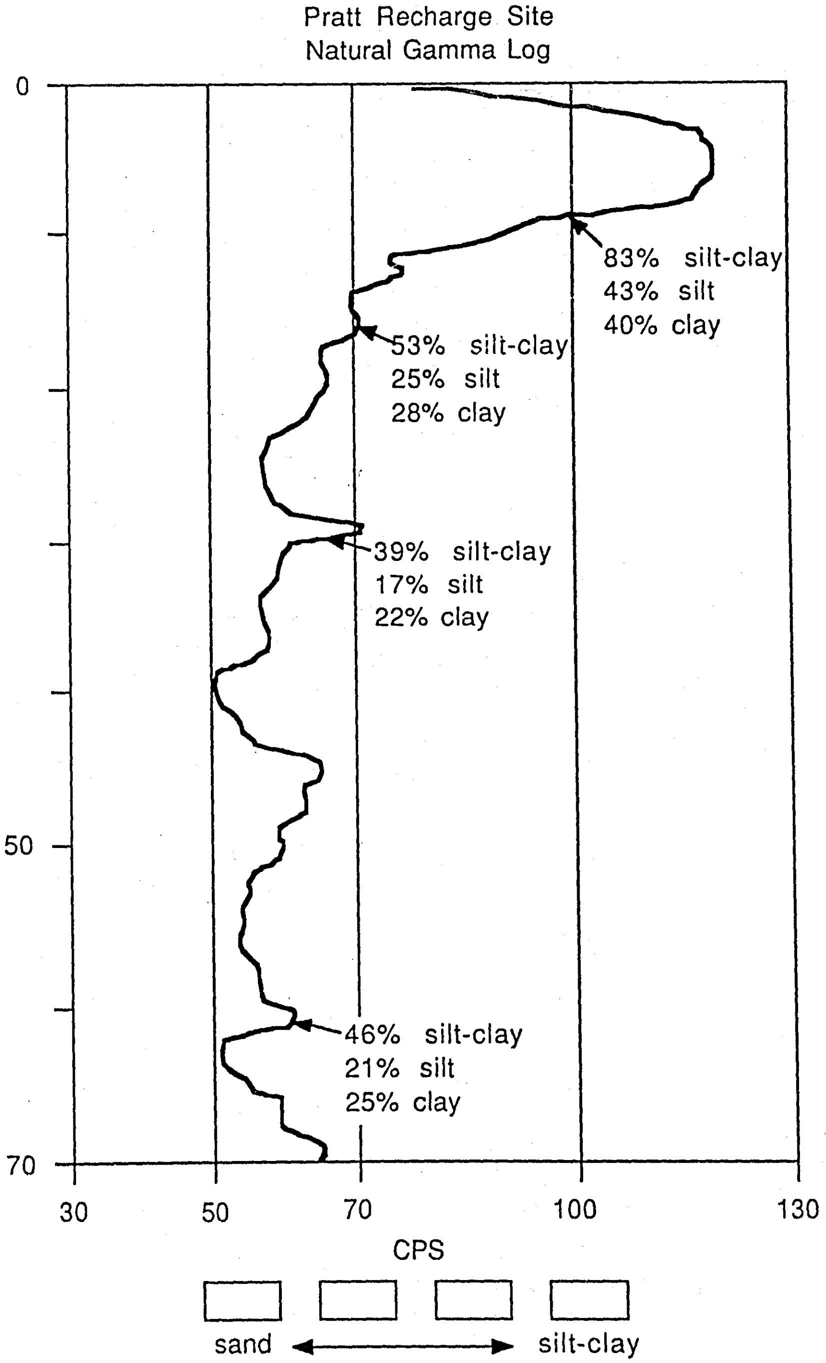

Pratt Recharge Site
Natural Gamma Log

Figure 19. Pratt recharge site natural gamma log.

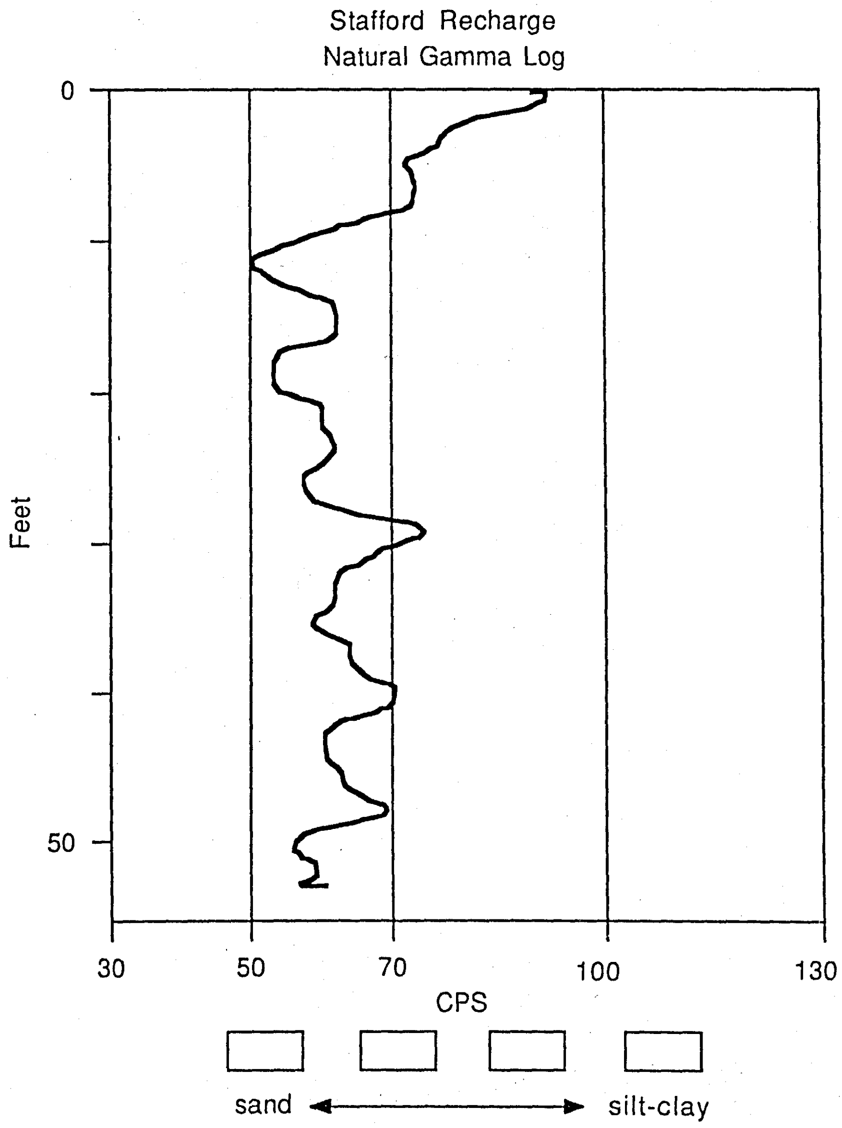


Figure 20. Stafford recharge site natural gamma log.

and 60 feet (18 meters). The silt-clay at 30 feet (9 meters) has a higher cps recording and a lower silt-clay percent than the silt-clay at 60 feet (18 meters). The Pawnee well has a silt-clay bed at 30 feet (9 meters) that shows a silt-clay that did not record at its full cps. Because the silt-clay is two feet or less in thickness. It is interesting to note that the Stafford Co. well was drilled very slowly and the sediments were extremely permeable. The slow drilling speed could have allowed drilling mud to permeate into the surround sand. The drilling mud in the permeable sand could shift the sandy portion of the log to the right. The correlation of cps to percent silt-clay is given in Table 13.

Table 13. The relationship of cps to percent silt-clay for this study.

Counts-per-second (cps)	% Silt-Clay
0 - 50	0 - 20 (sand)
50 - 70	20 - 50 (muddy sand)
70 - 100	50 - 70 (sandy mud)
< 100	70 - 100 (mud)

The cps and grain-size percent were then correlated to a lithologic tetrahedron (Figure 21). The shaded areas represent the different lithologies that can be determined from the natural gamma log. The tetrahedron shows that the natural gamma log can give the percent silt-clay present, but not the size of the sand or gravel. To obtain a more accurate interpretation, the

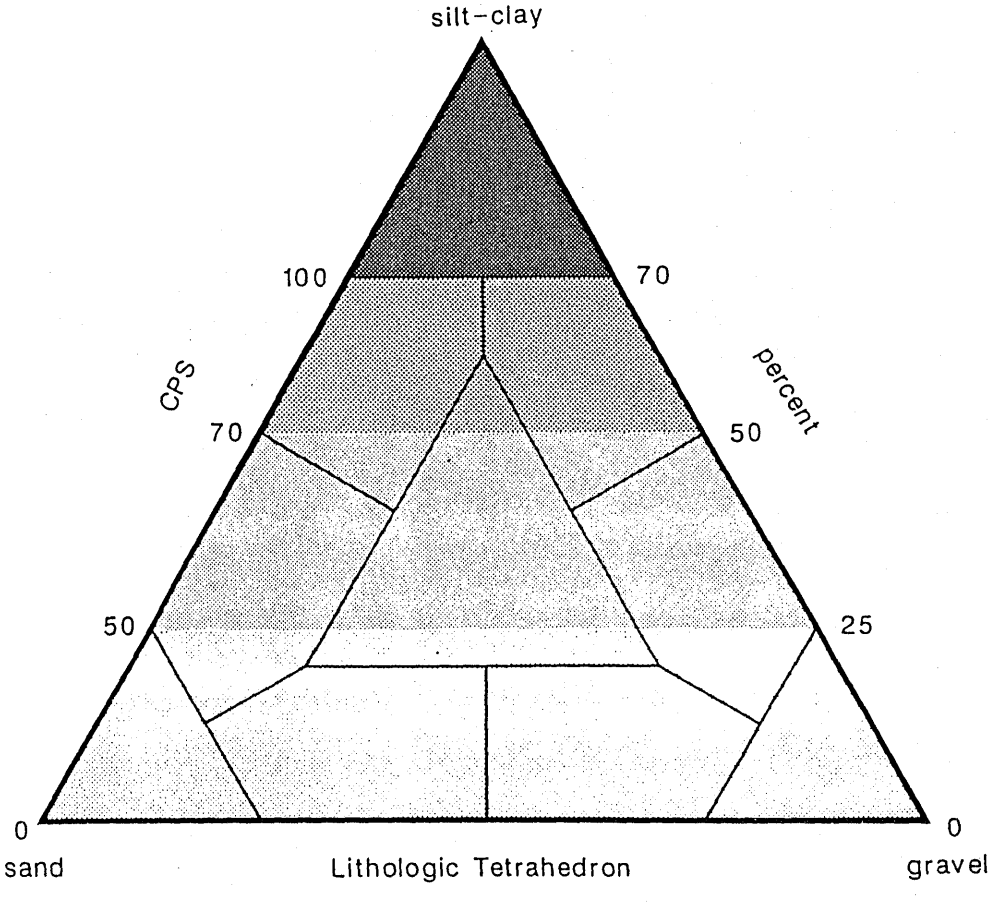


Figure 21. Lithologic tetrahedron

natural gamma log must be used in conjunction with the geologic log. The geologic log will provide the sand and gravel percentages, and allows the tetrahedron to be used to determine the facies classes. A tetrahedron with gravel, sand, and silt-clay ratio planes was used to classify the facies classes. This allowed each lithology to be defined by a range of cps that could be interpreted from the natural gamma logs of the 52 observation wells. This resulted in a better interpretation of the lithology from natural gamma logs and a better understanding of the stratigraphy.

The areas on the tetrahedron represent certain facies populations which correlate with mapping units (Krumbein, 1954). The advantages of using a tetrahedron are (1) there is one large central area which describes the uniform mixture of the three grades of sediments, and (2) each lithology could be defined by a range of cps, that could be interpreted for the other natural gamma logs. In this study the silt- and clay-size particles were classified together. Sand-, and gravel-size particles were added as the other end members. Silt and clay were combined because (1) the silt-clay fraction contains radioactive elements that are measured by the natural gamma logger, making it difficult to separate the silt and clay grain size fractions in gamma logs, (2) both are deposited together in the fluvial environment,

(3) the strata has lower permeability when they are the predominant grain-size. The silt-clay boundary was put at 70 % because at this percentage silt-clay could be correlated to a cps on the gamma log. The most permeable sediments contain from 0 to 30% silt-clay.

APPENDIX V

Grain Size Analysis Results

Site PR, Pratt Co., hydrometer results

Sample depth (feet)		% Sand	% Silt	% Clay	% Silt-clay
11	*XRD	17	43	40	83
17	*XRD	46	25	28	53
19		48	24	28	52
24	*XRD	60	14	26	40
31		61	17	22	39
33		39	32	29	61
35		48	26	26	52
40		52	26	22	48
42		55	23	22	45
44		56	20	24	44
46		57	19	24	43
48		57	17	26	43
49		56	20	24	44
50		60	14	26	40
52		46	28	26	52
58		54	21	25	46
63	(from sieve analysis)				31
65	" " "				20
68	" " "				22
72	" " "				04
75	" " "				00
79	" " "				01
80	" " "				01

* These samples were x-ray diffracted.

Site PN. Pawnee Co. hydrometer

Sample depth (feet)	% Sand	% Silt	% Clay	% Silt-clay
3.5 *XRD	27	42	31	73
7.5 *XRD	43	29	28	57
8	51	24	25	49
12.5	56	20	24	44
27 *XRD	34	40	26	66
29	51	26	24	50
31	47	29	25	54
32	50	27	23	50
37	55	24	21	45
39	58	22	20	42
41 *XRD	74	12	14	26
43	68	16	16	32
46	57	25	18	43
50	62	19	18	38
53 (from sieve analysis)				06
55 (from sieve analysis)				06
56	44	19	37	56
59	29	33	38	71
85	20	47	33	80

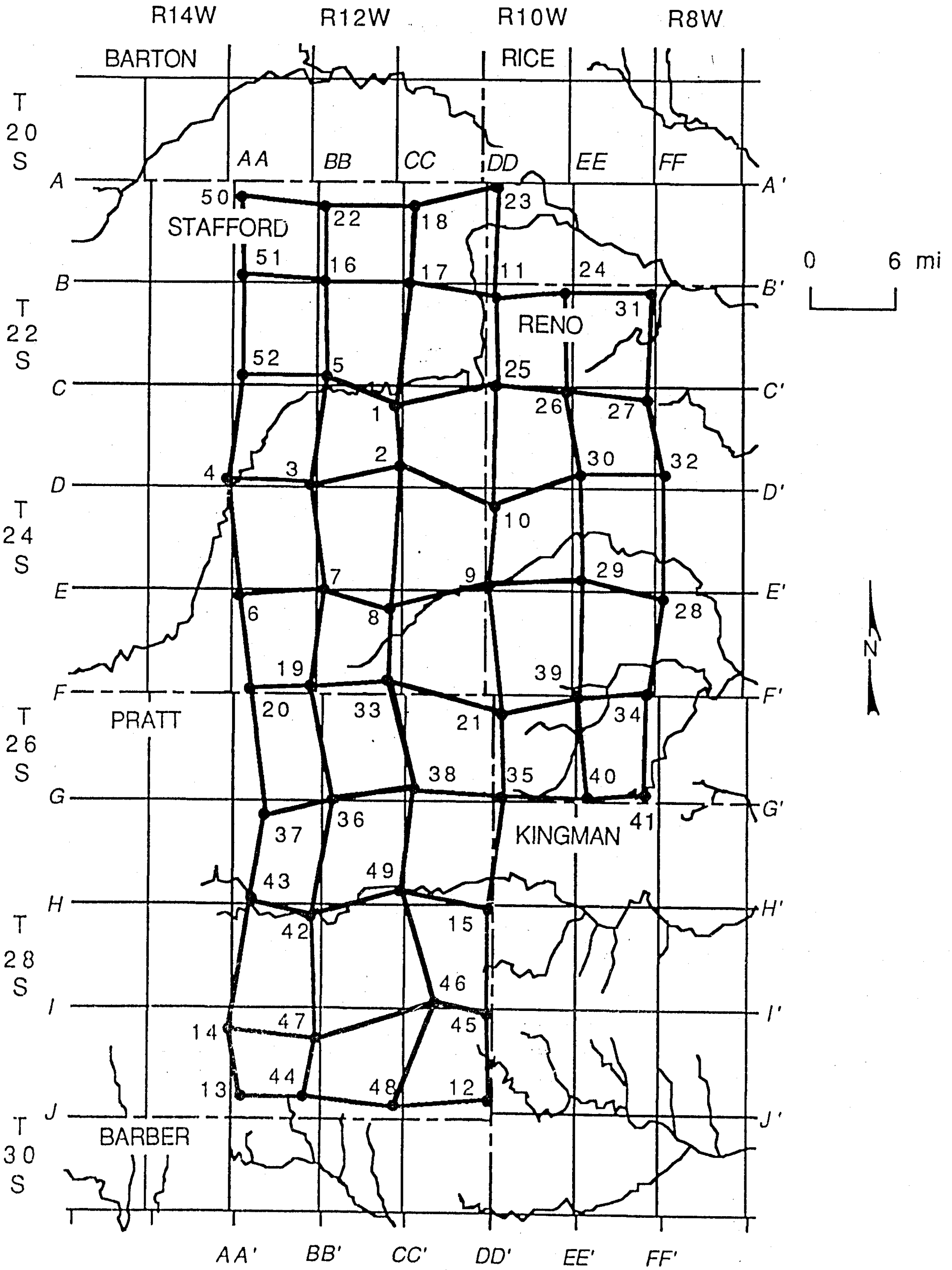
Site SF. Stafford Co.
Silt-clay percent from grain size analysis

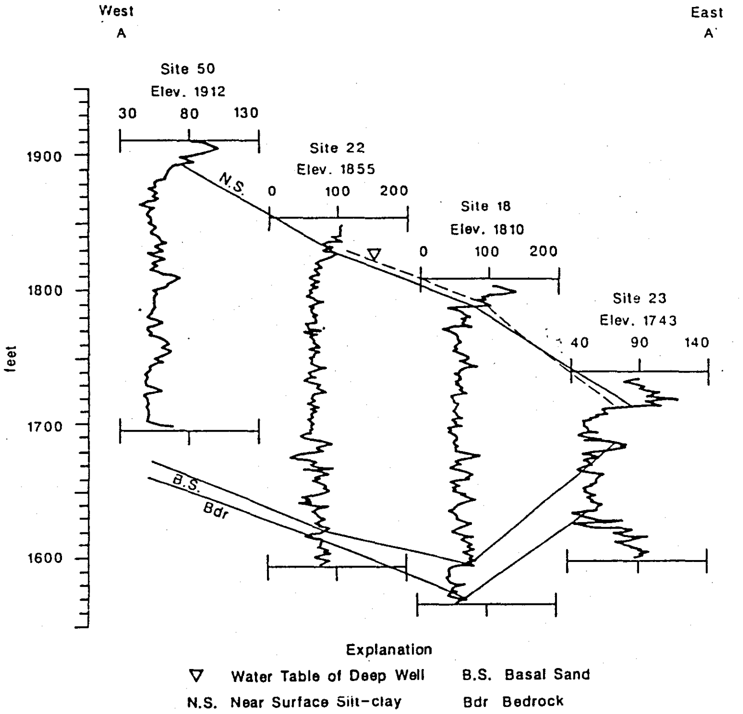
Sample depth (feet)	% Sand	% Silt-Clay
6	97	3
9	94	6
10	95	5
12	94	6
15	94	6
18	96	4
20	97	3
23	94	6
30	97	3
32	99	1
34	99	1
35	99	1
37	99	1
38	99	1
39	99	1

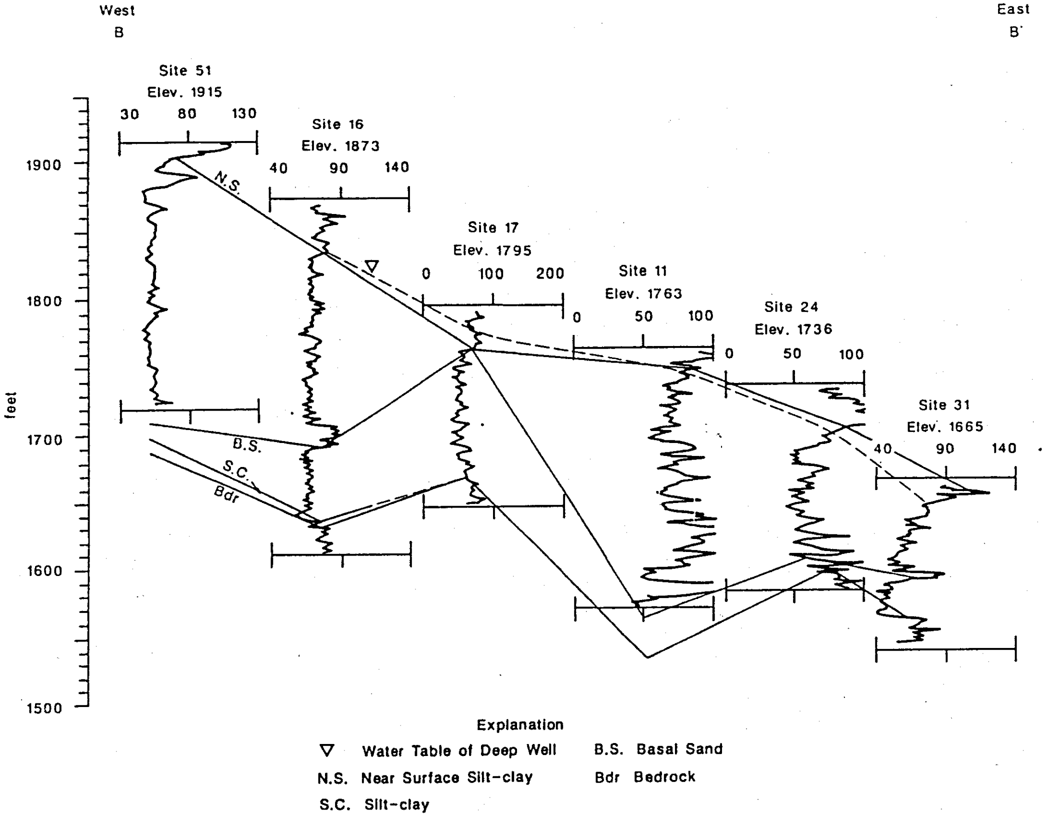
40	99	1
41	99	1
46	99	1
50	99	1
61	99	1

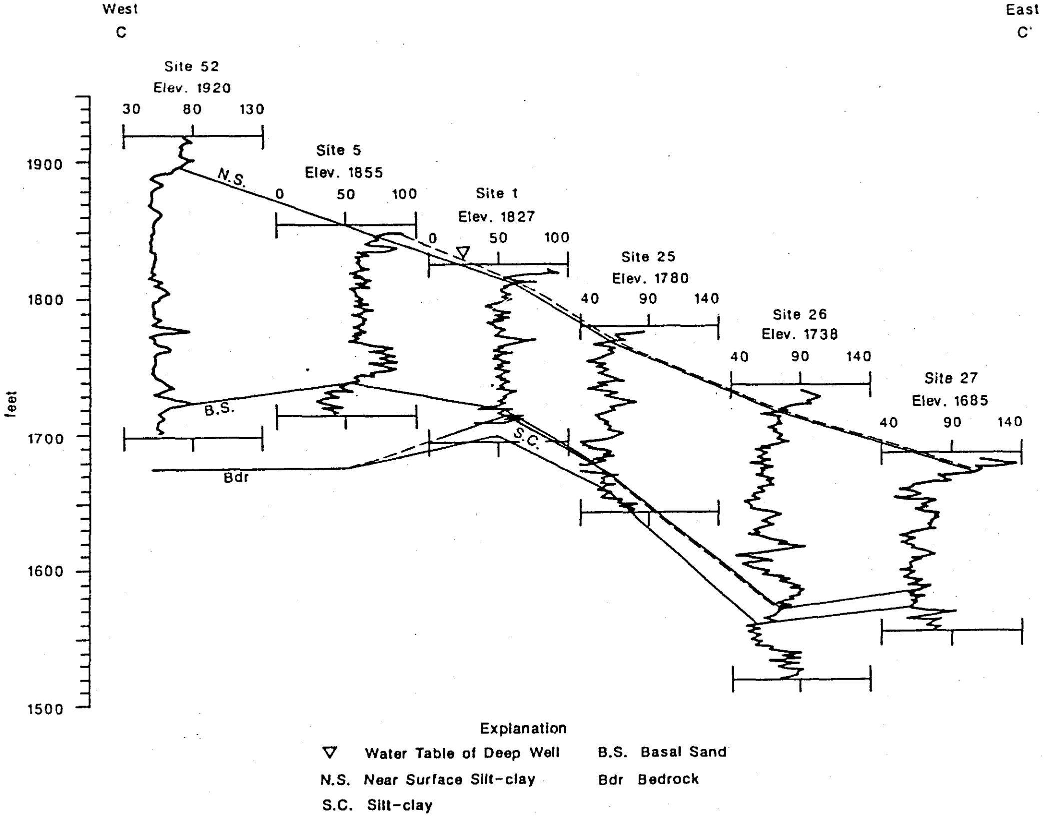
APPENDIX VI

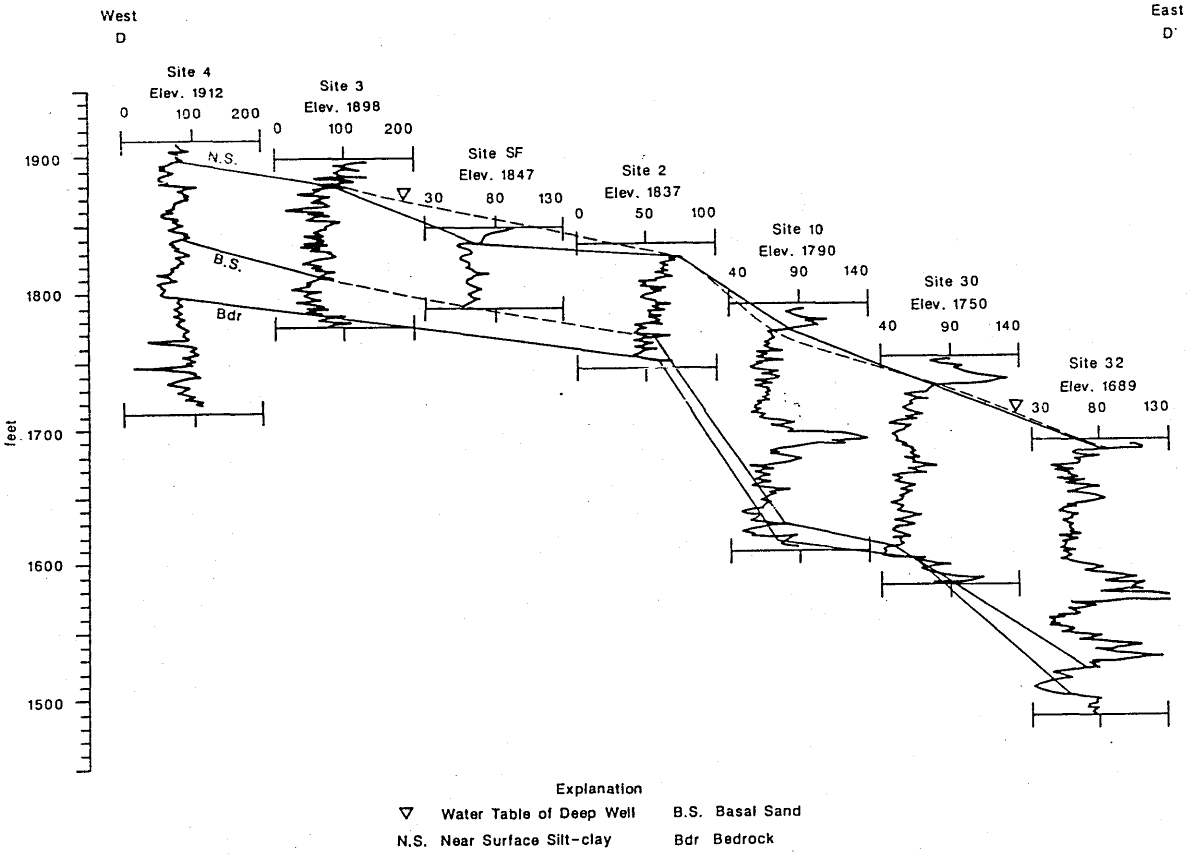
Observation Well Cross Sections

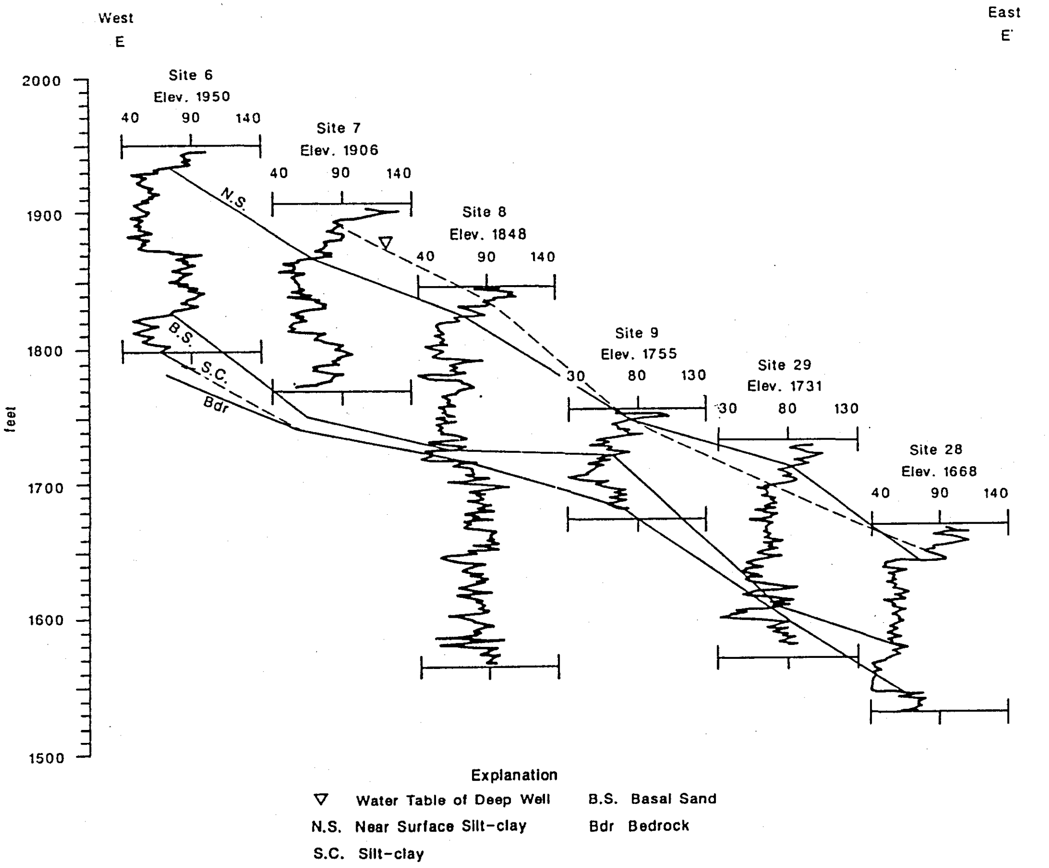


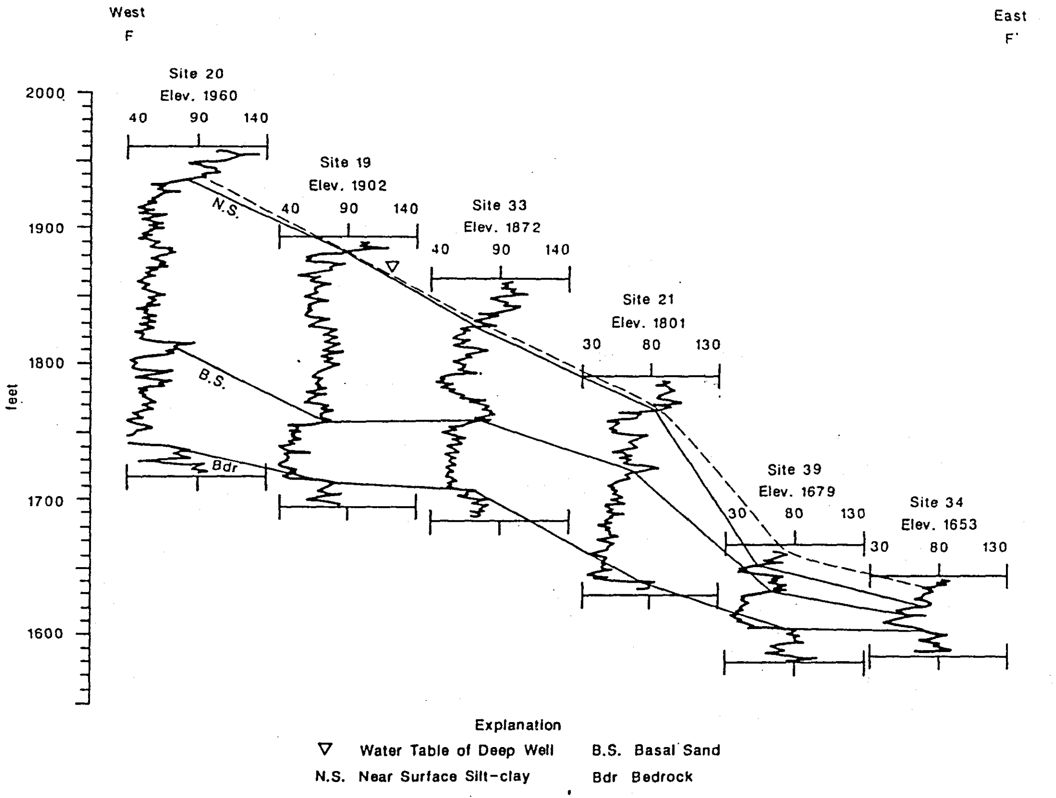

West
A
East
A'
Site 50
Elev. 1912
30
80
130
Site 22
Elev. 1855
0
100
200
Site 18
Elev. 1810
0
100
200
Site 23
Elev. 1743
40
90
140
1900
1800
1700
1600
feet
N.S.
B.S.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
B.S. Basal Sand
Bdr Bedrock

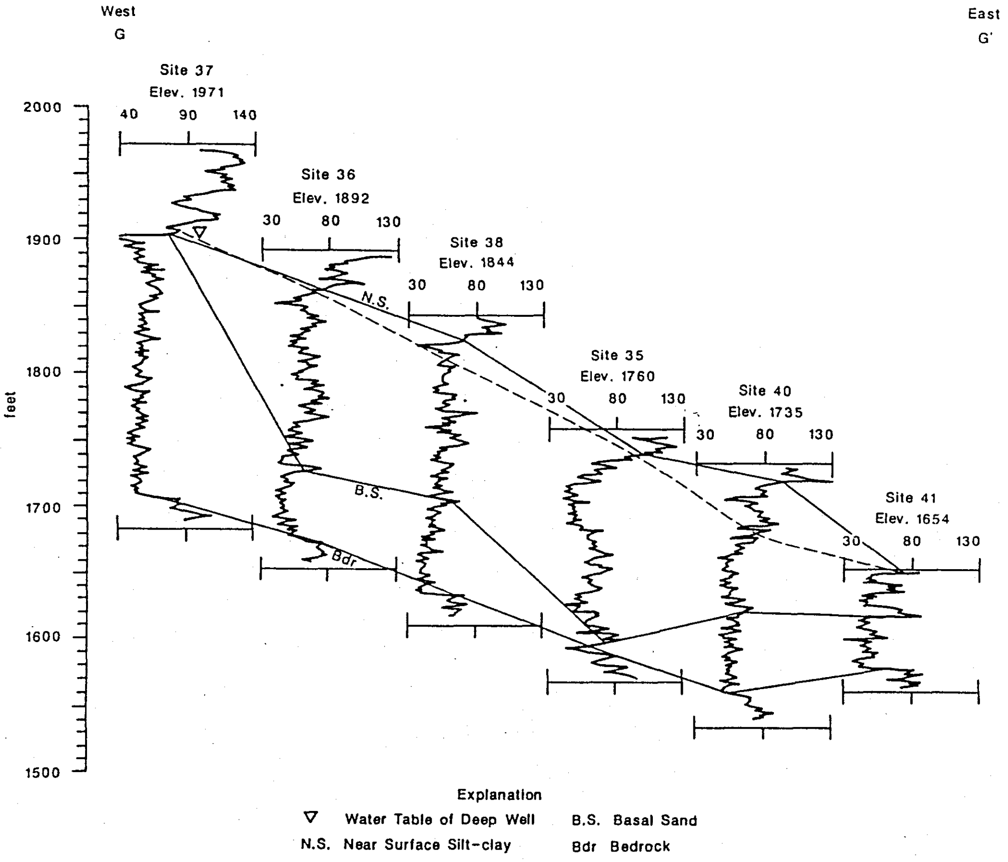

West
B
East
B'
Site 51
Elev. 1915
30 80 130
Site 16
Elev. 1873
40 90 140
Site 17
Elev. 1795
0 100 200
Site 11
Elev. 1763
0 50 100
Site 24
Elev. 1736
0 50 100
Site 31
Elev. 1665
40 90 140
N.S.
B.S.
S.C.
Bdr
feet
1900
1800
1700
1600
1500
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
S.C. Silt-clay
B.S. Basal Sand
Bdr Bedrock

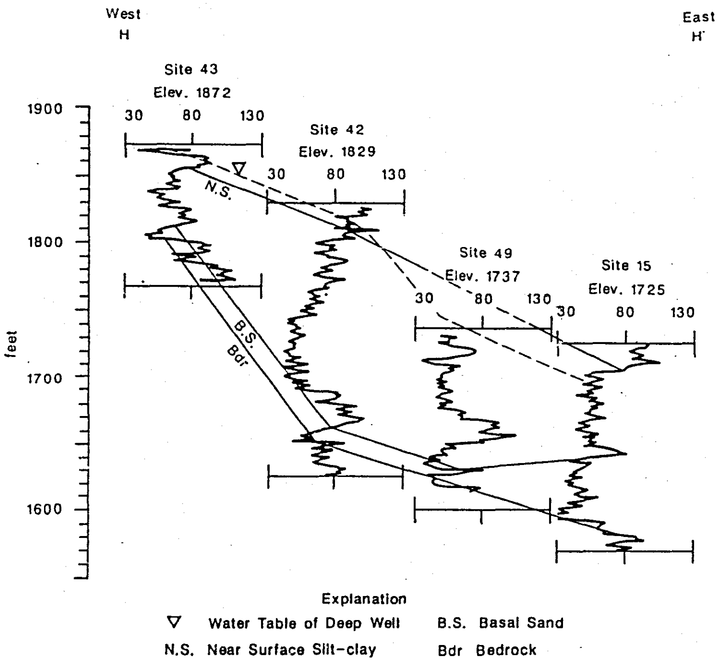

West
C
East
C'
Site 52
Elev. 1920
30 80 130
Site 5
Elev. 1855
0 50 100
Site 1
Elev. 1827
0 50 100
Site 25
Elev. 1780
40 90 140
Site 26
Elev. 1738
40 90 140
Site 27
Elev. 1685
40 90 140
1900
1800
1700
1600
1500
feet
N.S.
B.S.
S.C.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
S.C. Silt-clay
B.S. Basal Sand
Bdr Bedrock

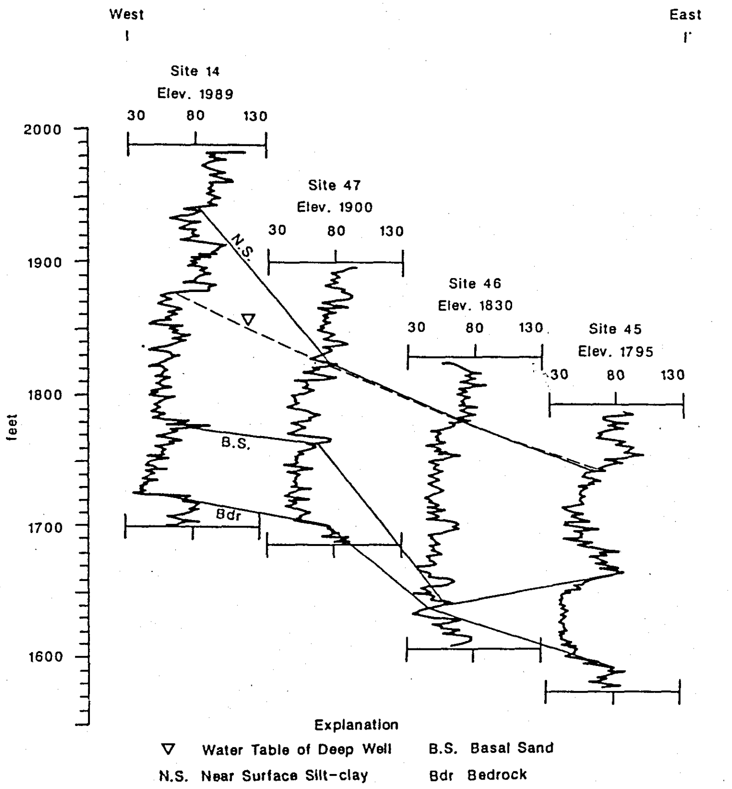

West
D
East
D'
Site 4
Elev. 1912
0
100
200
Site 3
Elev. 1898
0
100
200
Site SF
Elev. 1847
30
80
130
Site 2
Elev. 1837
0
50
100
Site 10
Elev. 1790
40
90
140
Site 30
Elev. 1750
40
90
140
Site 32
Elev. 1689
30
80
130
N.S.
B.S.
Bdr
1900
1800
1700
1600
1500
feet
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
B.S. Basal Sand
Bdr Bedrock

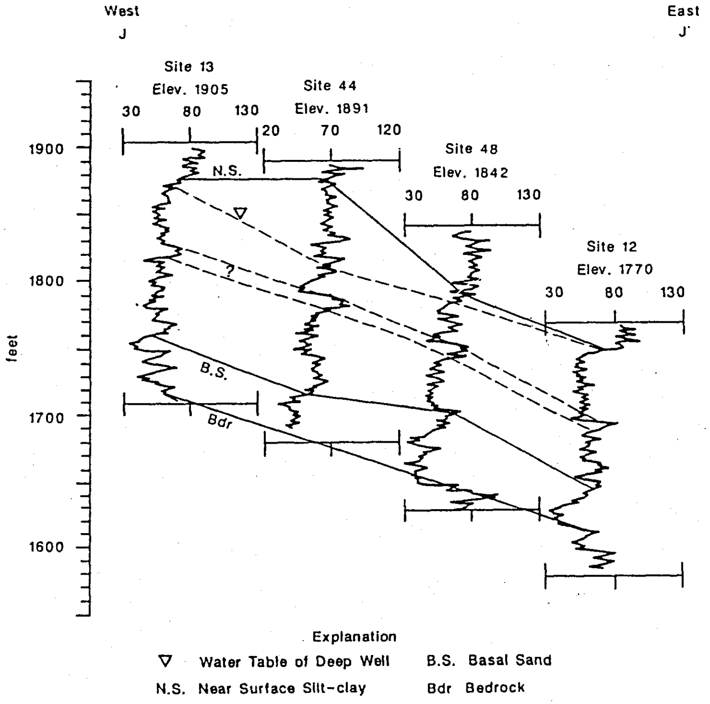

West
E
East
E'
2000
1900
1800
1700
1600
1500
feet
Site 6
Elev. 1950
40 90 140
Site 7
Elev. 1906
40 90 140
Site 8
Elev. 1848
40 90 140
Site 9
Elev. 1755
30 80 130
Site 29
Elev. 1731
30 80 130
Site 28
Elev. 1668
40 90 140
N.S.
B.S.
S.C.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
S.C. Silt-clay
B.S. Basal Sand
Bdr Bedrock

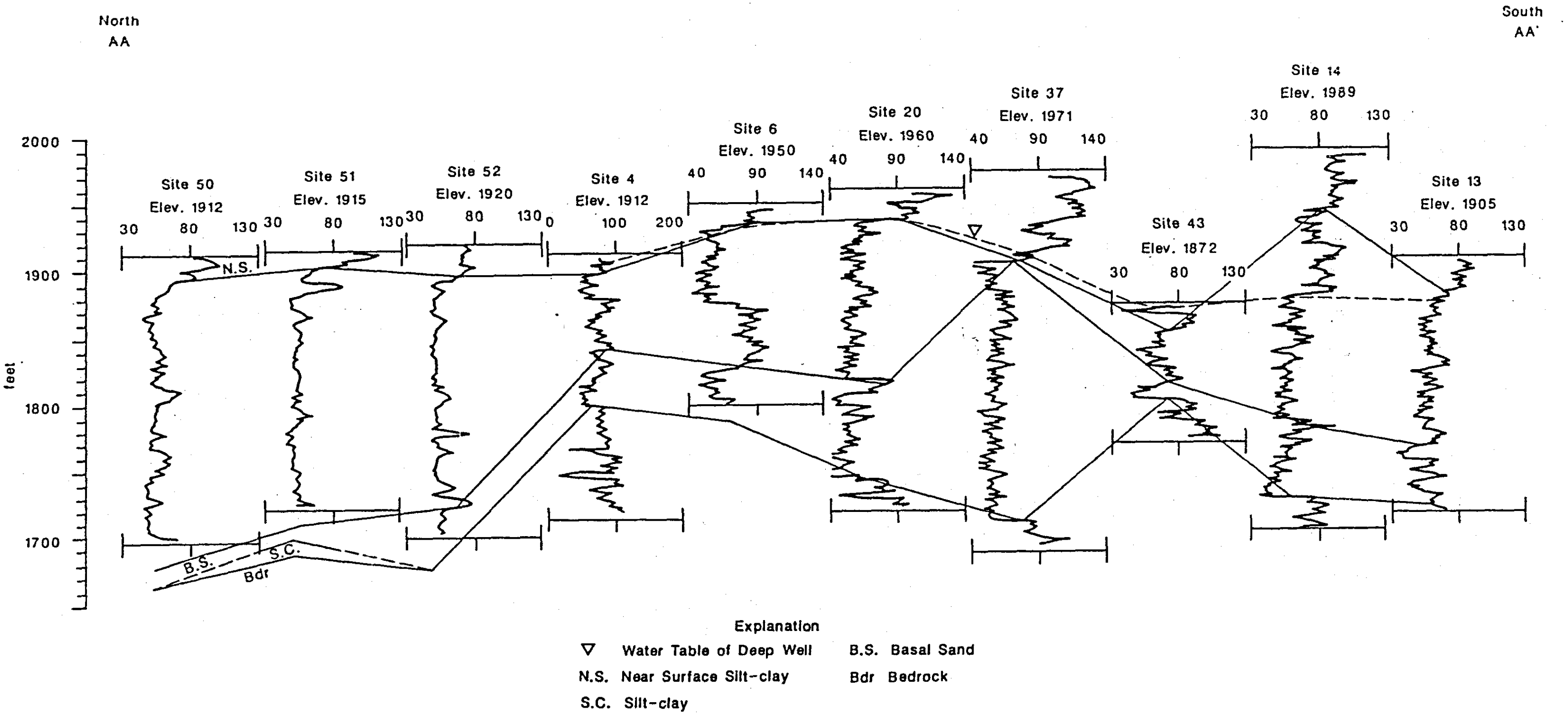

West
F
East
F'
2000
1900
1800
1700
1600
feet
Site 20
Elev. 1960
40 90 140
Site 19
Elev. 1902
40 90 140
Site 33
Elev. 1872
40 90 140
Site 21
Elev. 1801
30 80 130
Site 39
Elev. 1679
30 80 130
Site 34
Elev. 1653
30 80 130
N.S.
B.S.
Bdr
Explanation
▽ Water Table of Deep Well
B.S. Basal Sand
N.S. Near Surface Silt-clay
Bdr Bedrock

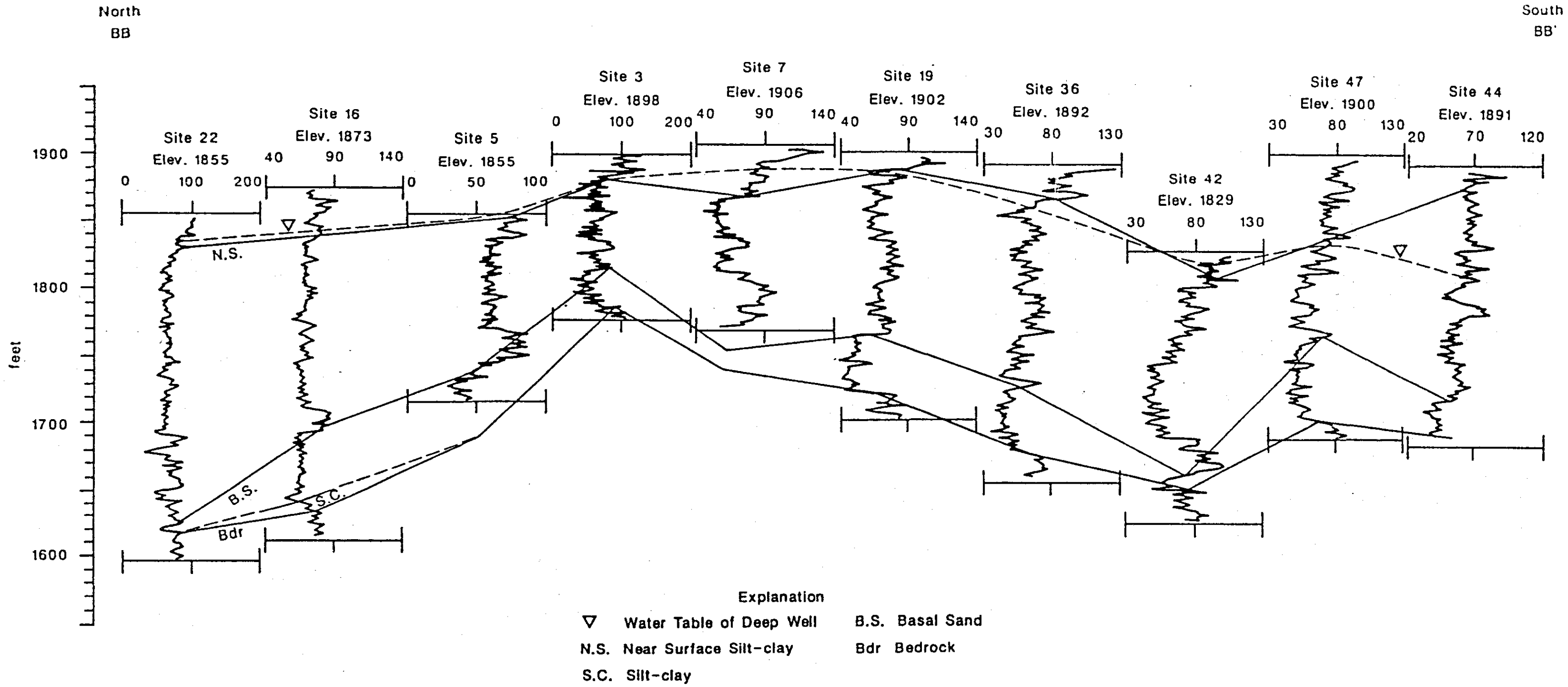

West
G
East
G'
Site 37
Elev. 1971
40 90 140
Site 36
Elev. 1892
30 80 130
Site 38
Elev. 1844
30 80 130
Site 35
Elev. 1760
30 80 130
Site 40
Elev. 1735
30 80 130
Site 41
Elev. 1654
30 80 130
2000
1900
1800
1700
1600
1500
feet
N.S.
B.S.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
B.S. Basal Sand
Bdr Bedrock

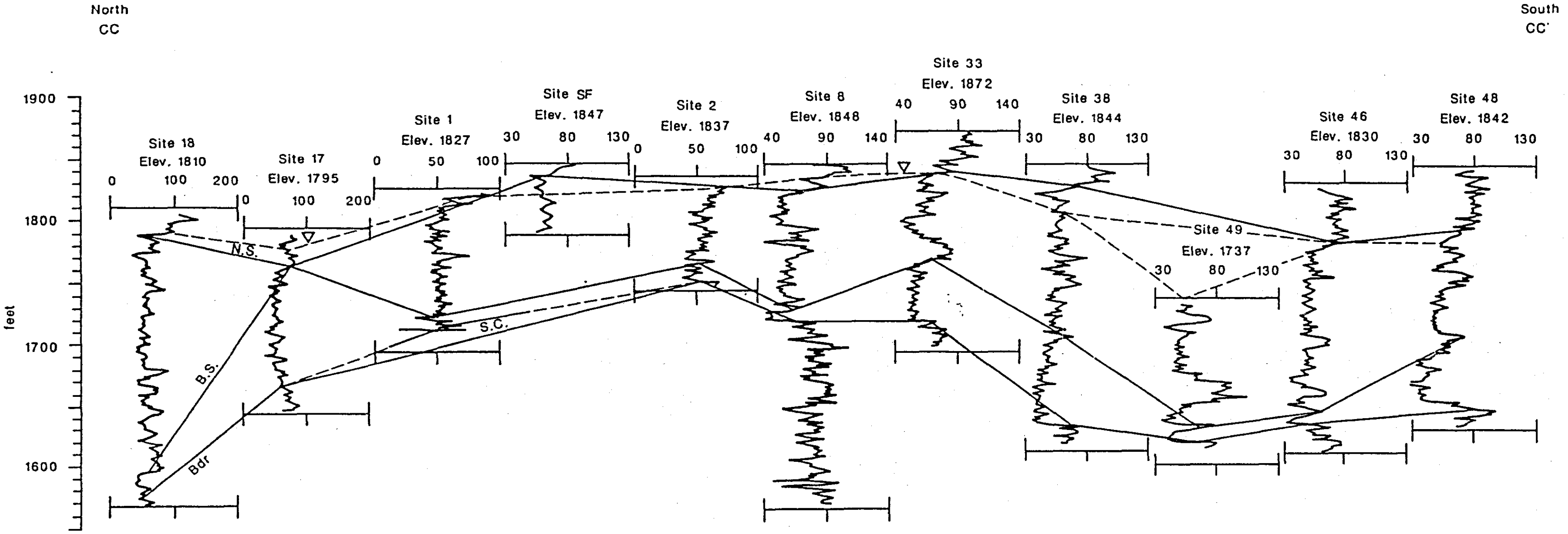

West
H
East
H'
Site 43
Elev. 1872
30 80 130
Site 42
Elev. 1829
30 80 130
Site 49
Elev. 1737
30 80 130
Site 15
Elev. 1725
30 80 130
1900
1800
1700
1600
feet
N.S.
B.S.
Bdr
Explanation
▽ Water Table of Deep Well
B.S. Basal Sand
N.S. Near Surface Silt-clay
Bdr Bedrock


West
I
East
I'
Site 14
Elev. 1989
Site 47
Elev. 1900
Site 46
Elev. 1830
Site 45
Elev. 1795
30
80
130
2000
1900
1800
1700
1600
feet
N.S.
B.S.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
B.S. Basal Sand
Bdr Bedrock


West
J
East
J'
Site 13
Elev. 1905
30 80 130
Site 44
Elev. 1891
20 70 120
Site 48
Elev. 1842
30 80 130
Site 12
Elev. 1770
30 80 130
1900
1800
1700
1600
feet
N.S.
?
B.S.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
B.S. Basal Sand
Bdr Bedrock


North
AA
South
AA'
feet
2000
1900
1800
1700
Site 50
Elev. 1912
30 80 130
Site 51
Elev. 1915
30 80 130
Site 52
Elev. 1920
30 80 130
Site 4
Elev. 1912
0 100 200
Site 6
Elev. 1950
40 90 140
Site 20
Elev. 1960
40 90 140
Site 37
Elev. 1971
40 90 140
Site 43
Elev. 1872
30 80 130
Site 14
Elev. 1989
30 80 130
Site 13
Elev. 1905
30 80 130
N.S.
B.S.
S.C.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
S.C. Silt-clay
B.S. Basal Sand
Bdr Bedrock


North
BB
South
BB'
feet
1900
1800
1700
1600
Site 22
Elev. 1855
0 100 200
Site 16
Elev. 1873
40 90 140
Site 5
Elev. 1855
0 50 100
Site 3
Elev. 1898
0 100 200
Site 7
Elev. 1906
40 90 140
Site 19
Elev. 1902
40 90 140
Site 36
Elev. 1892
30 80 130
Site 42
Elev. 1829
30 80 130
Site 47
Elev. 1900
30 80 130
Site 44
Elev. 1891
20 70 120
N.S.
B.S.
S.C.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
S.C. Silt-clay
B.S. Basal Sand
Bdr Bedrock



Explanation

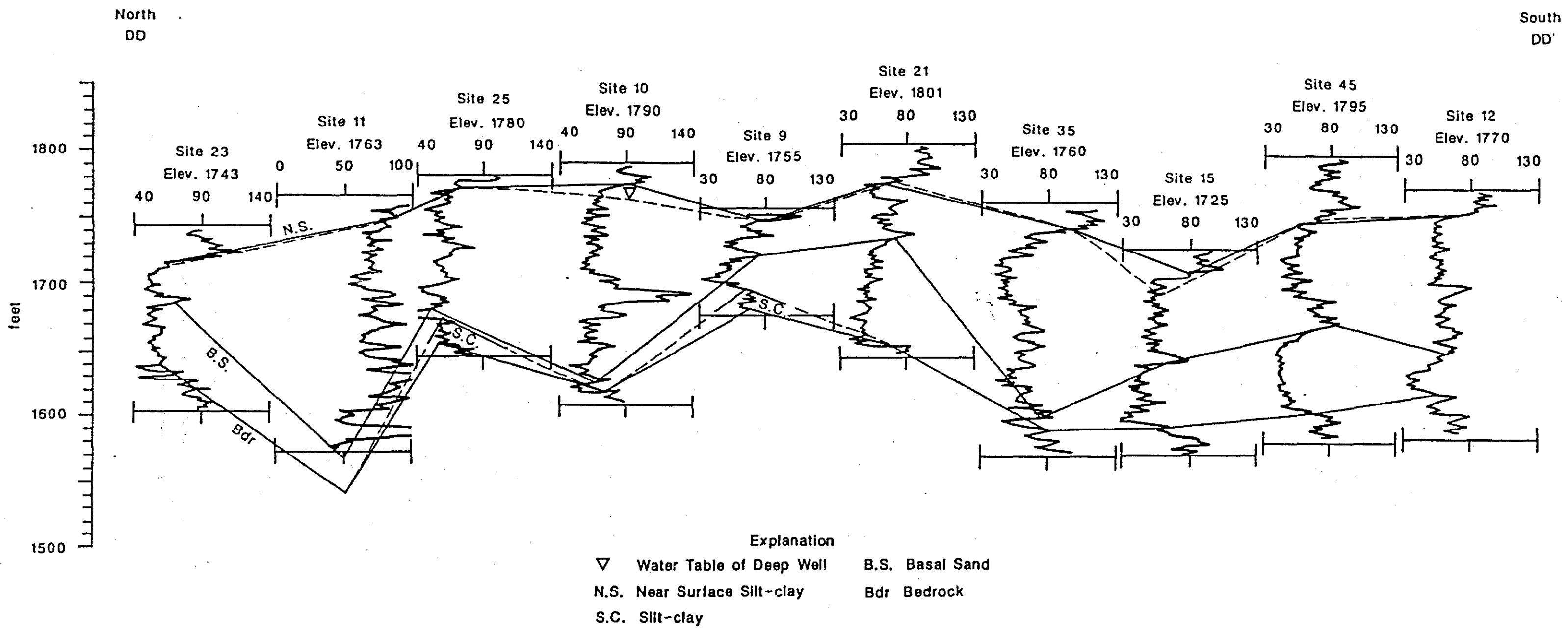
▽ Water Table of Deep Well

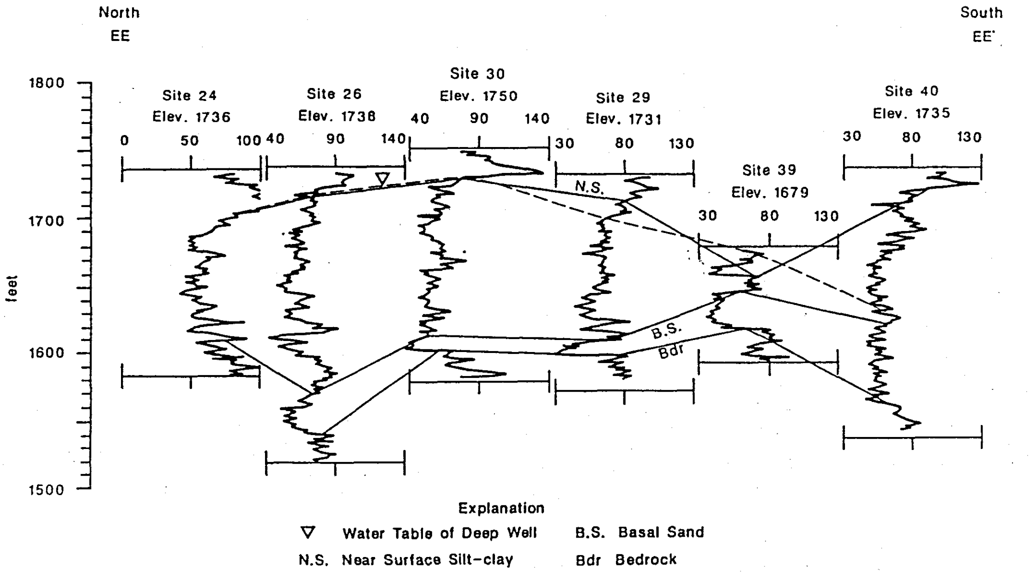
N.S. Near Surface Silt-clay

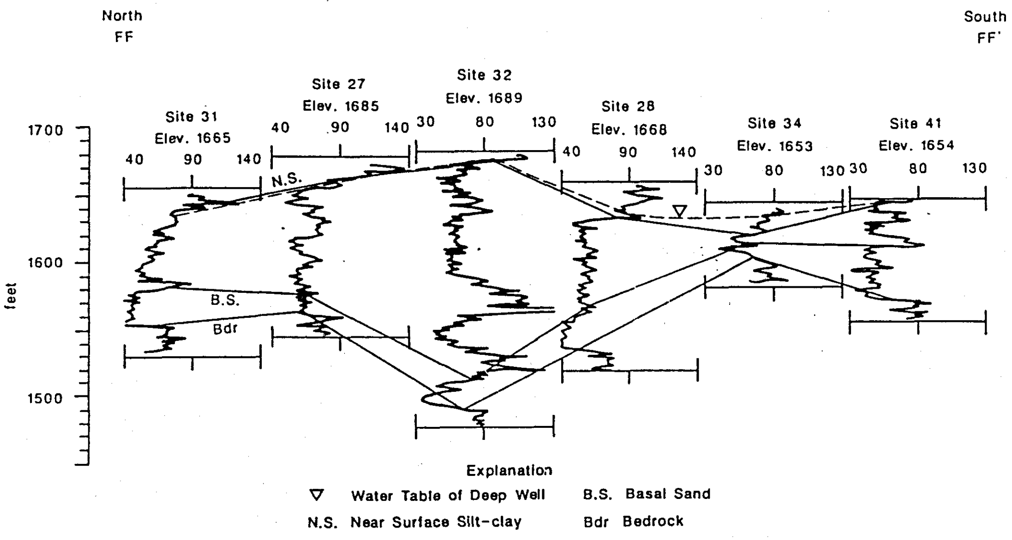
S.C. Silt-clay

B.S. Basal Sand

Bdr Bedrock


North
DD
South
DD'
feet
1800
1700
1600
1500
Site 23
Elev. 1743
40 90 140
Site 11
Elev. 1763
0 50 100
Site 25
Elev. 1780
40 90 140
Site 10
Elev. 1790
40 90 140
Site 9
Elev. 1755
30 80 130
Site 21
Elev. 1801
30 80 130
Site 35
Elev. 1760
30 80 130
Site 15
Elev. 1725
30 80 130
Site 45
Elev. 1795
30 80 130
Site 12
Elev. 1770
30 80 130
N.S.
B.S.
Bdr
S.C.
S.C.
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
S.C. Silt-clay
B.S. Basal Sand
Bdr Bedrock


North
EE
South
EE'
1800
1700
1600
1500
feet
Site 24
Elev. 1736
0 50 100
Site 26
Elev. 1738
40 90 140
Site 30
Elev. 1750
40 90 140
Site 29
Elev. 1731
30 80 130
Site 39
Elev. 1679
30 80 130
Site 40
Elev. 1735
30 80 130
N.S.
B.S.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
B.S. Basal Sand
Bdr Bedrock


North
FF
South
FF'
Site 31
Elev. 1665
Site 27
Elev. 1685
Site 32
Elev. 1689
Site 28
Elev. 1668
Site 34
Elev. 1653
Site 41
Elev. 1654
40 90 140
40 90 140
30 80 130
40 90 140
30 80 130
30 80 130
1700
1600
1500
feet
N.S.
B.S.
Bdr
Explanation
▽ Water Table of Deep Well
N.S. Near Surface Silt-clay
B.S. Basal Sand
Bdr Bedrock