SEDIMENT CHARACTERIZATION: ALLUVIUM AND TERRACE DEPOSITS, ARKANSAS RIVER, SOUTHERN OSAGE COUNTY, OKLAHOMA

By

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CHAPTER I

INTRODUCTION

The Quaternary aquifer along the Arkansas River in Western Osage County, Oklahoma (Figure 1) was thought to represent a substantial potential water resource, but no data were available as to the quality and availability. In response to increasing demands for water on the Osage Reservation, the U.S.Geological Survey (USGS), in cooperation with the Osage Tribe and the Bureau of Indian Affairs, conducted a study to assess the availability and quality of ground water in the Quaternary aquifer on the Osage Reservation side of the river. The project consisted primarily of the collection and analysis of data from 103 test holes in the aquifer (Figures 2 and 3). The fieldwork was conducted from January to September 2002. Data collected included electrical conductivity measurements, sediment cores, and water-quality field parameters. When feasible, water levels in the test holes were measured. This thesis focuses primarily on characterizing the alluvium and terrace deposits and making inferences regarding their origin. The results of the water quality and aquifer flow study may be found in Mashburn (2003).

Description of the Study Area (Osage Reservation)

The Osage (Reservation), also known as Osage County, consists of about 2,260 square miles. The Reservation is characterized by gently-rolling uplands with sharp cuestas formed by resistant sandstone and limestone ledges. The Arkansas River borders the Reservation on the south and southwest. The western part of the Reservation, known informally as the Bluestem Hills, is mostly open savanna. The highest altitude is about 1,350 feet above sea level along the cuesta northeast of Foraker in the northwestern part of the Reservation; the lowest altitude is about 600 feet above sea level along Hominy and Delaware Creeks south of Skiatook in the southeastern part of the Reservation. Mean annual precipitation across the Reservation ranges from 34 inches near Ponca City, on the western edge to greater than 38 inches near Tulsa, in the southeast part (Oklahoma Climatological Survey, 2002).

Description of Quaternary Aquifer

The Quaternary aquifer along the Arkansas River in Western Osage County covers about 125 square miles and consists of alluvium and terrace deposits of sand, silt, clay, and gravel sized sediments (Figures 2 and 3). The contact between the alluvium and terrace deposits is recognized as the location where the slope changes from a low angle on the alluvium to a greater angle on the terrace deposits (Figure 4). Change in slope is a good indicator of the contact between alluvial and terrace sediments, except in areas where terrace sediments are absent, and the alluvium abuts Pennsylvanian or Permian bedrock (Figure 5).

Aquifer infiltration and recharge to the Quaternary alluvium and terrace deposits in the Reservation is from rainfall and was estimated to be similar to the Enid isolated terrace aquifer that receives 2.3 inches of recharge from 31 inches of precipitation or, 7.4 percent of mean annual precipitation (Kent and others, 1982). The Enid isolated terrace aquifer, 50 miles west of the Reservation, is of similar age, deposition, and cementation (Beausoleil, 1981). Based on calculations for the Enid aquifer, recharge to the Quaternary aquifer in the Reservation may range from about 2.5 inches near Ponca City to about 2.7 inches near Tulsa. Limited recharge, combined with recent increases in water demands, have made understanding the thickness and internal characteristics of the aquifer a primary concern of the Osage Tribe and the USGS.

Thickness, grain size characteristics, and mineralogy of the alluvial aquifer in southern Osage county were largely unknown before the onset of this study. This is a result of the fact that past descriptions of the alluvium and terrace deposits were based on surface geology and or cuttings produced from the drilling of oil wells in the area. Logs and other data from these wells generally ignored the Quaternary deposits and focused primarily on the deeper consolidated formations that contain the county's oil reserves. This information allowed for a general understanding of the distribution of deposits, but did not allow for the type of detailed characterization that could only be attained from the examination of a set of continuous sediment cores whose locations are distributed across the area.

Goals and Objectives

The overall objective of this thesis is to characterize the sediments that compose the Quaternary aquifer. To address this objective the following tasks were formulated:

1) Examine stratigraphy of sediments using continuous cores and electrical conductivity logs
2) Determine statistical grain size parameters including mean grain size, sorting, and graphic skewness for samples taken from the sediment cores.
3) Establish detrital grain mineralogy of the sediments as well as the size and distributions of heavy grains, (magnetite) in alluvium and terrace deposits.
4) Determine if differences in grain size, mineralogy and stratigraphy are evident between alluvium and terrace deposits.

5) Compare the findings of this study with scientific literature and establish the origins of the alluvium and terrace deposits along the Arkansas River in southern Osage County.

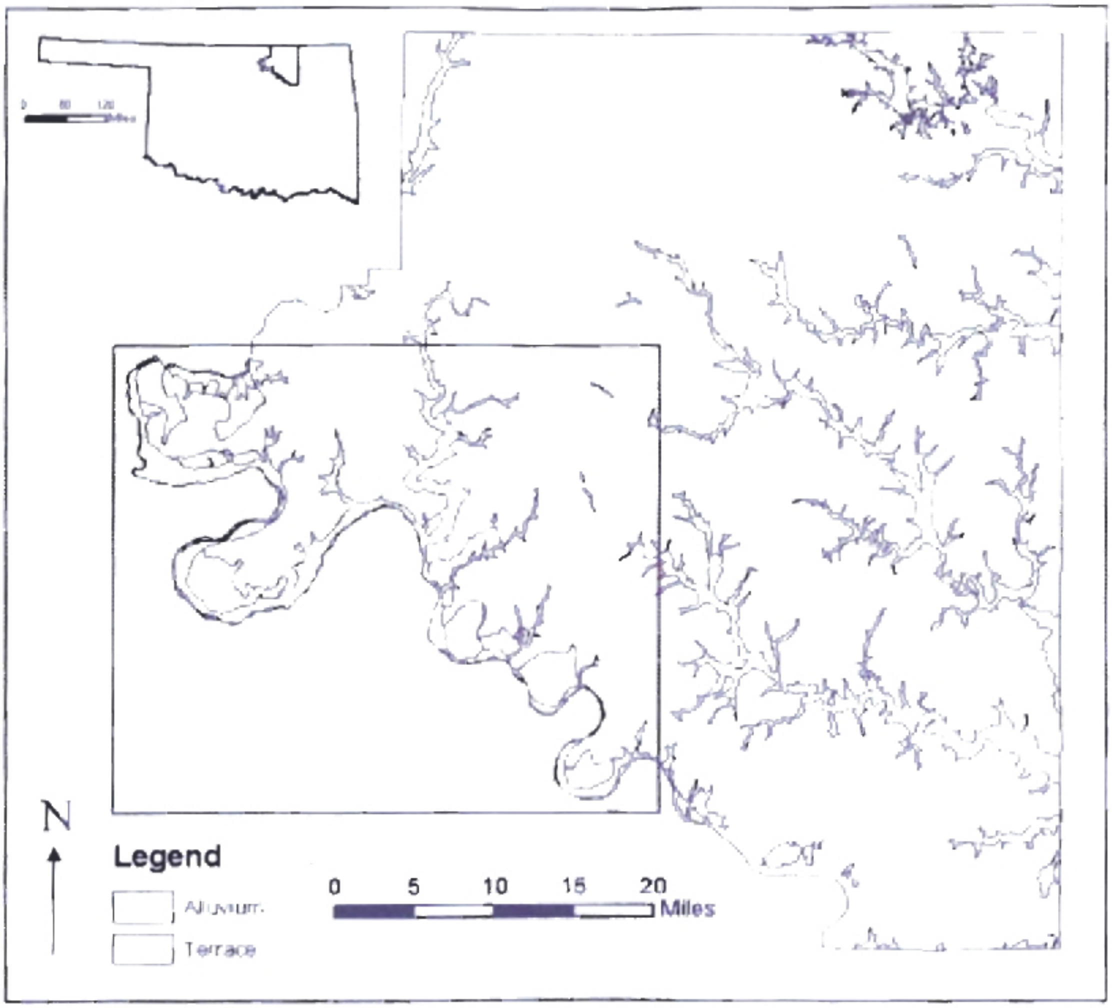


Figure 1. Map of study area showing Quaternary alluvium and terrace deposits, Osage Reservation, Oklahoma

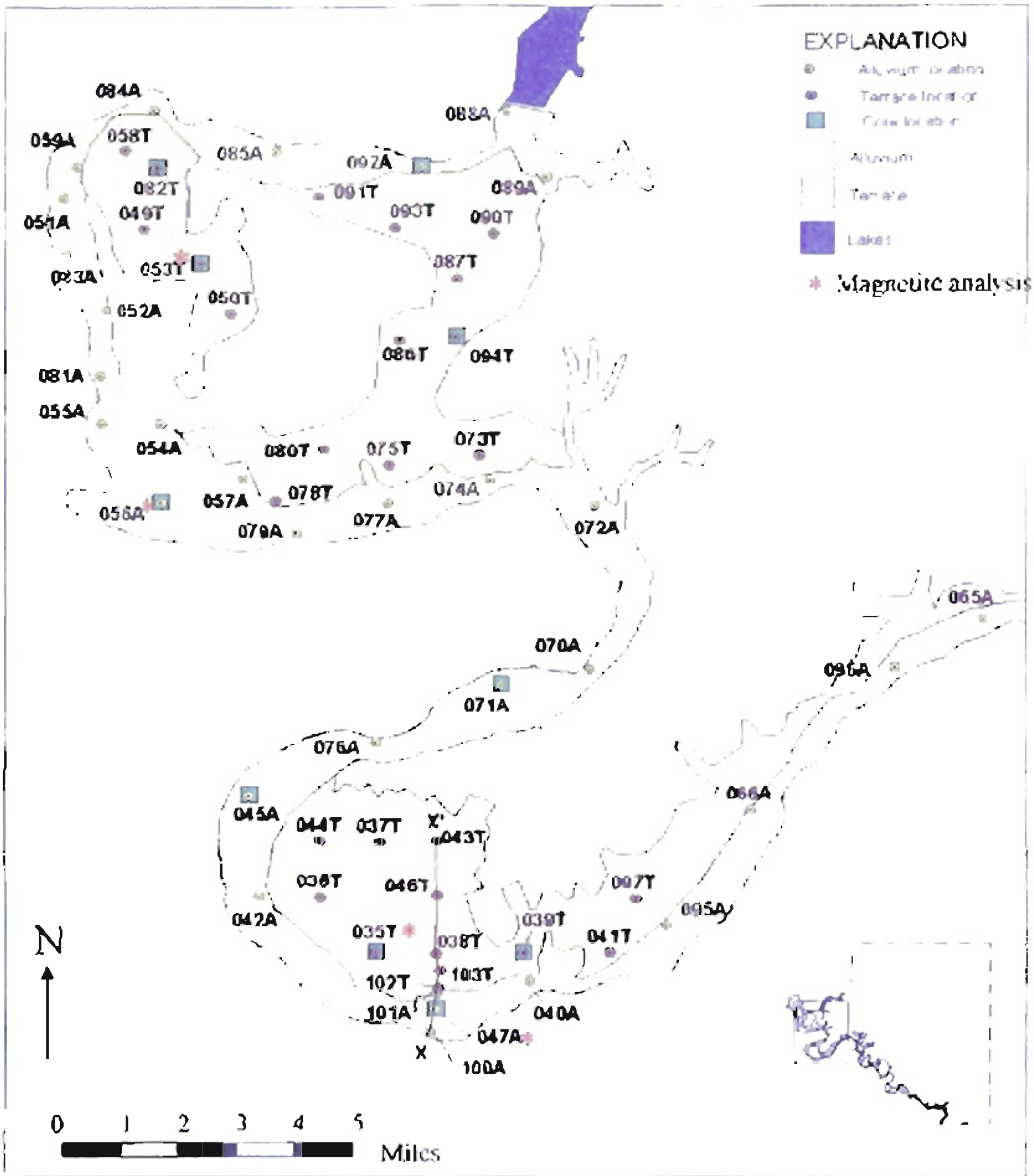


Figure 2. Test hole locations in alluvium and terrace deposits, western portion of study area. Profile X-X' is shown in Figure 4.

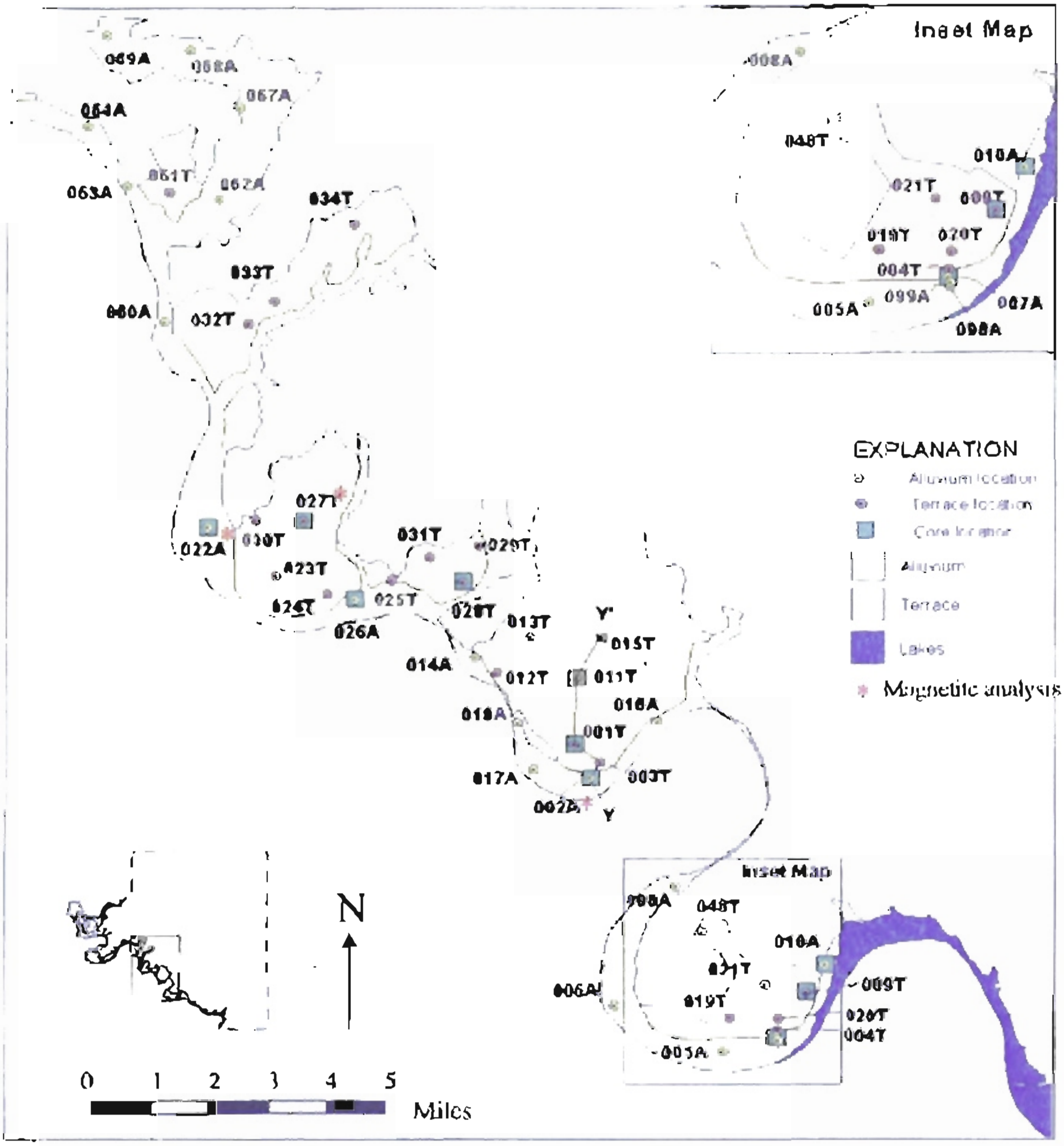


Figure 3. Test hole locations in alluvium and terrace deposits, eastern portion of study area. Profile Y-Y' is shown in Figure 4.

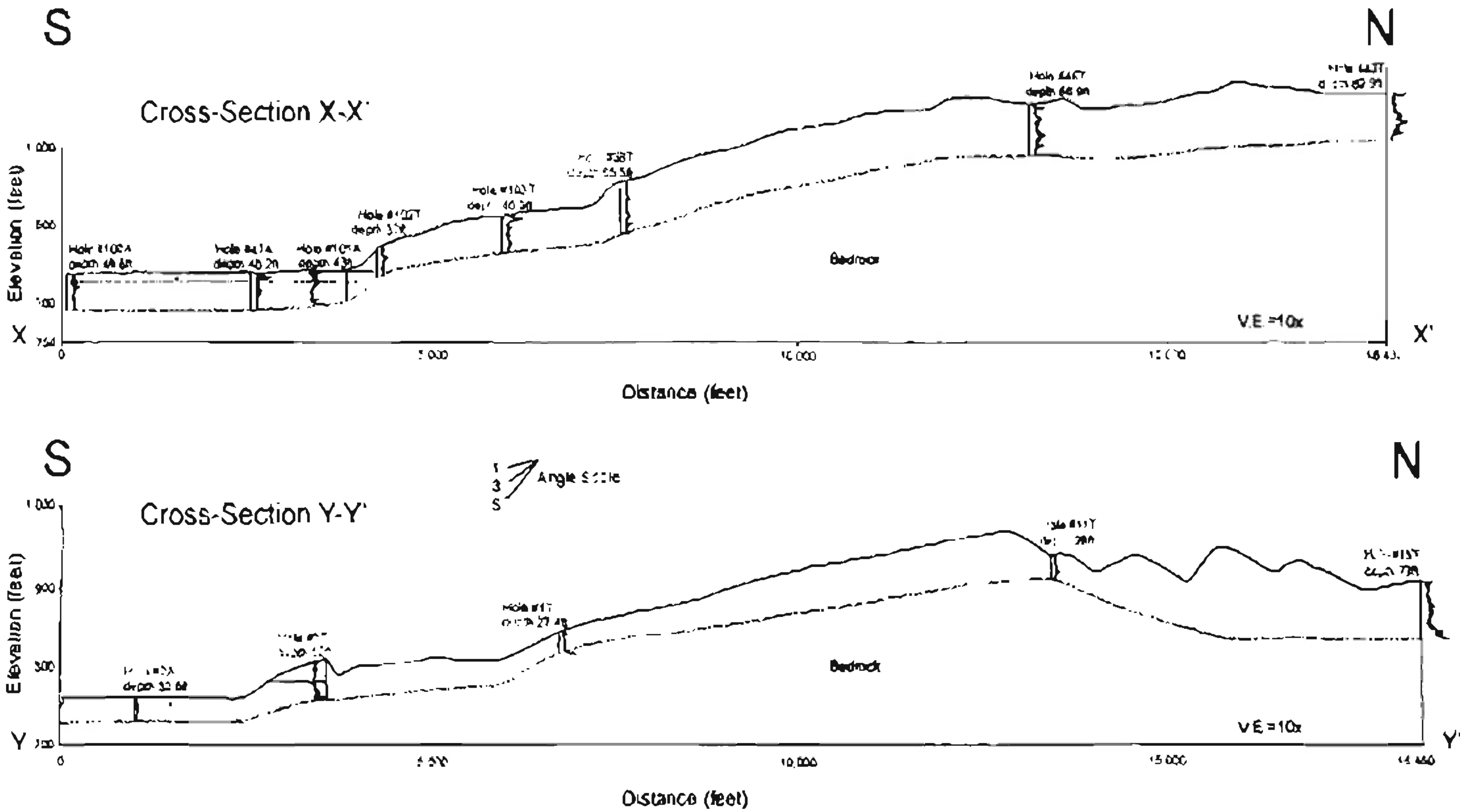


Figure 4. Cross-sectional profiles X-X' and Y-Y' that transect alluvium and terrace deposits. Vertical exaggeration is approximately 10X. The locations of these cross sectional profiles are shown in Figures 2 and 3.

CHAPTER II

GENERAL GEOLOGY AND PREVIOUS INVESTIGATIONS

The study area contains Quaternary sediments that are underlain by sedimentary rocks of Permian and Pennsylvanian age that dip gently west-northwest (Figures 5 and Rocks under the western part of the Reservation in the open savanna are predominately limestone, dolomite, and shale, whereas rocks under the eastern part in the woodlands a primarily sandstone and shale with some limestone and dolomite (Abbott, 1997). The sandstones are well cemented to semi-cemented with clay and calcite (Oakes, 1952).

Pennsylvanian Ada-Vamoosa system

Outcrops of the Ada-Vamoosa system form a broad north-south trending band i the eastern portion of the study area (Figure 5). The Ada Formation in the Reservation about 400 feet thick and consists of interbedded limestone and shale units near the Kansas border grading into fine-grained sandstones interbedded with limestone and sha near the southern boarder of the Osage Reservation (Bingham and Bergman, 1980).

The Vamoosa Formation is approximately 630 feet thick and consists of alternating layers of shale and fine to coarse-grained sandstone with some limestone (Bingham and Bergman, 1980).

Pennsylvanian Vanoss group

The Pennsylvanian Vanoss group crops out in a north-south trending band near the center of the study are (Figure 5). The Pennsylvanian Vanoss Group consists of alternating layers of limestone and shale to the north, grading southward into limestone, shale, and fine-grained sandstone. The thickness of the Vanoss Group is approximately 500 feet (Bingham and Bergman, 1980).

Pennsylvanian Oscar group

The Pennsylvanian Oscar group crops out in a north-south trending band in the western portion of the study area (Figure 5). The Oscar group consists mainly of shale with many layers of limestone that pinch-out southward, where the fine-grained sandstones are thicker and more numerous. The thickness of the Oscar group is approximately 400 feet (Bingham and Bergman, 1980).

Permian Wellington Formation

The Permian Wellington Formation is exposed in the far western portion of the study area, near Ponca City (Figure 5). The Wellington is composed mostly of red-browr shale to the North, grading into fine-grained sandstone and mudstone conglomerate southward into Logan County. The thickness of the Wellington formation is approximately 850 feet (Bingham and Bergman, 1980).

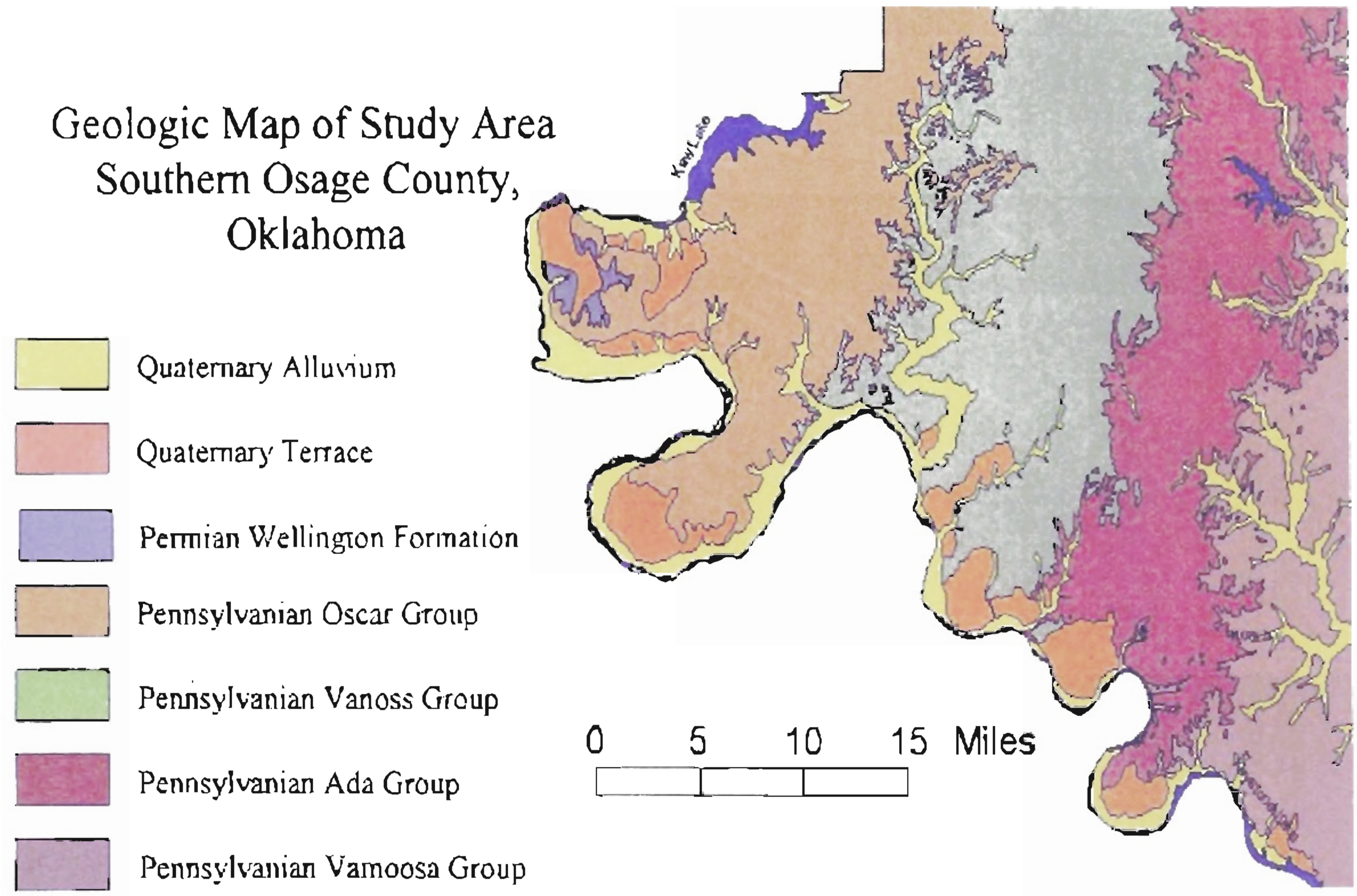


Figure 5. Geologic map of Pennsylvanian, Permian and Quaternary Units

System	Series	Group	Hydrogeologic unit	Formation	Member	Informal subsurface unit
Quaternary			Quaternary aquifer	Alluvium		
				Terrace		
Permian		Sumner		Wellington		
Pennsylvanian	Gearyan			Oscar		
				Vanoss		
	Virgilian		Ada-Vamoosa sandstone aquifer	Ada	Auburn Shale Wakarusa Limestone Soldier Creek Shale Burlingame Limestone Silver Lake Shale Rulo Limestone Cedar Vale Shale Happy Hollow Limestone White Cloud Shale Bird Creek Limestone Severy Shale Turkey Run Limestone Pearsonia Limestone Little Hominy Limestone Deer Creek Limestone Plummer Limestone Lecompton Limestone	
				Vamoosa	Elgin Sandstone Kanwaka Shale Wynona Sandstone Cochahee Sandstone Kiheki Sandstone Cheshewalla Sandstone	
	Missourian	Ochelata	Minor Pennsylvanian sandstone aquifer	Tallant		Revard sand Bigheart sand
				Barnsdall		Okesa sand
				Wann		Torpedo sand Clem Creek sand
				Iola		
				Chanute		
		Skiatook		Dewey Limestone		
				Nellie Bly		Mussellem sand Peoples sand
				Hogshooter Limestone		
				Coffeyville		Layton sand Cleveland sands
				Checkerboard Limestone		

Figure 6. Stratigraphic column depicting rock units in the study area

Previous Studies on the Arkansas River Alluvial Aquifer

Studies were conducted on the Arkansas River alluvial aquifer by several authors in locations outside the study area of this thesis. Generally these studies report that the alluvial aquifer deposits have two origins: 1) Floodplain alluvium deposited by running water, and 2) fluvial or eolian terrace deposits.

The alluvial aquifer along the Arkansas River in Tulsa County was examined by Oakes (1952), who described the alluvium deposits of the Arkansas as being composed of clay, silt, and sand deposited by water. The thickness of these deposits was unknown but a maximum thickness on the order of 100 feet was inferred. Oakes (1952) referred to the terrace deposits as a mantle of sand, silt, and clay that covers the older rocks in a belt up to two miles wide, along the north side of the Arkansas River. Maximum thickness of the terrace deposits was also estimated to be approximately 100 feet. Oakes (1952) inferred that while part of the terrace material was deposited by the Arkansas River at a time when it flowed at a higher level, much of the terrace deposits were likely deposited by the prevailing wind from the southwest, which transported sand and silt from the river bed during times of low water level and high winds. Oakes (1952) stated that these deposits are now much dissected by tributary streams that flow into the Arkansas River from the north.

Tanaka and Hollowell (1966) described the alluvial deposits along the Arkansas River between Muskogee, Oklahoma and Fort Smith, Arkansas. They found that alluvium grain size generally ranged from coarse sand and gravel near the base, to silt or clay near the surface. The reported average total thickness of the alluvium was 42 feet.

Tanaka and Hollowell also stated that terrace deposits were composed mainly of silt and fine sand, with small amounts of coarse sand and gravel near the base.

Bedinger, Emmett and Jeffery (1963), in their description of the Quaternary aquifer on the Arkansas River between Little Rock and Fort Smith, Arkansas, described the alluvium as being composed of sand, gravel, silt and clay. They stated that the alluvium graded generally from fine grained at the surface to coarse grained at the base.

Forman and Sharp (1980) utilized field observations, pump tests and analyses of 3-D digital simulations in a study of the hydraulic properties of the alluvial aquifer along a stretch of the Missouri River. They noted three distinct facies that they recognized to be typical of alluvial floodplain deposits: 1) A lower cobble facies, 2) a middle gravel-sand facies, and 3) an upper sand-silt-clay facies.

Nature of Alluvium Deposits

Alluvium deposits along the Arkansas River were classified by Oakes (1952) and Tanaka and Hollowell (1966), as fluvial in origin. According to Garde and Raju (1985), the majority of sediment carried by streams comes from the erosion of material in the drainage basin. A certain amount of sediment also originates as a result of weathering of rocks from the bed and banks of the stream. The size of the sediment transported is dependent on the geology of the basin as well as the distance of the reach from the source (Garde and Raju, 1985). The amount of sediment load carried depends on the size of the material, discharge, slope, and channel and catchment characteristics. When there is reduction either in the discharge or in the slope of an equilibrium stream, the stream cannot transport the material supplied to it and the excess material is deposited (Garde, and Raju, 1985).

According to (Boggs, 1987), in a meandering stream system, sedimentation may take place essentially simultaneously in the lag channel, on point bars, and in the various overbank environments. As shifting of these different environments takes place owing to stream meandering, sediments from laterally contiguous environments will become superimposed or vertically stacked. Coarse-grained lag deposits may be overlain by sandy, fining upward point-bar deposits, which are in turn overlain by silty and muddy overbank deposits, producing an overall fining upward succession (Boggs, 1987).

According to (Boggs, 1987), in a braided river system, channels may fill by aggradation during waning current flow, and flooding can cause beds formed under decreasing current velocity to be superimposed. These depositional processes involving channel shifting and migration, as well as tectonic changes that affect base level, generate vertical successions, (multiple cyclic successions). Individual cycles commonly display a fining upward trend (Boggs, 1987).

Nature of Wind-blown Deposits

Terrace deposits along the Arkansas River have been classified by Oakes (1952) and Tanaka and Holloweil (1966), to be partly wind-deposited (eolian). The movement of sediment by the wind has been the subject of numerous investigations. Free (1911) stated that most of the sediment carried by the wind is moved by a series of short bounces called "saltation". Furthermore, it was reported by Free (1911) that the smaller the sediment particle, the closer the approach of the path of saltation to a line parallel with the direction of the wind. Udden (1894) asserted that quartz grains larger than about 0.5 mm in diameter and smaller than 1 mm are too heavy to be transported through the air, but roll and slide along the surface of the ground. Bagnold (1941) termed this type of sediment movement as "surface creep". Chepil (1941) stated that grains larger than 1 mm in diameter are too large to be moved by ordinarily erosive winds.

Dijkmans, Galoway and Koster (1988) characterized the sediment attributes of 5 eolian, (wind-blown), sediment samples and five fluvial, (river-deposited) sediment samples taken from the central Kobuk valley in northwestern Alaska. They found that mineralogy of the eolian sands was very similar to that of the fluvial sands, and concluded that the eolian sands were derived from the older fluvial sediments.

Dijkmans, Galoway and Koster (1988) found the most significant difference between the eolian and fluvial sands was the consistently finer grain size of the eolian sediments. The fluvial samples taken along the Kobuk River, displayed an average mea grain size of 1.97 phi, (0.255mm) whereas the eolian samples, displayed an average me grain size of 2.62 phi, (0.163mm). Although this analysis of Kobuk valley sediments w conducted on single-depth grab samples and not multi-layer continuous cores, which m contain some clay as well as gravel layers, relative grain size differences between paren material and eolian sediments are apparent. The findings of Dijkmans, Galoway and Koster (1988) suggest that sediments carried by the wind and redeposited away from th river channel are finer grained than the source material contained within the river channel.

CHAPTER III

METHODS OF STUDY

Site Selection

Test hole sites were placed on private land and along road right of ways underlai by alluvium and terrace deposits. Location of test holes depended on landowner permission and road accessibility. The test holes were evenly distributed across the alluvium and terrace deposits (Figures 2 and 3). Two transects of closer spaced sites crossed the terrace deposits and ended on the alluvium near the river channel (Figures 2, 3, and 4). These transects were designed to detect changes in sediment type, water level and water quality that might occur when moving from the alluvium to the terrace deposits. Latitude and longitude of site locations were determined using the global positioning system to a horizontal accuracy of approximately ten meters.

Collection of Continuous Cores

A truck-mounted Geoprobe® (Figure 7) was used to extract continuous sedimen cores from 20 of the 103 test holes (Figures 2 and 3). Ten cores each were collected from alluvium and terrace deposits. Cores were extracted in four feet intervals. The tot depths of cored test holes ranged from 16 feet to 52 feet and included the entire thicknes of the Quaternary sediments, (i.e. from land surface to bedrock). Penetration of the core barrel slowed markedly at the bedrock boundary. In cases in which the underlying bedrock consisted of weathered shale, the core barrel penetrated slightly below the alluvial aquifer and some of the bedrock was recovered. A Geoprobe® macro-core piston rod soil sampler was used to extract the cores (Figure 8). The macro-core sampling tube is four feet in length with a two-inch diameter. The sampling tube contains a removable polycarbonate core liner that is 1.5 inches in diameter. The sampling tube also contains a piston that holds the sampling tube in a closed position until the desired sampling depth is reached (Figure 8). Complete sediment recovery is often difficult in coarse-grained, water-saturated material, as some of the sediment often falls out of the sampling tube before reaching the surface. This is an inherent difficulty with macro-core sampling and despite proper field techniques; recovery of this type of sediment was as low as 25% in some cases.

Electrical Conductivity Logs

An SC400 probe attached to the probe rods measured the electrical conductivity of the alluvium and terrace sediments (Figure 9). Conductivity log data were collected as the probe advanced into the ground. Penetration rates slowed markedly at the lower boundary of the Quaternary aquifer. Electrical conductivity logs for each cored test hole are included in Appendix E.

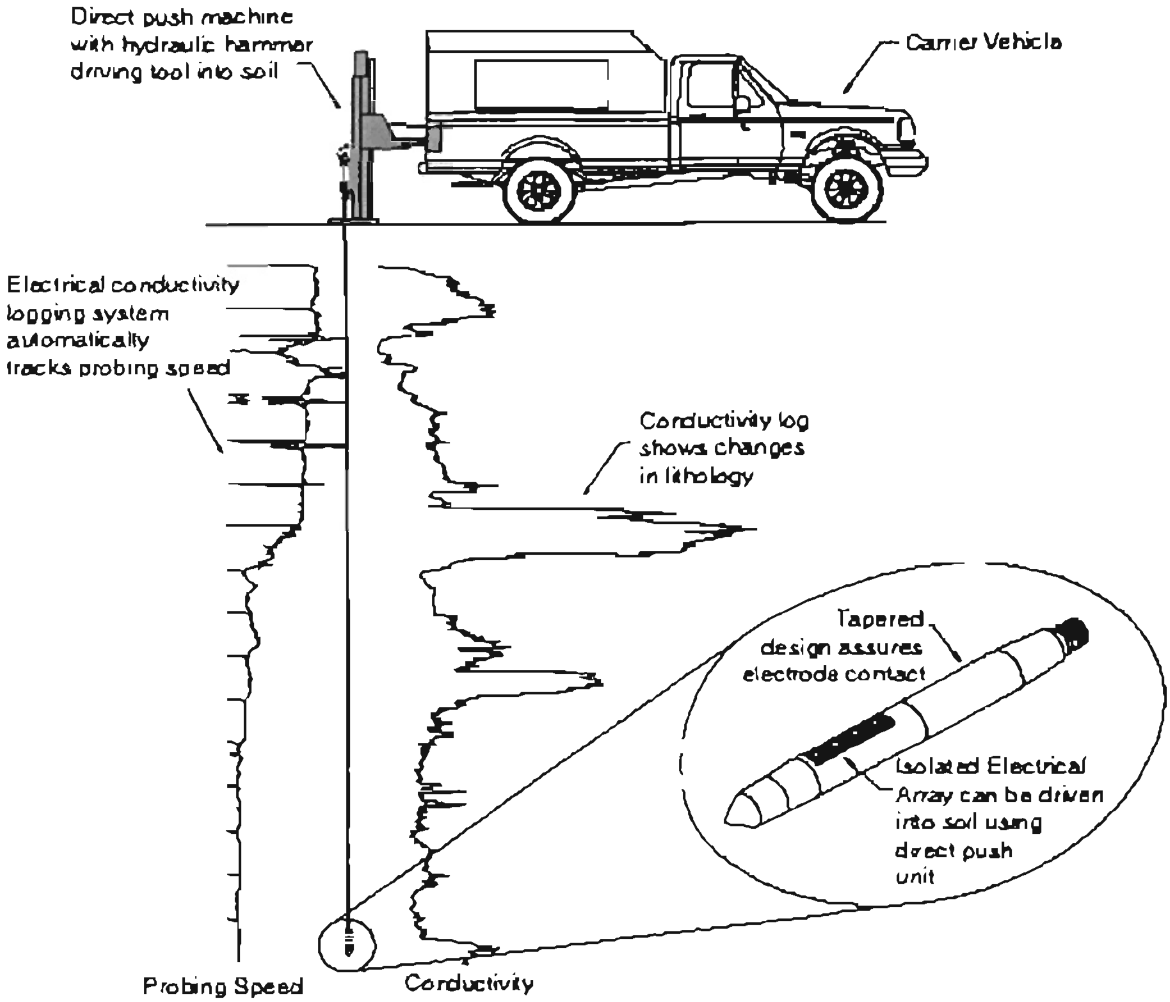


Figure 7. Schematic showing Geoprobe® set-up (Illustrations Courtesy of Geoprobe® website)

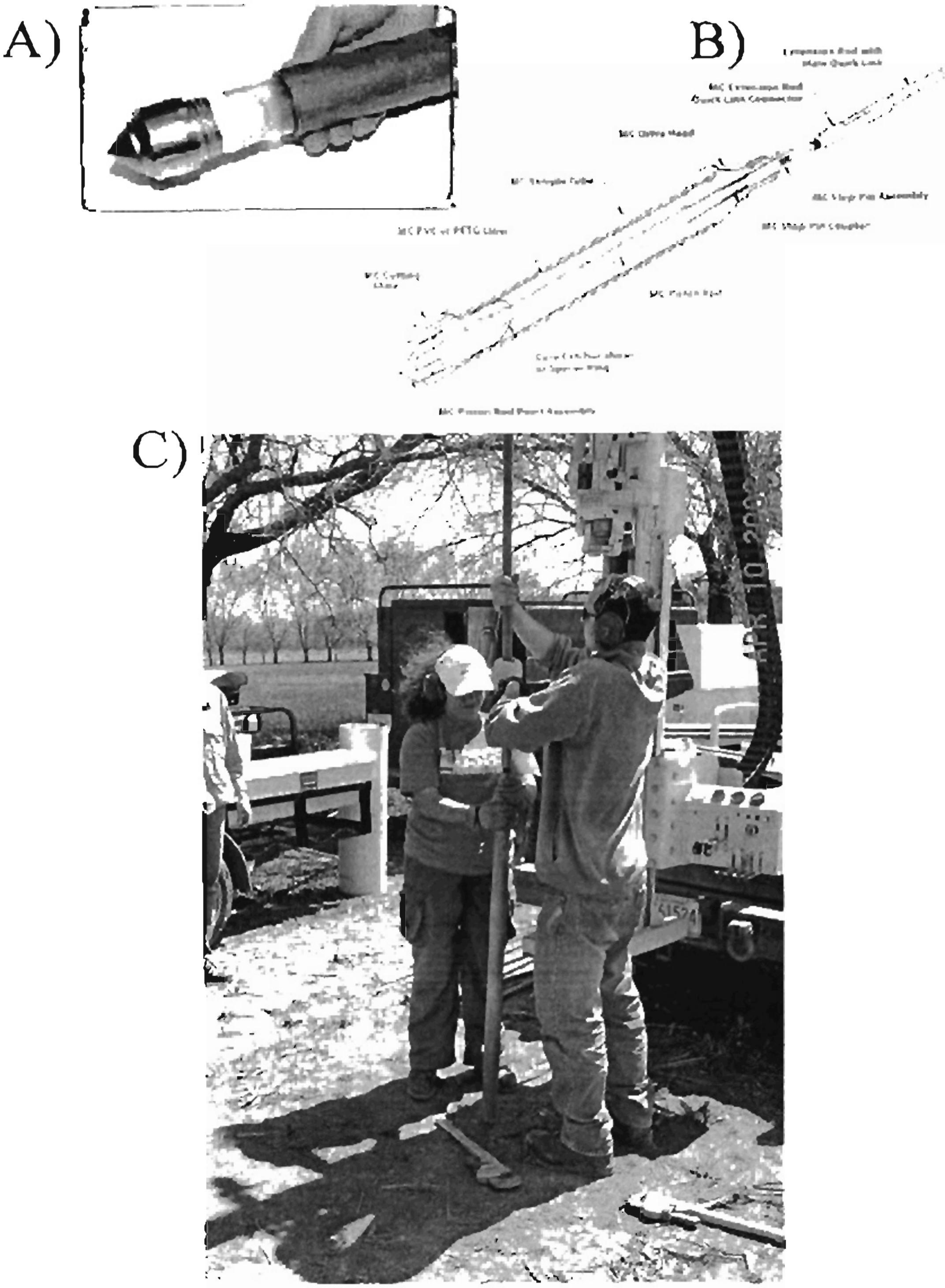
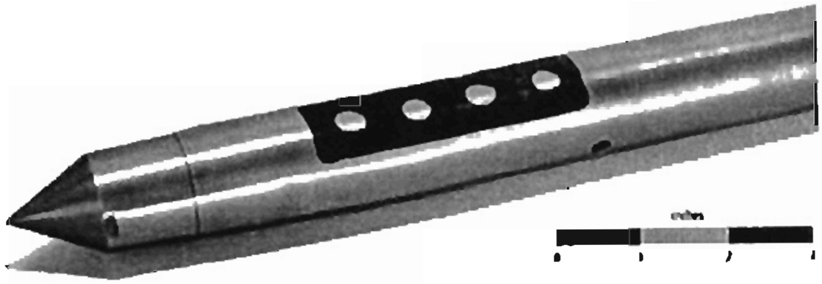
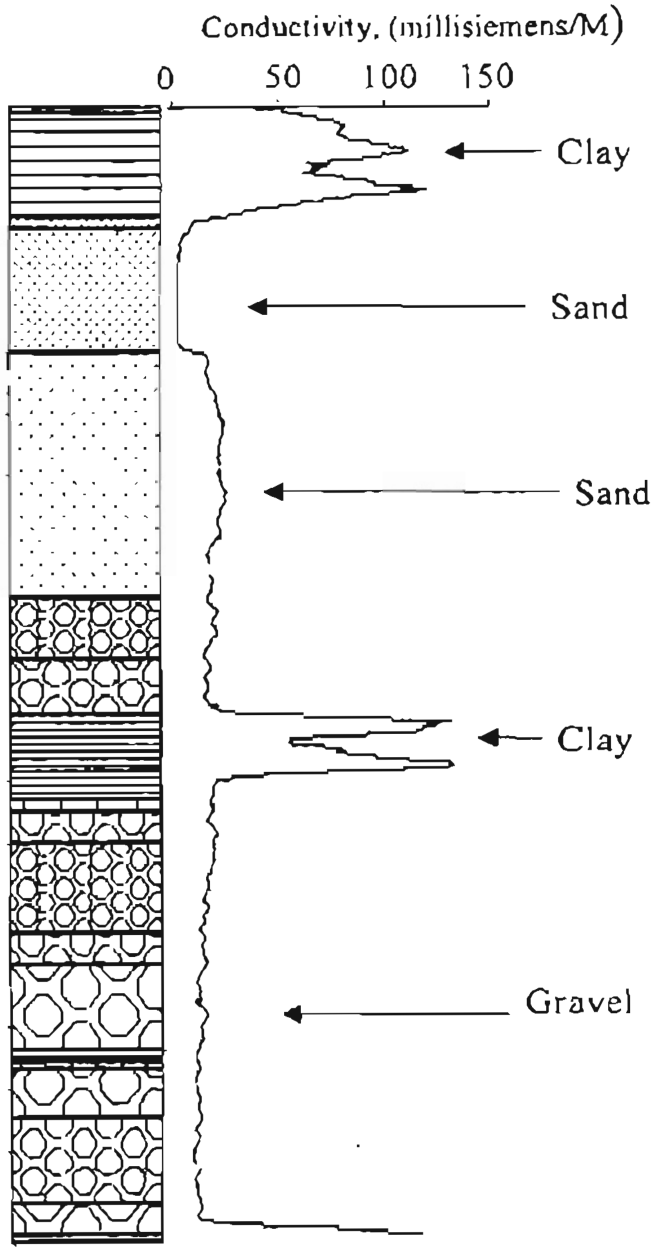


Figure 8. A) Photo of core barrel and piston B) Schematic of Geoprobe® macro-core piston rod soil sampler C) Field photo of core extraction from Arkansas River floodplain. A) and B) courtesy of Geoprobe website



SC400 Electrical Conductivity Probe



Finer-grained sediments typically display higher conductivities. Coarser-grained Sediments typically display lower conductivities

Figure 9. Conductivity probe and typical log response to varying sediment type

Description of Cores

To maintain the stratification of sediments, cores were stored vertically in the laboratory and allowed to dry. After drying, the cores were placed horizontally and the polycarbonate core liners were sliced open. The cores were described and their properties indicated using a standard Petra-log form at a scale of 1 inch equals 1 foot of core. Properties of the sediments noted in the descriptions included estimates of texture, (grain size and sorting), color, and bed thickness. Grain size and sorting estimates were made by comparing hand samples to a grain size/sorting estimator card. Conductivity logs were correlated to cores to establish log responses to varying sediment type and bedrock (Figure 9). This allowed the use of conductivity logs to infer sediment type when core recovery was limited or cores were unavailable. Each core was divided into genetic units. These units were chosen based on grain size and sorting. After the sediment cores were described, they were photographed using a digital camera. Photographs of the twenty continuous cores are included in Appendix E.

Core Textural Analysis

Sediment samples with a mass of approximately 100 grams were taken from each genetic unit. The samples were placed in plastic bags and labeled for storage. A series of eleven wire-mesh sieves with openings ranging in size from 16mm-.045mm. (16000µm-45µm), were stacked in descending order with the largest size on top. Each sample was then sieved for approximately 12 minutes using a Ro-Tap machine. The mass of sediment collected in each sieve was determined using an electronic balance. Mass percent of each grain size was plotted against cumulative mass percent to produce a cumulative frequency curve for each sample (Figure 10). Cumulative frequency curves for each sample are included in Appendix D.

Grain sizes shown on the cumulative frequency curves are expressed in phi units. The phi scale is a logarithmic scale that allows grain size data to be expressed in units of equal value for the purpose of graphical plotting and statistical calculations. Particle size, expressed in millimeters, decreases with increasing phi values and increases with decreasing negative values (Boggs, 1987). The relationship of phi to millimeter diameter is expressed by:

$$\text{Phi} = -\log_2 d$$

where d = diameter of grains in mm.

Each cumulative frequency curve was used to determine the statistical parameters of mean grain size, sorting, (expressed as standard deviation), and skewness for each sample (Folk, 1967), (Figure 10). The formulas used to determine these statistical parameters are provided in (Appendix A). The statistical parameters calculated in this thesis were utilized by (Mashburn, 2003) to determine hydraulic conductivity and transmissivity of the alluvial aquifer.

General Mineralogical Analysis

Mineralogical composition of selected sediment samples was evaluated by two methods: 1) Thin-section microscopy of the sand-size grain size fractions and 2) visual examination of pebble sized and larger grains. Thin-sections were produced from selected samples (Tables 1 and 2). The unconsolidated sediment was embedded in epoxy and secured to a glass slide. After hardening, the sediment-epoxy mixture was sliced and ground to a desired thickness and its surface polished. The completed thin-sections were viewed under a Nikon petrographic microscope. Mineralogy of individual grains was identified and photo-micrographs of the thin sections were taken. Mineralogy and roundness of the pebble sized and larger grains are recorded in Tables 1 and 2.

Heavy Grain (Magnetite) Analysis and Comparisons

After each individual sediment sample had been sieved and the mass of each grain size had been entered into an Excel spreadsheet, samples from selected test holes were homogenized and sieved a second time. Sediment samples from a given core were divided into the following seven grain-size fractions: (>1mm, 500-1000μm, 250-500μm, 125-250μm, 63-125μm, 45-63μm and <45μm). Sediments from each of these seven grain-size fractions were labeled and placed in separate plastic bags. The sediments were thoroughly homogenized within the sample bags, and a fifty-gram sample was extracted from each of the core's grain size fractions. These samples were subjected to a magnetic field to determine mass percent of magnetite in the sediment and the distribution of magnetite by grain size. Magnetite separation was achieved by placing magnets on either side of the neck of a glass laboratory funnel, and slowly trickling the fifty grams of sediment through the funnel (Fig 11).

Grains of magnetite and grains containing magnetite were retained inside the funnel neck while the remaining sediment was allowed to fall freely and collect in a beaker. This proccss was repeated on the sediment collected in the beaker to ensure complete capture of magnetite. The magnetic grains collected during these two trials were passed through the apparatus a third time to remove non-magnetic grains that may have been trapped in the field by adjacent magnetic grains. Magnetite grains collected from each fifty-gram sample were placed in separate containers and labeled. The mass of the extracted magnetite grains was determined and recorded in (Table 3).

Magnetite grains were systematically extracted from the sediments of eight continuous cores. Four cores were sampled from the alluvium, and four cores were sampled from the terrace deposits (Figures 2 and 3). For each alluvium core examined a corresponding terrace core located in close proximity and roughly downwind, (to the north-northeast), from the alluvium core was examined (Figures 2 and 3). This was done to determine if similarities or differences in grain size existed between wind-blown terrace deposits and their alluvium source material. Magnetite was chosen because preliminary visual examination of the samples revealed an apparent lack of magnetite grains in the coarser grained fractions of the terrace deposits as compared to the similar-sized alluvium sediments.

Cumulative curves for samples taken from Test Hole 002A

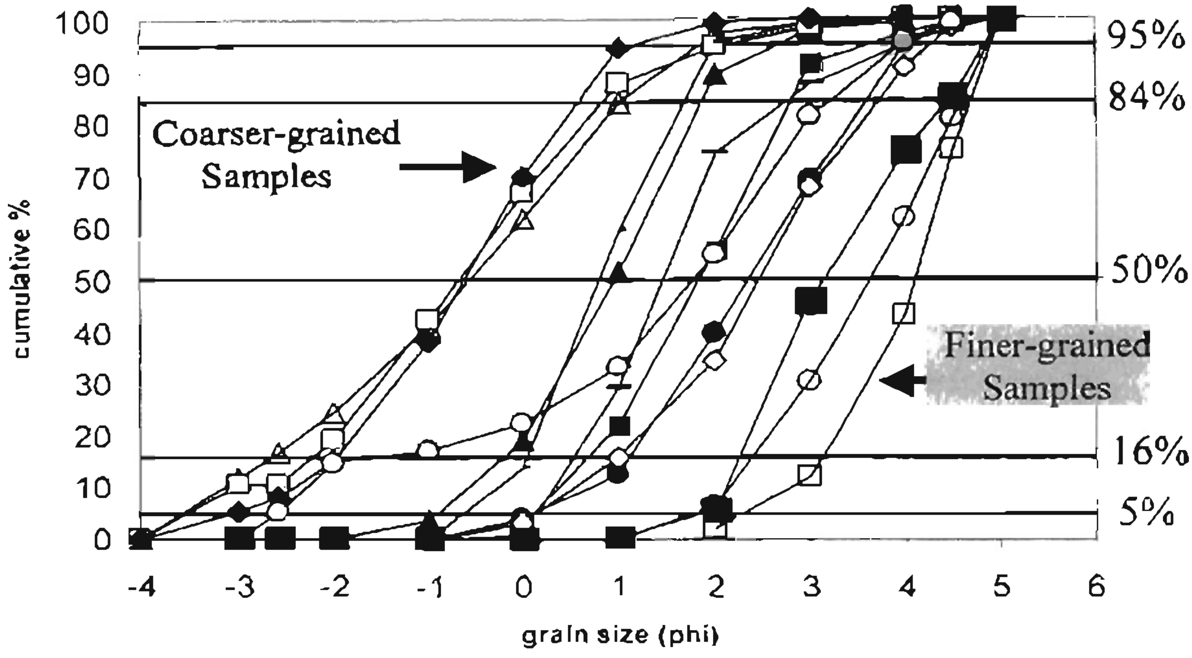


Figure 10. Example of cumulative curves used for estimating mean grain size, sorting and skewness. (Formulas included in Appendix A)

Lithology of Selected Alluvium Sediment Cores

Test Hole	Composition of Grains >4mm	Angularity	Cored Type of Bedrock	Underlying Formation	Sand Size Composition
002A	Limestone	Sub-angular	Weathered Shale	Pennsylvanian Ada: fine-grained sandstones interbedded with limestone and shale	Quartz, feldspar, granitic and sedimentary rock fragments, with some chert and magnetite grains
	Chert	Sub-rounded			
	Siltstone	Sub-rounded			
	Sandstone	Sub-rounded			
	Granitic	Sub-rounded			
010A	Chert	Sub-angular	Weathered Shale	Pennsylvanian Vamoosa: shale and fine to coarse grained sandstone with some limestone	No thin section
	Siltstone	Sub-angular			
	Granitic	Sub-rounded			
022A	Limestone	Sub-angular	Not Penetrated	PennsylvanianVanoss : Limestone, shale and sandstones	No thin section
	Chert	Sub-angular			
	Sandstone	Sub-angular			
	Granitic	Sub-rounded			
071A	Limestone	Sub-angular	Not Penetrated	Pennsylvanian Oscar: Mainly shale with layers of limestone and sandstones	Quartz, feldspar, granitic and sedimentary rock fragments, with some chert and magnetite grains
	Sandstone	Sub-angular			
	Granitic	Sub-rounded			

Table 1. Composition of alluvium cores. Sand-sized composition is based upon thin section microscopy, and is Similar in all cores. Composition of large grains, (>4mm) is based upon visual inspection of cores and seems to reflect local bedrock lithology.

Lithology of Selected Terrace Sediment Cores

Test Hole	Composition of Grains >4mm	Angularity	Cored Type of Bedrock	Underlying Formation	Sand Size Composition
028T	NA	NA	Weathered Shale	Pennsylvanian Ada: fine-grained sandstones interbedded with limestone and shale	No thin section
035T	NA	NA	Not Penetrated	Pennsylvanian Oscar: Mainly shale with layers of limestone and sandstones	Quartz, feldspar, granitic and sedimentary rock fragments, with some chert and magnetite grains
039T	NA	NA	Weathered Shale	Pennsylvanian Oscar: Mainly shale with layers of limestone and sandstones	No thin section
053T	NA	NA	Weathered Shale	Permian Wellington : Shale, fine-grained Sandstone and mudstone conglomerate	No thin section

Table 2. Composition of Terrace cores. Sand-sized composition is based upon thin section microscopy, and is similar in all cores. No grains larger than >4mm were found.

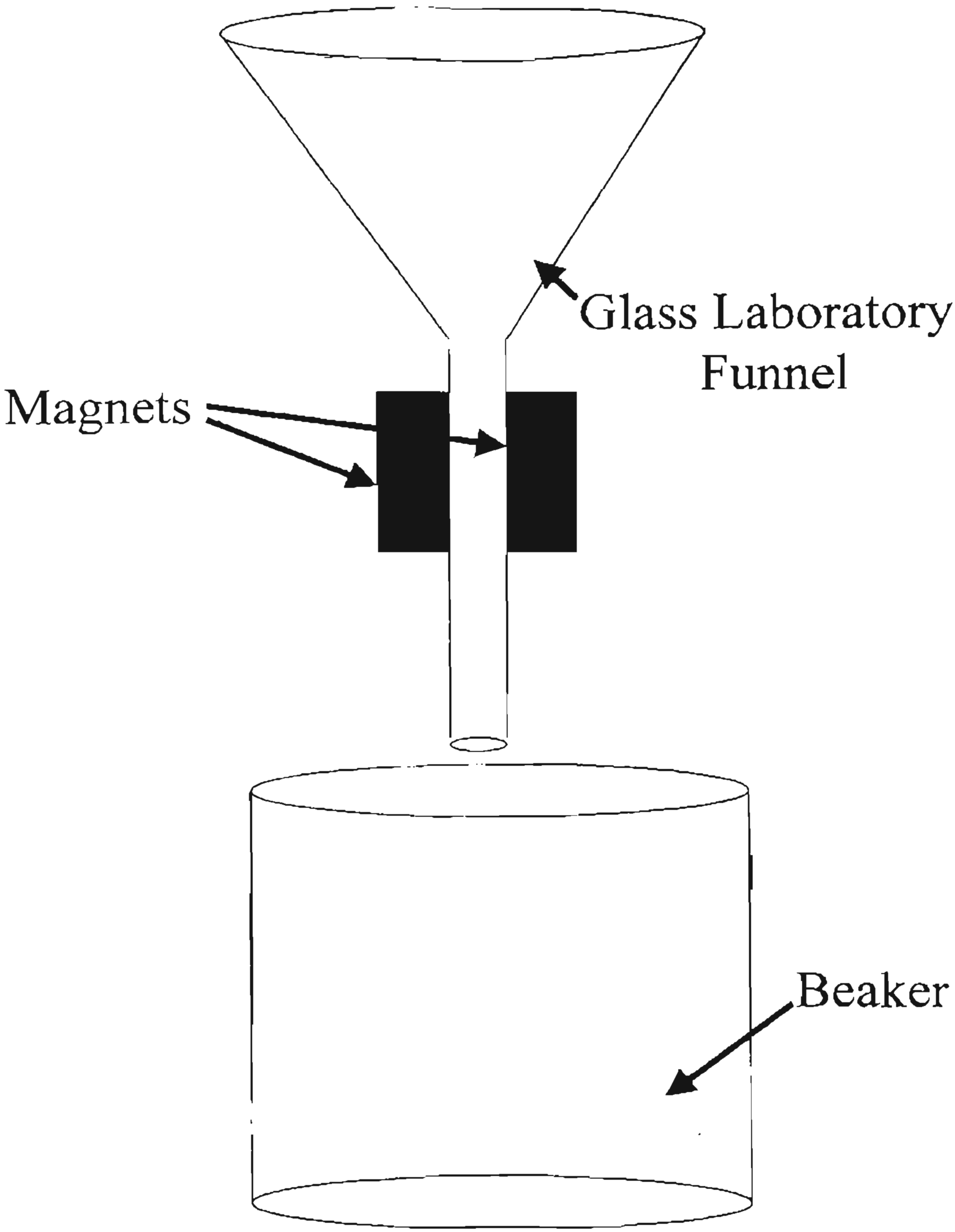


Figure 11. Schematic diagram of magnetite separation apparatus

Test Hole ID	grain size fraction	mass retained (grams)	Well ID	grain size fraction	mass retained (grams)
002A	>1mm	0.02	011T	>1mm	na
002A	500-1mm	0.04	011T	500-1mm	0.01
002A	250-500µm	0.09	011T	250-500µm	0.01
002A	125-250µm	0.19	011T	125-250µm	0.08
002A	63-125µm	0.13	011T	63-125µm	0.13
002A	45-63µm	0.12	011T	45-63µm	0.05
002A	<45µm	0.03	011T	<45µm	0.00
056A	>1mm		053T	>1mm	
056A	500-1mm	0.00	053T	500-1mm	
056A	250-500µm	0.04	053T	250-500µm	0.01
056A	125-250µm	0.04	053T	125-250µm	0.00
056A	63-125µm	0.07	053T	63-125µm	0.02
056A	45-63µm	0.03	053T	45-63µm	0.01
056A	<45µm	0.00	053T	<45µm	0.00
022A	>1mm	0.02	035T	>1mm	
022A	500-1mm	0.05	035T	500-1mm	0.02
022A	250-500µm	0.06	035T	250-500µm	0.03
022A	125-250µm	0.05	035T	125-250µm	0.03
022A	63-125µm	0.09	035T	63-125µm	0.17
022A	45-63µm	0.06	035T	45-63µm	0.04
022A	<45µm	0.05	035T	<45µm	0.01
047A	>1mm	0.04	027T	>1mm	
047A	500-1mm	0.01	027T	500-1mm	0.01
047A	250-500µm	0.11	027T	250-500µm	0.01
047A	125-250µm	0.07	027T	125-250µm	0.03
047A	63-125µm	0.43	027T	63-125µm	0.13
047A	45-63µm	0.14	027T	45-63µm	0.04
047A	<45µm	0.01	027T	<45µm	0.02

Table 3. Mass of magnetite by size extracted from 4 terrace and 4 alluvium cores, (see figures 2 and 3 for locations)

Chapter IV

RESULTS AND DISCUSSION

Stratigraphy of Sediments

Cores taken from terrace deposits contained relatively uniform stratigraphy from land-surface to bedrock. These deposits consisted mostly of coarse silt and very fine to medium-grained sand. They contained very few clay layers or grains larger than 1mm.

A typical terrace core is shown in Figures 12 through 14. A thin, organic-rich soil horizon forms the uppermost unit (Figures 13 and 14). A color change from light brown to reddish brown at approximately 1.75 feet (Figures 13 and 14) appears to be the result of hematite staining. Overall sorting is moderate and other than color change, there is no significant change in sediment character from this point to bedrock.

Cores taken from alluvium deposits displayed significant variability in grain size and compositon when compared to cores taken from terrace deposits. Grain sizes of alluvium sediments ranged from cobble to clay-sized particles. As suggested by the work of Foreman and Sharp (1980), there appear to be three general facies associated with the alluvium: 1) A lower cobble-pebble facies, 2) a middle coarse-medium size sand facies, and 3) an upper silt-clay facies. However, the alluvium sediment column along the Arkansas River is more complex. The lower cobble-pebble facies contained multiple smaller-scale fining-upward sequences, each of which was approximately 2-4 feet thick, (Figures 15-18). The grain size in these sequences ranged from granule-pebble to fine grained sand with each cycle containing pebbles at its base. The middle part of the cores was dominated by fine to medium grained sand, and the upper sections were dominated by very fine grained sand and coarse silt.

A typical alluvium core is shown in (Figures 15-18). A thin, organic rich soil horizon forms the uppermost unit (Figures 16 and 17). Smaller-scale fining-upward sequences present in the lower sections of the core are evident (Figures 16 -18). In general, fining upward sequences indicate a decrease in transporting power of currents during deposition. These fining upward sequences are inferred to be the result relatively brief periods of high depositional energy such as those associated with storm events.

General stratigraphy of the alluvium cores suggests that the sediments were deposited in a fluvial system that experienced fluctuations in depositional energy. The coarse-grained material was deposited during a high flow regime. As the current energy decreased, finer grained material was deposited above these sediments. The uniform nature of the terrace stratigraphy suggests a relatively stable depositional setting in which energy did not fluctuate significantly.

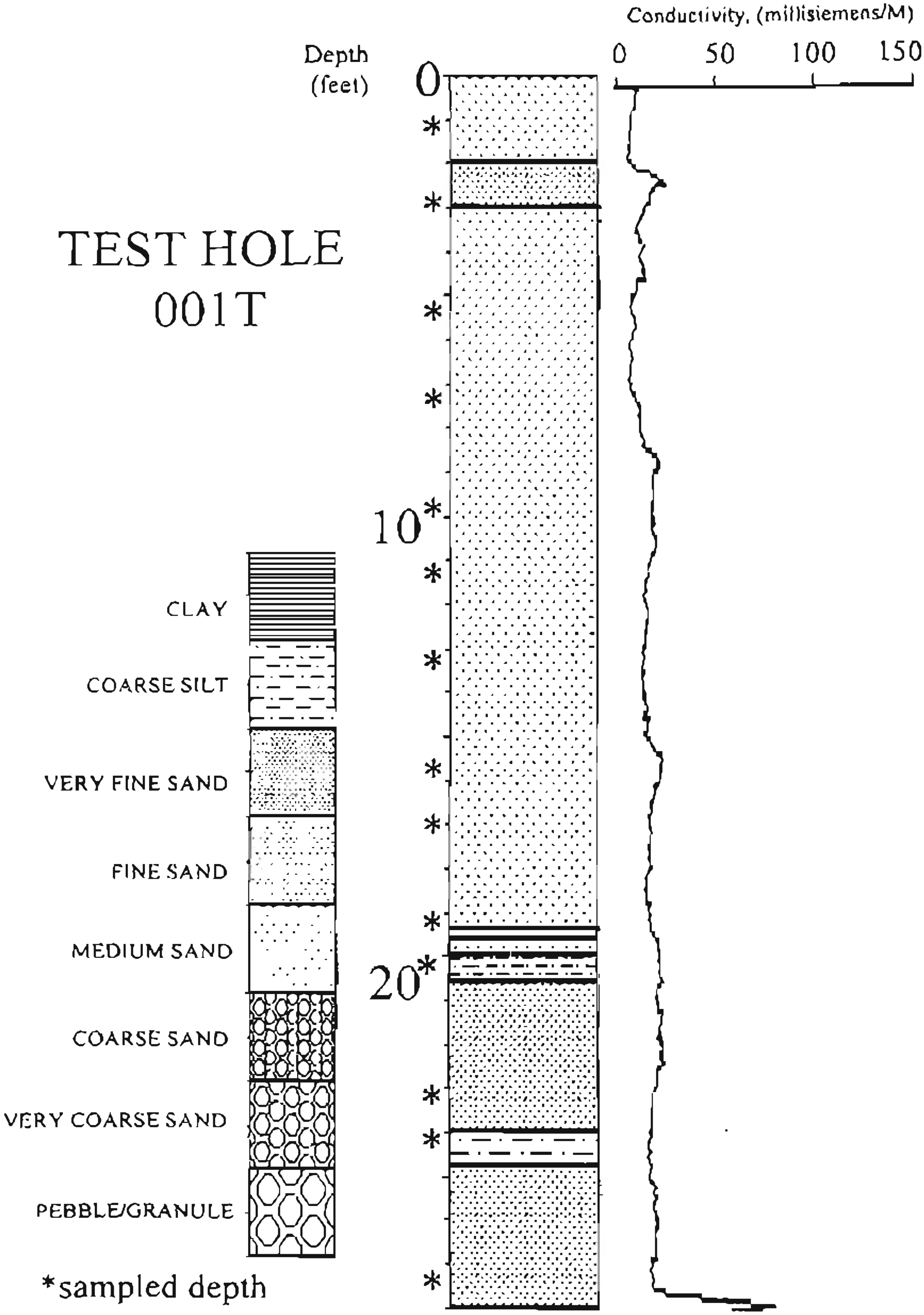


Figure 12. Strip log of typical terrace core (001T)

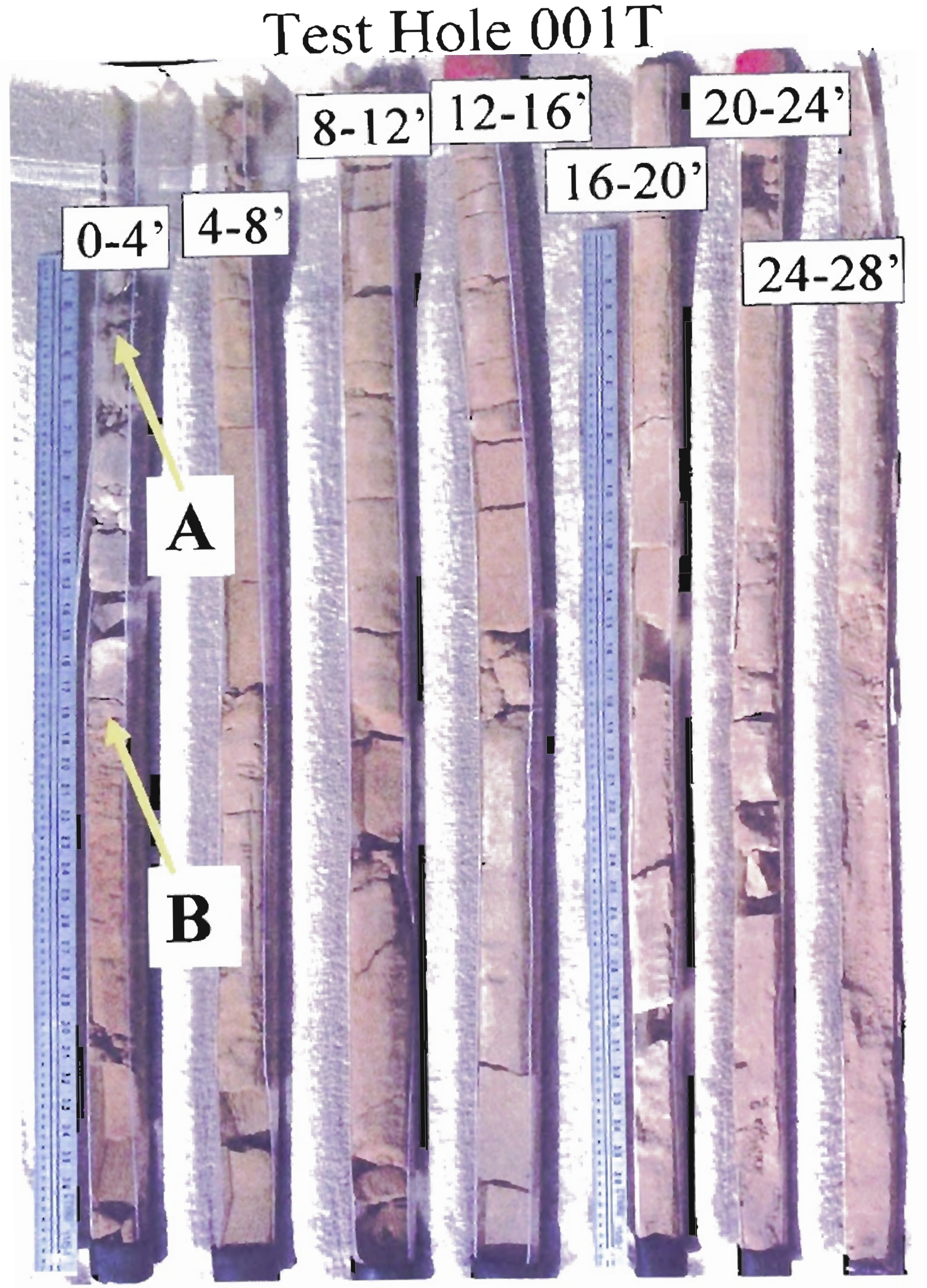


Figure 13. Photo of typical terrace core (001T)

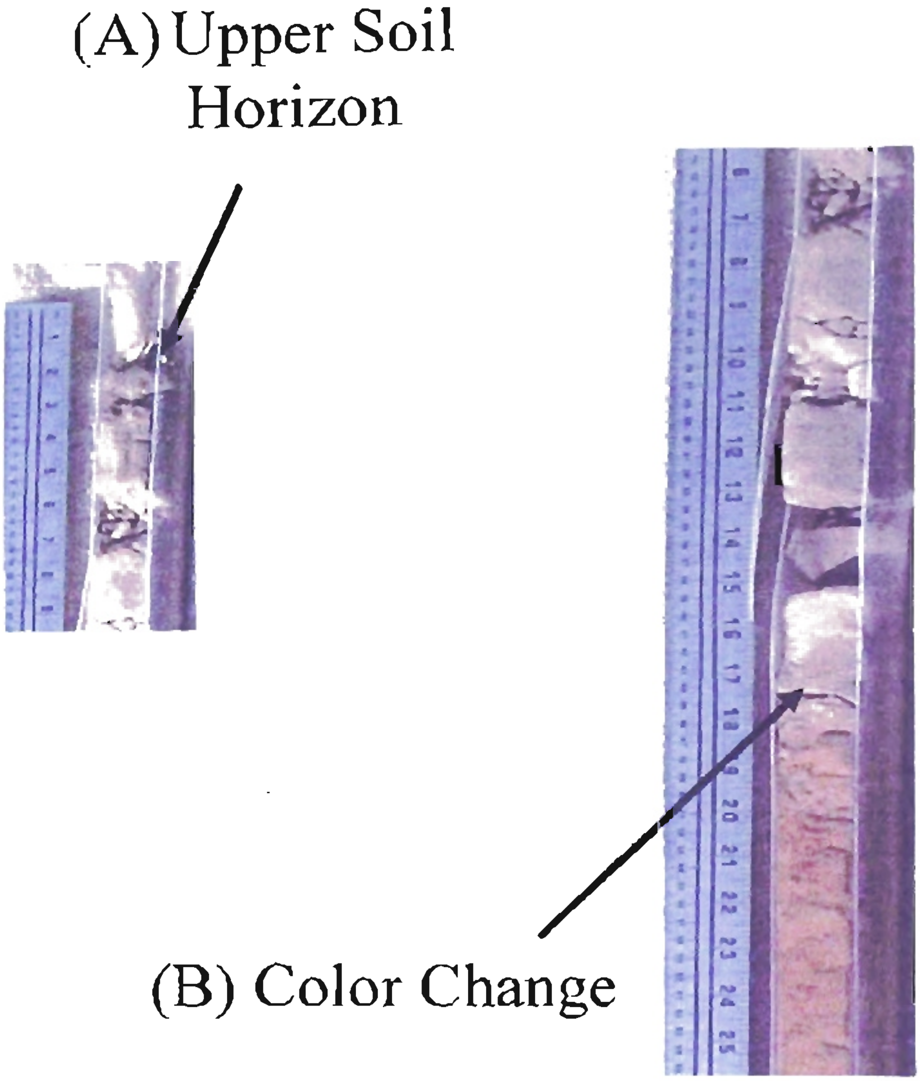


Figure 14. Close-ups of typical terrace features: A) Upper soil horizon B) Color change indicating possible hematite staining resulting from oxidation

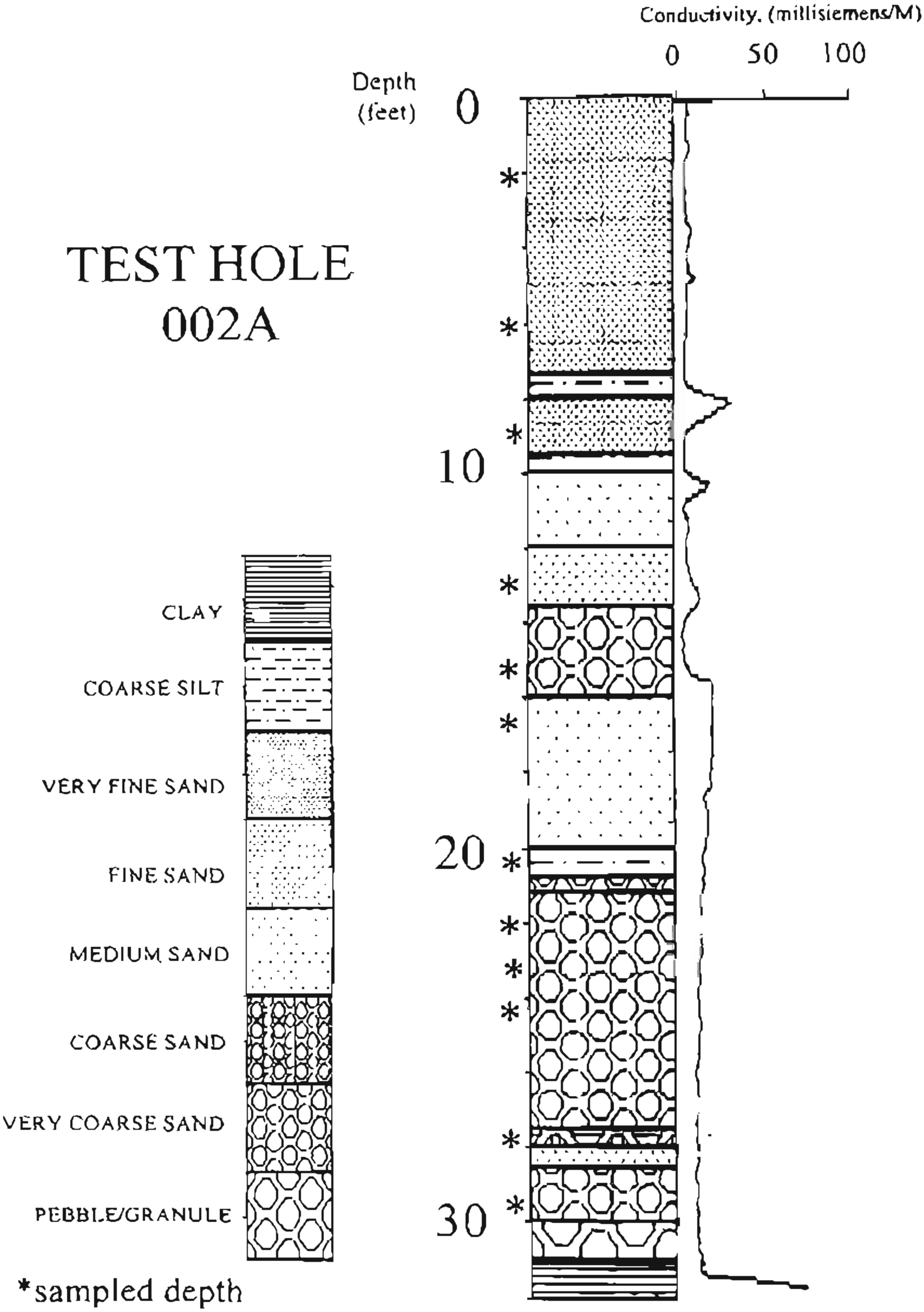


Figure 15. Strip log of typical alluvium core (002A)

Test Hole 002A

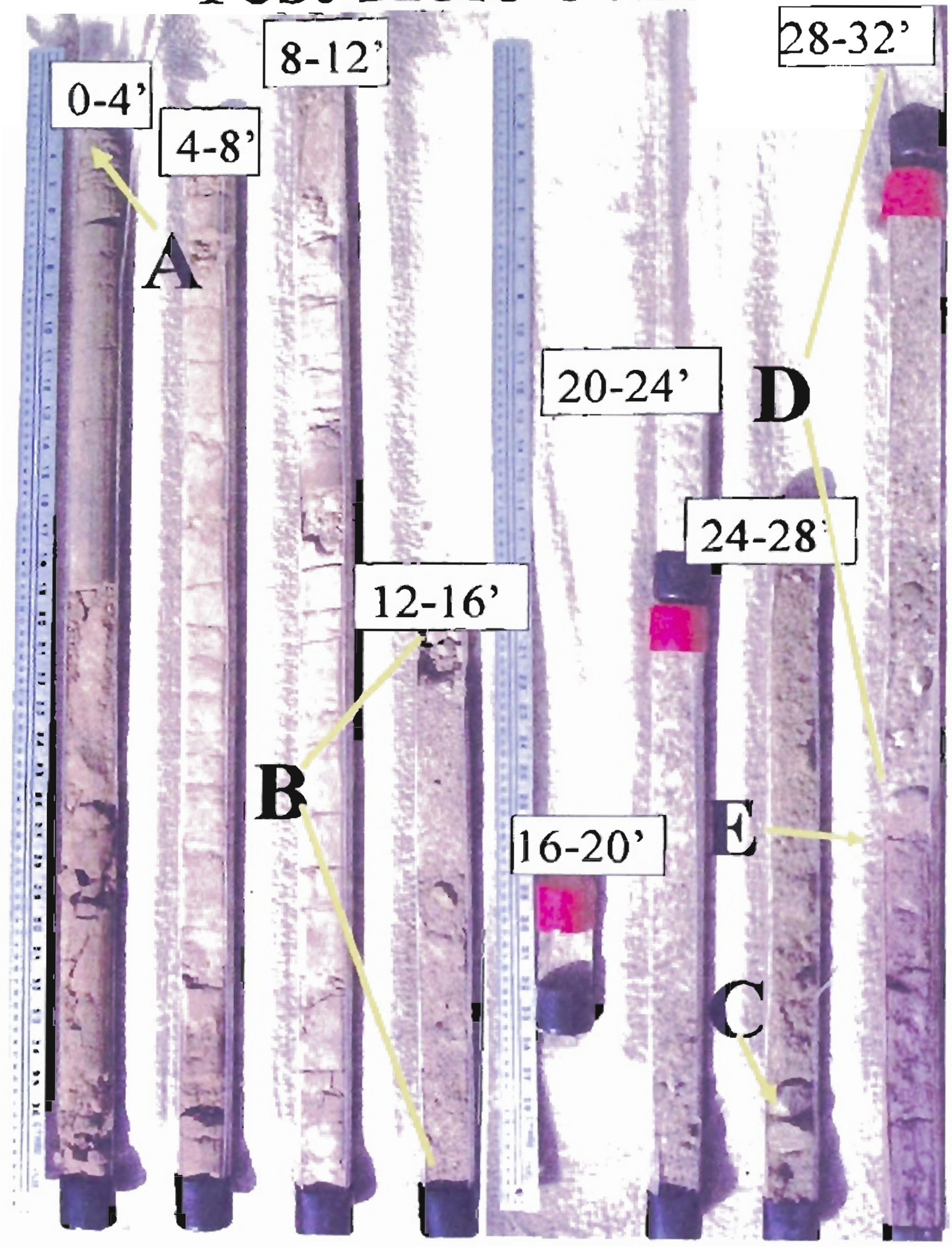


Figure 16. Typical alluvium core (002A), contains stacked fining-upward Sequences with lag deposits at base (B, C and D)

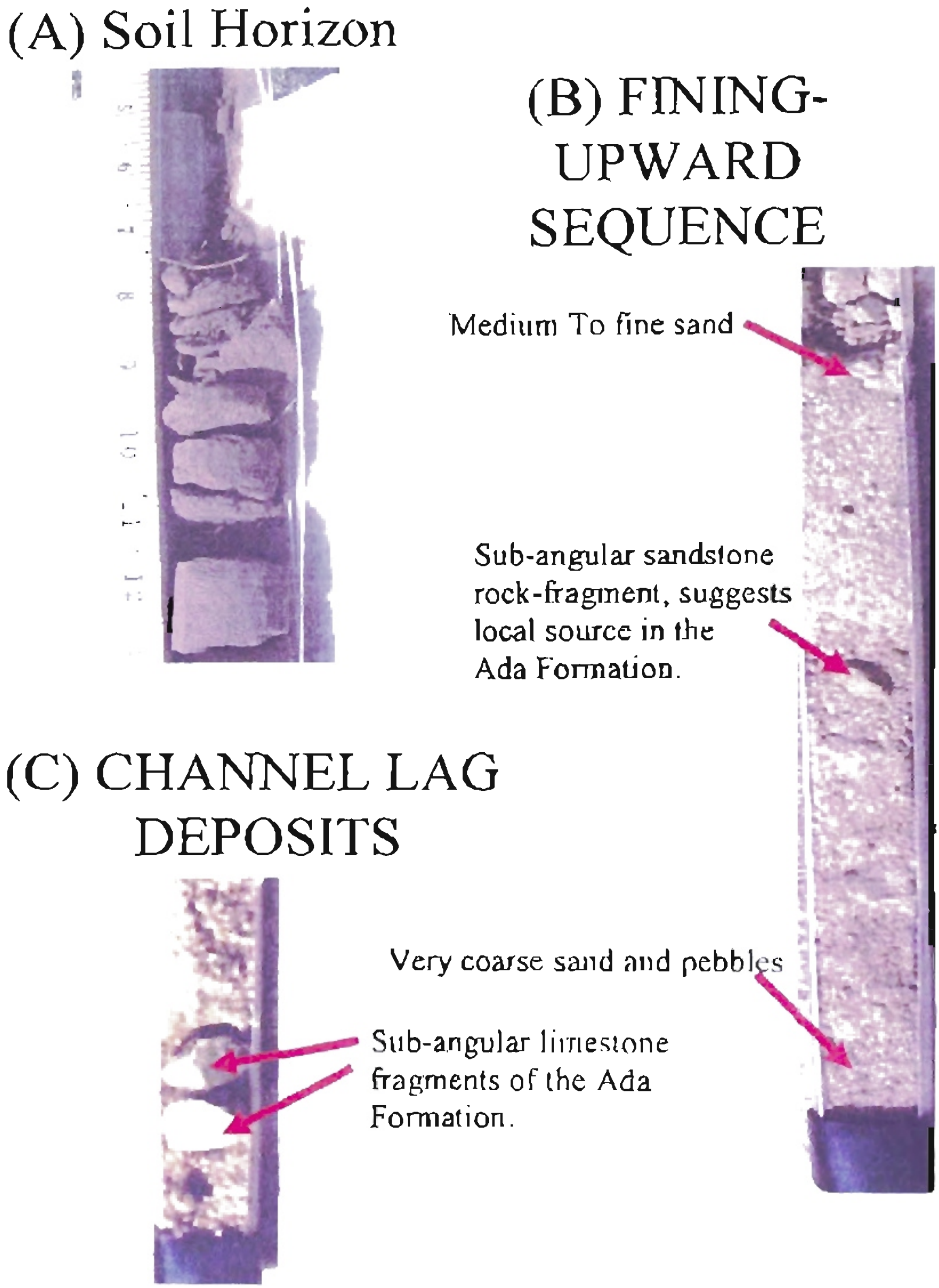


Fig. 17-Photographs of typical alluvium features: A) Organic rich soil horizon B) Fining-upward sequence C) Pebble lag deposits at base of fining-upward sequence

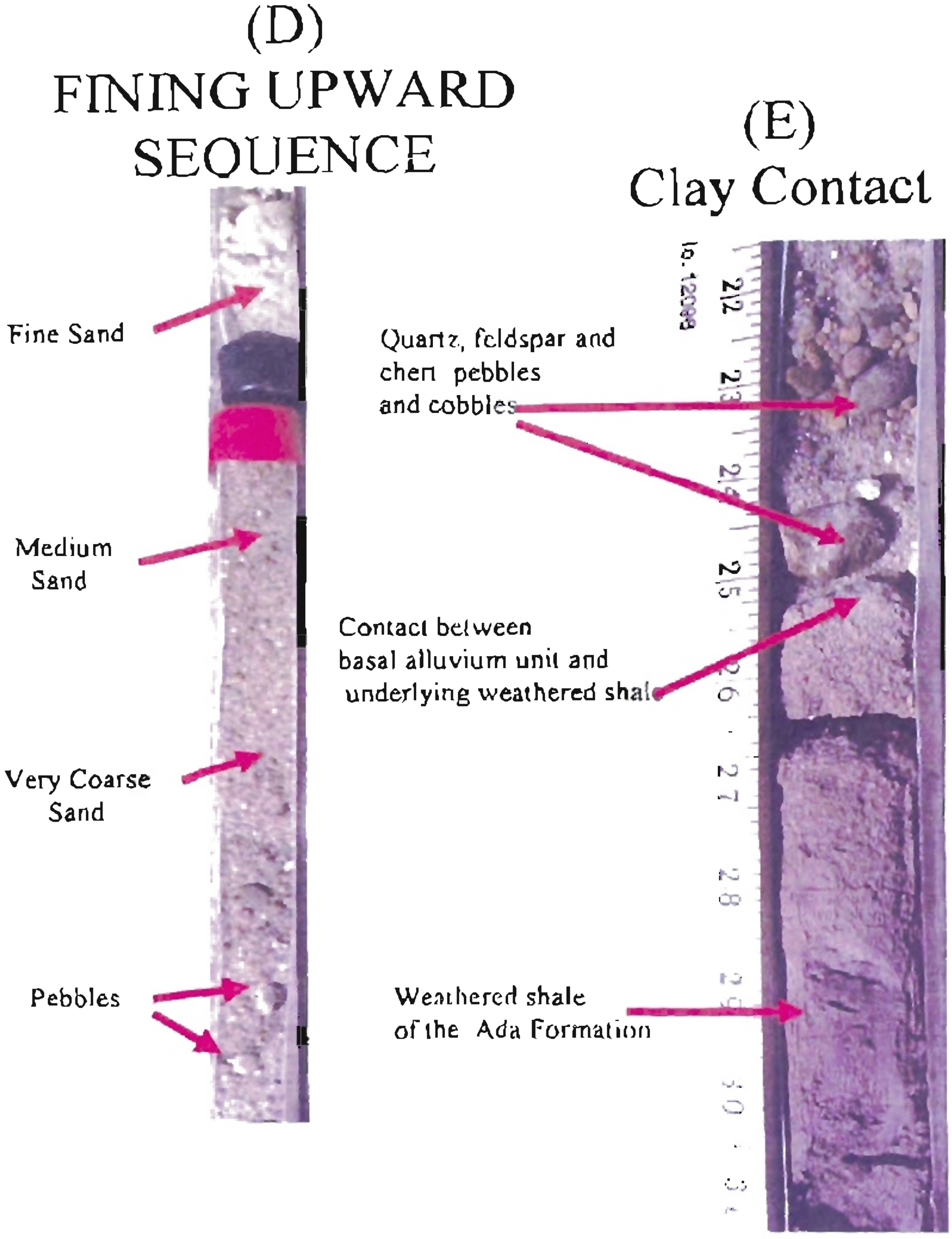


Figure 18. Photographs of typical sediment features of alluvium deposits: D) Fining-upward sequence E) Contact with weathered shale at base of aquifer, where Quartz, feldspar and chert pebbles overly clayey material.

Grain Size Statistics

Mechanical sieving of samples taken from alluvium and terrace cores generated a volumous amount of grain size data. Sieve data, in its entirety is included in Appendix B. Data are represented graphically by the cumulative frequency curves (Appendix D). By extracting data from the curves, average properties of the grain size population, (mean grain size, sorting and skewness), were evaluated through statistical methods (Appendix A) (Figure 10).

Mean Grain Size

The mean grain size is an arithmetic average of all the particles in a sample. Due to the difficulties of counting the total number of grains and measuring the size of each of these grains, the true arithmetic mean size cannot be easily determined. Instead, the arithmetic mean can be approximated by picking selected percentile values from each sample's cumulative frequency curve and averaging these values (Boggs, 1987). The formula used to determine each sample's mean grain size is included in Appendix A. Mean grain size values for each sample are included in Appendix C.

Mean grain size values for terrace samples were consistently smaller than those associated with alluvium samples (Appendix C). Mean grain size for terrace samples ranged from 4.1 to 1.5Φ, (.06-.35mm). Mean grain sizes for alluvium samples ranged from 4.7 to .2Φ, (.04-.87mm).

In addition to each individual sample's mean grain size, an average grain size for each test hole was estimated. This was achieved by multiplying each sample's mean grain size by the thickness of the genetic unit from which the sample was collected. These interval values were summed and divided by the total thickness of each core to calculate an estimated mean grain size for each test hole. Estimated Mean grain sizes for each core are included in Appendix C. Values ranged from 4.02 to 2.01Φ, (0.06-0.25 mm) for terrace test holes, and ranged from 3.69 to .64Φ, (0.08-0.64 mm) for alluvium test holes. The mean of these values was 1.67Φ, (0.31millimeters) for the alluvium test holes and 2.73Φ, (0.15 millimeters) for the terrace test holes. The difference in estimated mean grain size between cores of terrace deposits and cores of alluvium deposits is statistically significant at the $p = 0.0108$ level.

The fine-grained nature of the terrace deposits (Figure 19) supports the notion that they are eolian, (wind deposited). In addition, eolian deposition is supported by the uniform stratigraphy of the terrace deposits from land surface to bedrock. The coarse-grained nature and fining-upward sequences contained in the alluvium cores suggest fluvial depositional processes.

Sorting

The sorting of a grain population is a measure of the range of grain sizes present and the magnitude of the scatter of these sizes around the mean size. The mathematical expression of sorting is standard deviation (Boggs, 1987). The formula for calculating standard deviation is given in Appendix A. According to Folk (1968), sorting depends on at least three major factors: 1) Size range of the material supplied to the environment, (samples with a large range of grain sizes will be more poorly sorted than samples of a smaller range of grain sizes), 2) type of deposition, and 3) current characteristics, (currents of relatively constant strength, will give better sorting than currents which fluctuate rapidly). Sorting values calculated for each sample are included in Appendix C.

Sorting values, derived from sieve data and calculated as standard deviation according to Folk (1968) indicated that terrace deposits were better sorted than alluvial deposits, (Figures 20, 21 and Appendix C). 70% of the 92 alluvium samples were either poorly or very poorly sorted, whereas only 57% of the 89 terrace samples fell within this range. In contrast, 41% of the terrace samples were moderately sorted whereas 23% of the alluvium samples fell in the moderately sorted range (Figure 20 and Appendix C).

Skewness

Most natural sediment grain-size populations do not exhibit a normal or log-normal grain-size distribution. The cumulative frequency curves of such non-normal populations are not perfect bell-shaped curves, instead they show some degree of asymmetry, or skewness (Boggs, 1987). Skewness reflects sorting in the "tails" of a grain size population. Populations that have a tail of excess fine particles are said to be positively skewed or fine-skewed. Populations with a tail of excess coarse particles are negatively skewed, or coarse skewed (Folk, 1968). According to Folk (1968), single source sediments (beach or eolian sands) tend to have fairly normal curves, whereas sediments from multiple sources (river sands with locally derived pebbles) show pronounced skewness. The formula for calculating skewness is included in (Appendix A).

Measurements of skewness, based upon sieve data and calculated according to Folk (1968) showed that the terrace samples were more finely skewed than the alluvium samples (Figure 22) and (Appendix C). Of the 89 terrace samples analyzed, 74% were fine-skewed to near symmetrical, whereas only 52% of the 92 alluvium samples fell within this range. 49% of the alluvium samples were categorized as either coarse-skewed or strongly-coarse skewed, while only 26% of the terrace samples fell within this range.

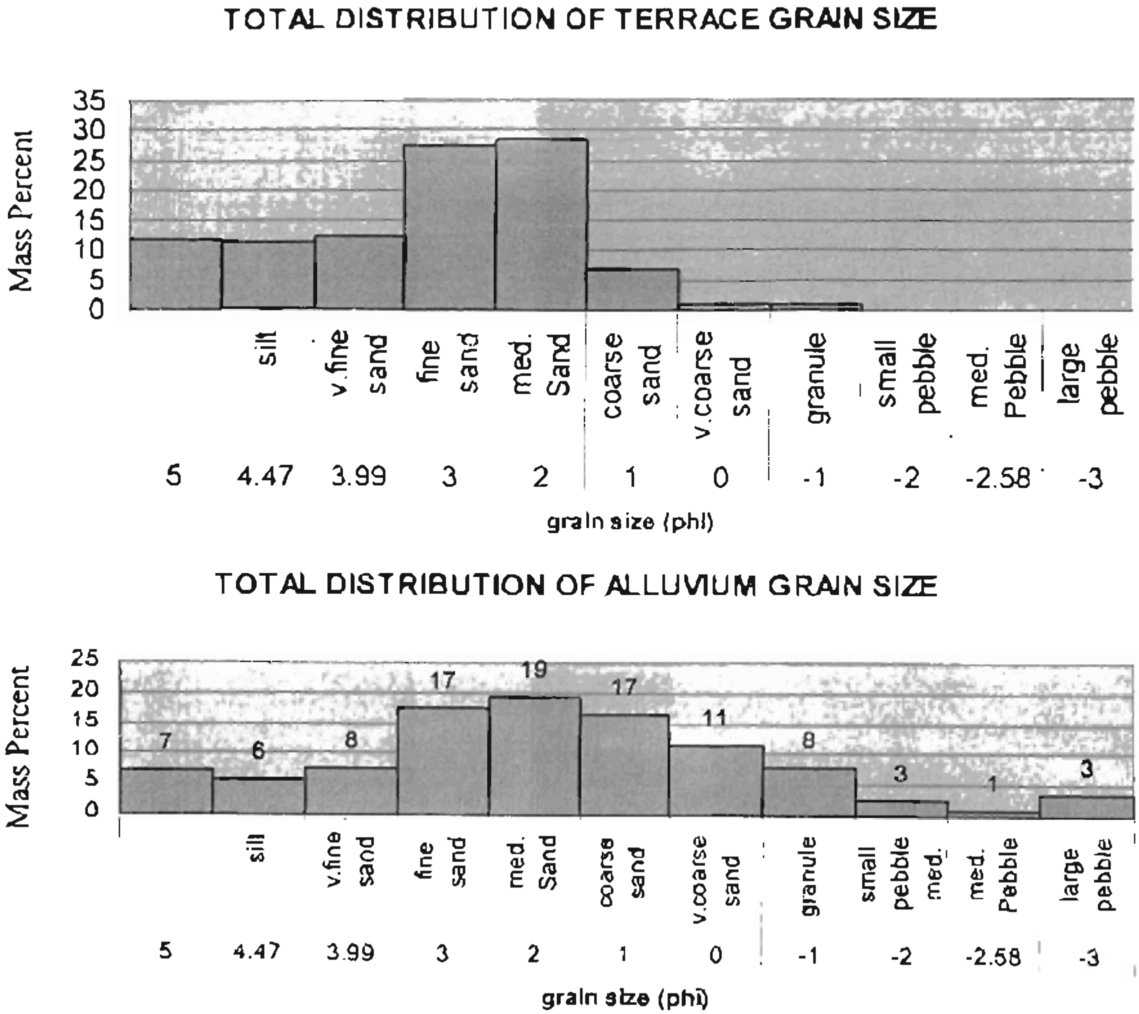
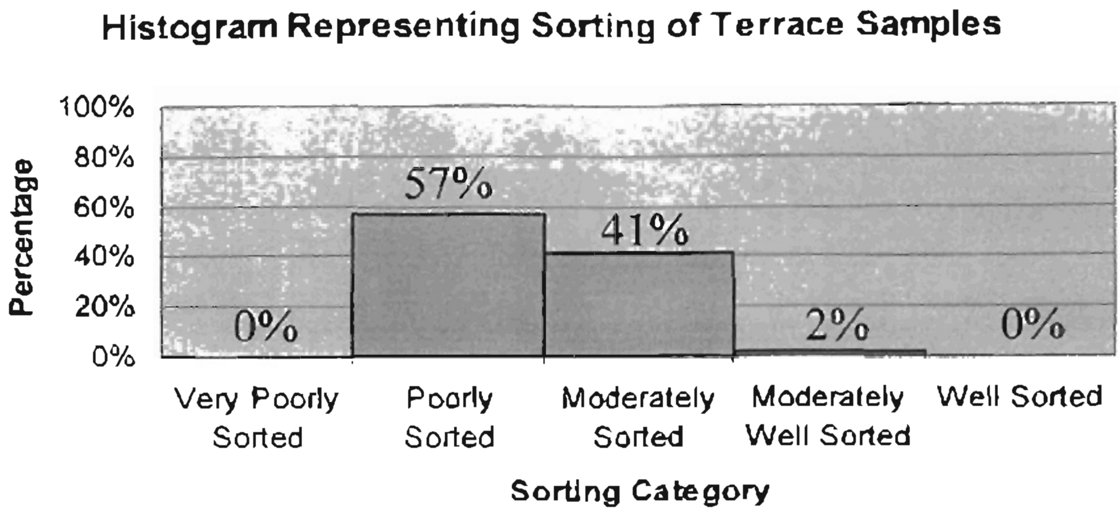


Figure 19. Histograms representing total grain size distribution of terrace and alluvium cores. Represents total distribution of grain size from sieving of ninety-two alluvium samples and 89 terrace samples



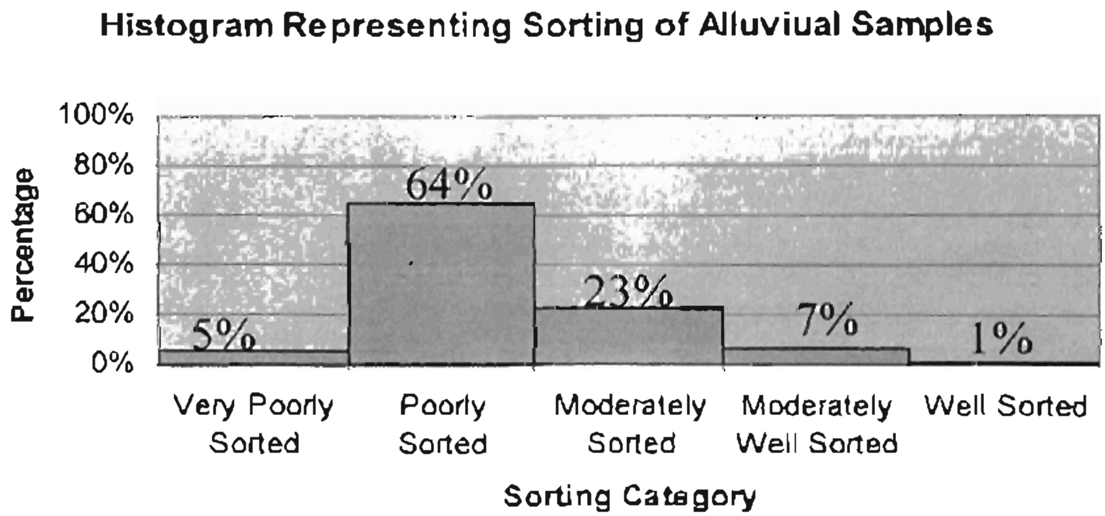
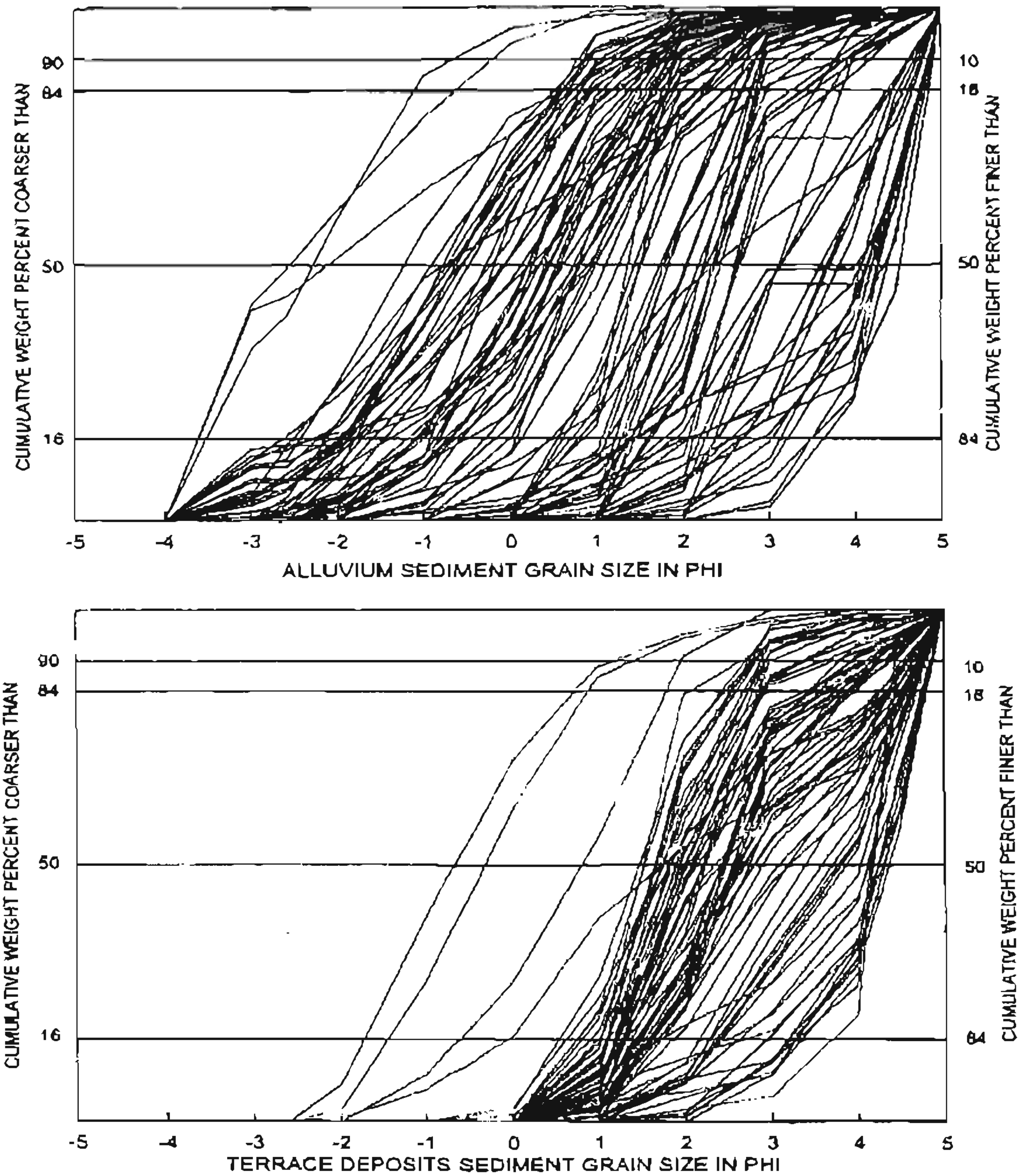


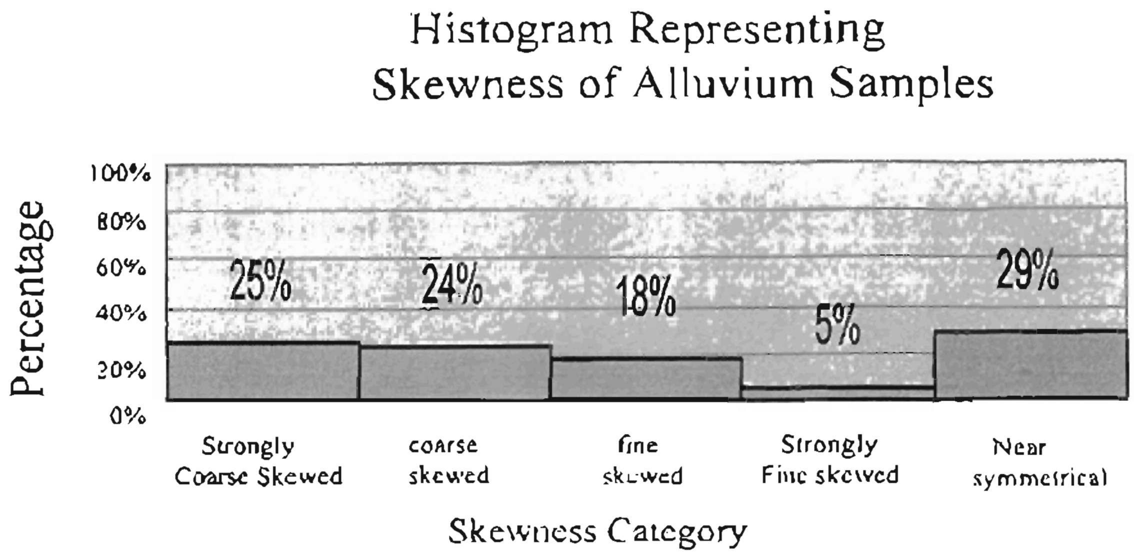
Figure 20. Histograms representing sorting of alluvium and terrace samples. Terrace sediments are better sorted than alluvium sediments. Note that both sediment types are predominately poorly to moderately sorted.



Pebble	Gravel	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Coarse Silt

(Udden, 1914, Wentworth, 1922)

Figure 21. Cumulative Frequency curves for alluvium and terrace deposits. Distribution of curves indicates that the terrace deposits are better sorted.



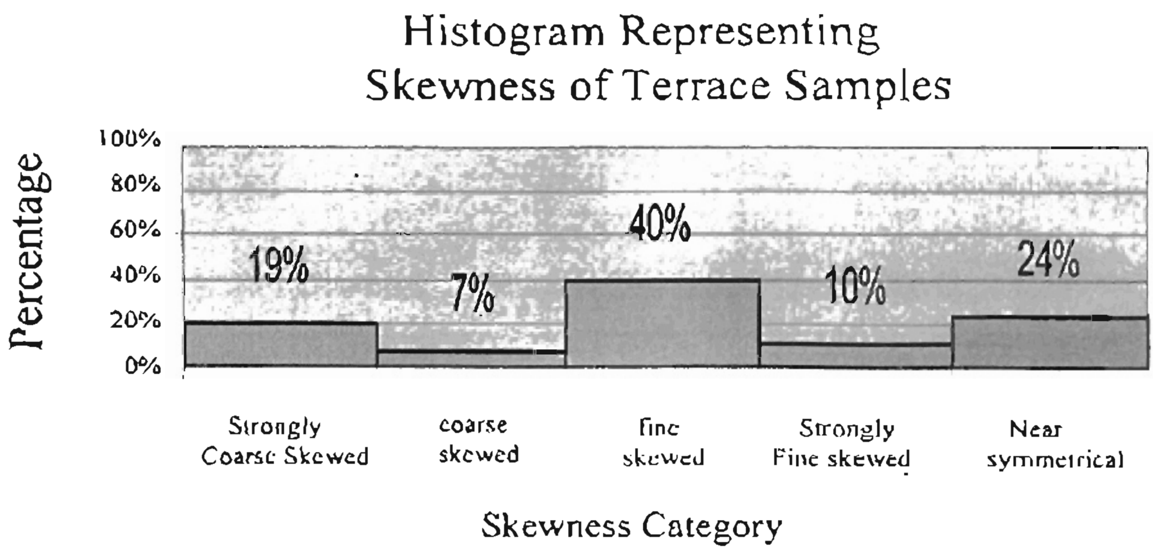


Figure 22. Histograms representing skewness of alluvium and terrace samples. Terrace samples tend to be more finely skewed, whereas alluvium samples are more coarsely skewed.

Mineralogy

The detrital composition of alluvium and terrace deposits was determined by visual examination of pebble size and coarser fragments as well as thin-section microscopy. Mineralogy of both terrace and alluvium deposits was dominated by quartz. feldspar and smaller amounts of other granitic minerals including magnetite (Tables 1 and 2 , Figures 23-25). Based upon the similar nature of alluvium and terrace mineralogy, it is likely that both types of deposits were derived form the same granitic source material. The major difference in mineralogy of alluvium and terrace deposits is the presence of sedimentary rock fragments located within the coarser grain sizes of the alluvium deposits (Tables 1 and 2). These fragments include limestone, chert and sandstone and are inferred to be the result of localized erosion of bedrock units by the Arkansas River.

Analysis of Magnetite Size Distribution

A total mass of 2.0 grams of magnetite was extracted from sediment samples taken from the alluvium cores. A total mass of .86 grams of magnetite was extracted from sediment samples taken from the terrace cores (Table 3). The majority of magnetite grains extracted from both terrace and alluvium samples were contained within the 63-125 micron grain size fraction (Table 3, Figure 26). 52% by mass of the total magnetite extracted from the terrace samples came from the 63 –125 micron fraction, and 36% by mass of the total magnetite extracted from the alluvium samples came from the 63-125 micron fraction (Figure 26, Table 3). Mass percentages extracted from the 45-63 micron and <45 micron fractions were 17% and 4% respectively for both terrace and alluvium samples (Figure 26, Table 3).

A larger percentage of magnetite was extracted from the coarse grained fraction, (>125 micrometers), in the alluvium samples. 18% by mass of the magnetite extracted from alluvium samples was found in the 125-250 micron fraction, whereas only 16% by mass of the magnetite extracted from terrace samples was found in the 125-250 micron fraction (Figure 26, Table 3). Much of the magnetite extracted from the -250 micron fraction occurred in rock fragments. The rock fragments contained small crystals of magnetite that were 63-125 microns in size (Figure 27). 15% by mass of the alluvium magnetite was contained within the 250-500 micron fraction, while only 7% by mass of the terrace magnetite was contained within the 250-500 micron fraction (Figure 26, Table 3). 5% by mass of magnetite-bearing grains were found within 500-1000 micron fraction for both terrace and alluvium samples (Figure 26, Table 3). 4% by mass of the magnetite bearing grains found within the alluvium samples were greater than 1000 microns, while no magnetite bearing grains larger than 1000 microns were found within the terrace samples (Figure 26, Table 3).

In contrast to larger grain sizes, almost all magnetite smaller than 125 microns was composed of magnetite fragments that were not attached to other mineral grains. This "clean" magnetite was apparently separated from the rock fragments by mechanical degradation or milling of rock fragments during sediment transport.

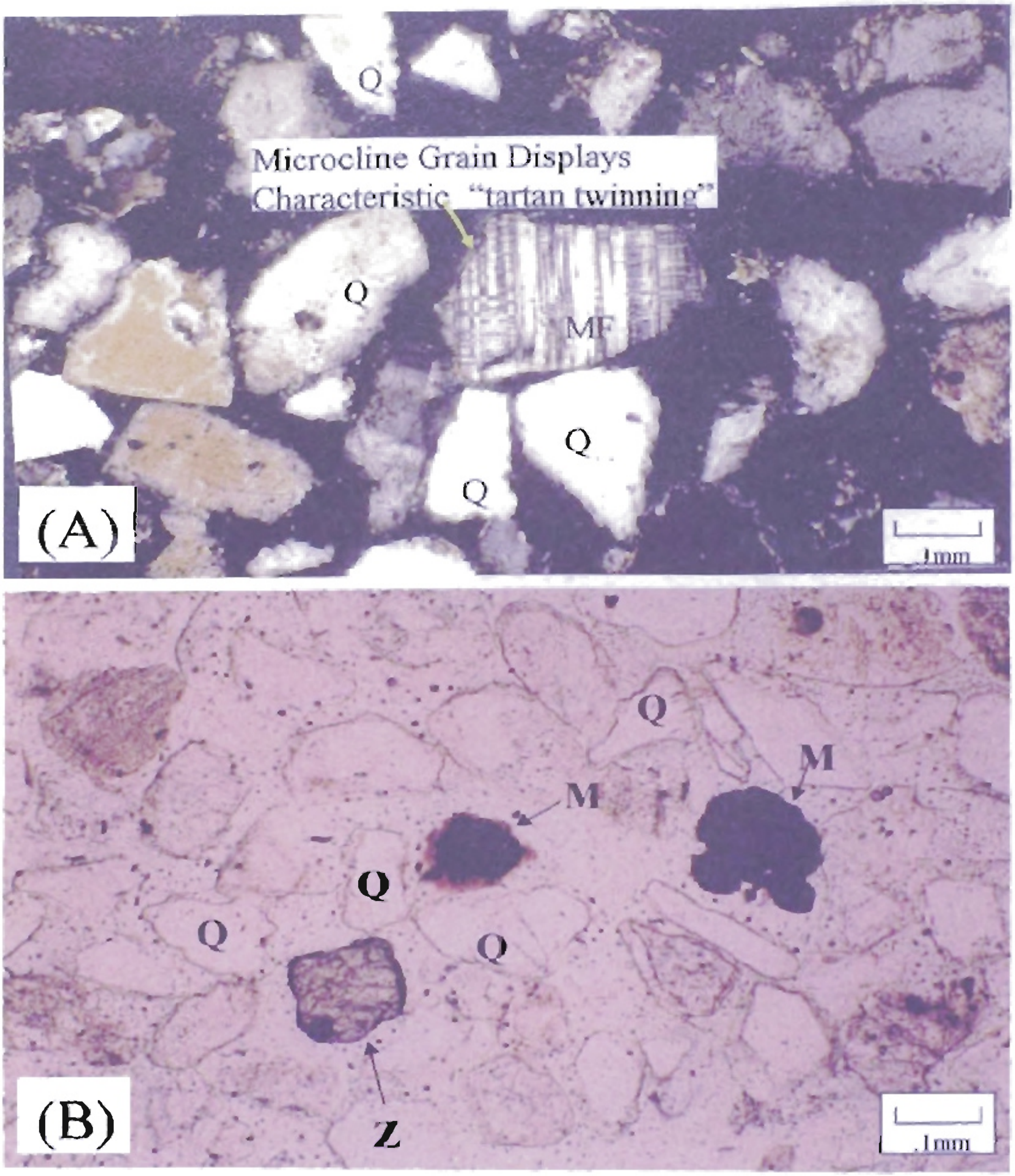


Figure 23. Photomicrographs showing composition of representative Quaternary sediment. Quartz (Q) and microcline feldspar (MF) indicate granitic origin. Accessory grains such as zircon (Z) and magnetite (M) are common. A) Core 035T, cross- polarized light (CPL). B) Core 002A plane-polarized light (PPL)

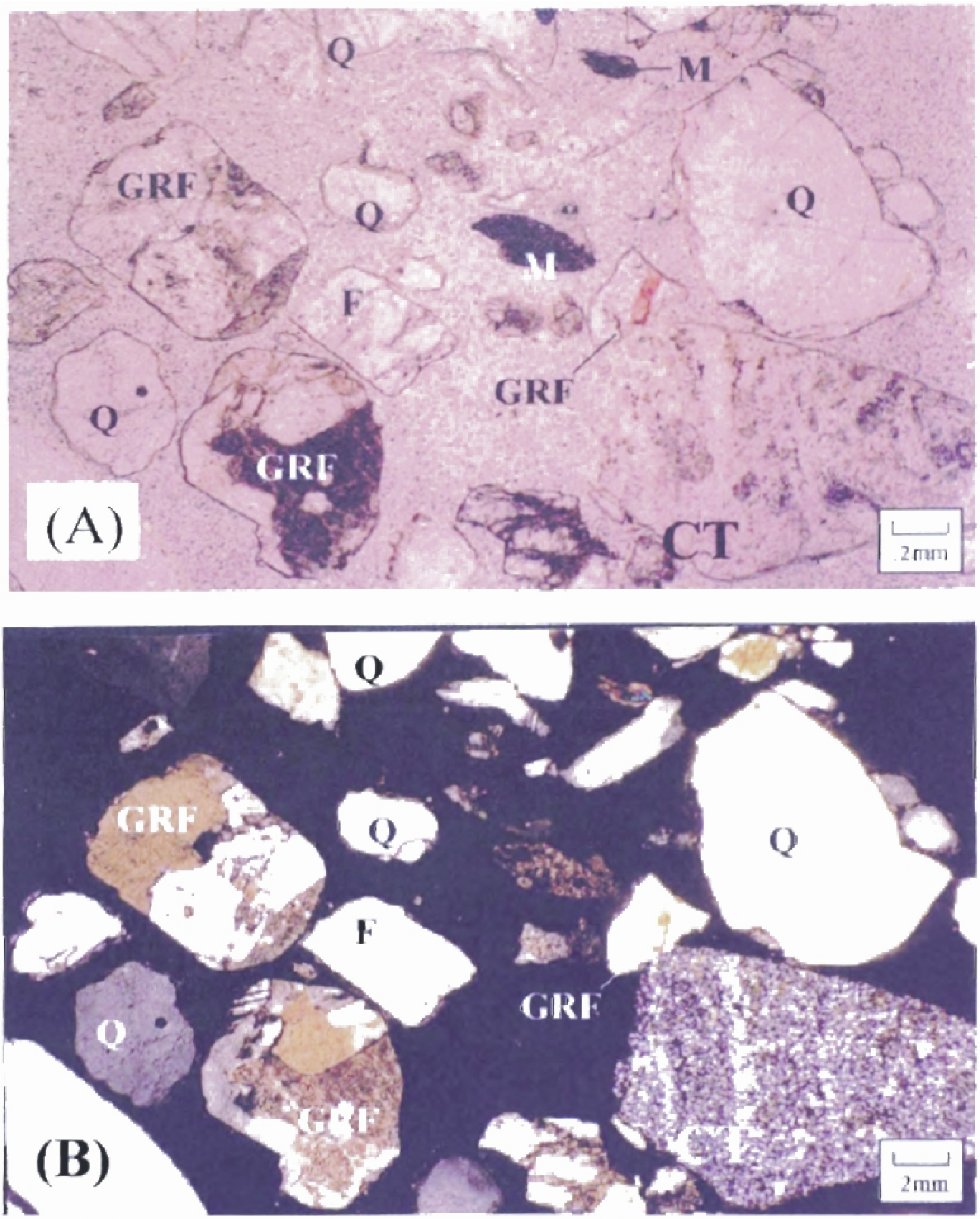


Figure 24. Photomicrographs showing common grains in Quaternary Sediments including quartz (Q), granitic rock fragments (GRF), (which contain feldspar and quartz), and chert (CT) A) Core 071A PPL B) Core 071A CPL

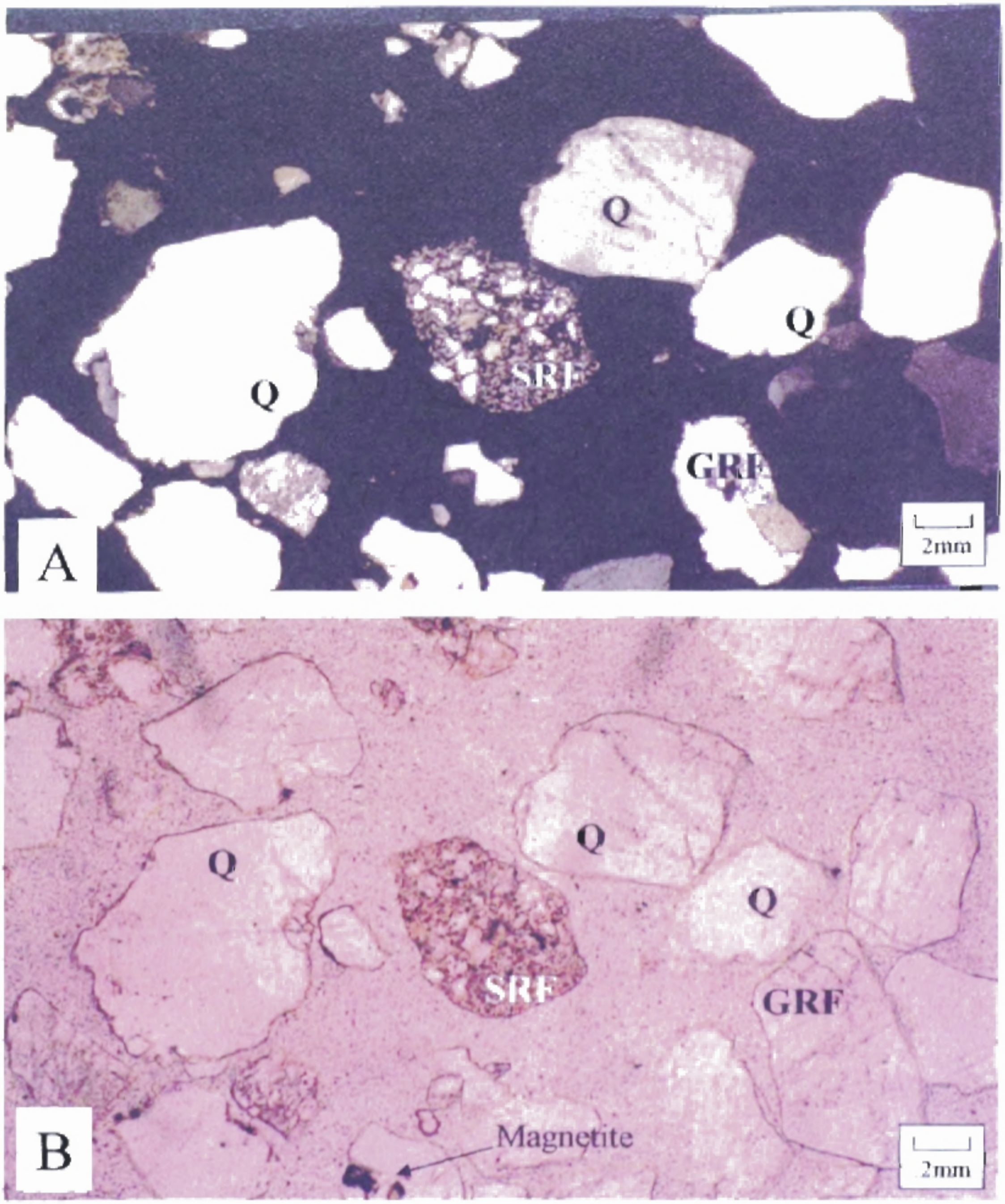


Figure 25. Photomicrograph of Quaternary sediment. Grains include quartz (Q), granitic rock fragments (GRF), sedimentary rock fragments (SRF) and magnetite. A) Core 071A CPL B) Core 071A PPL

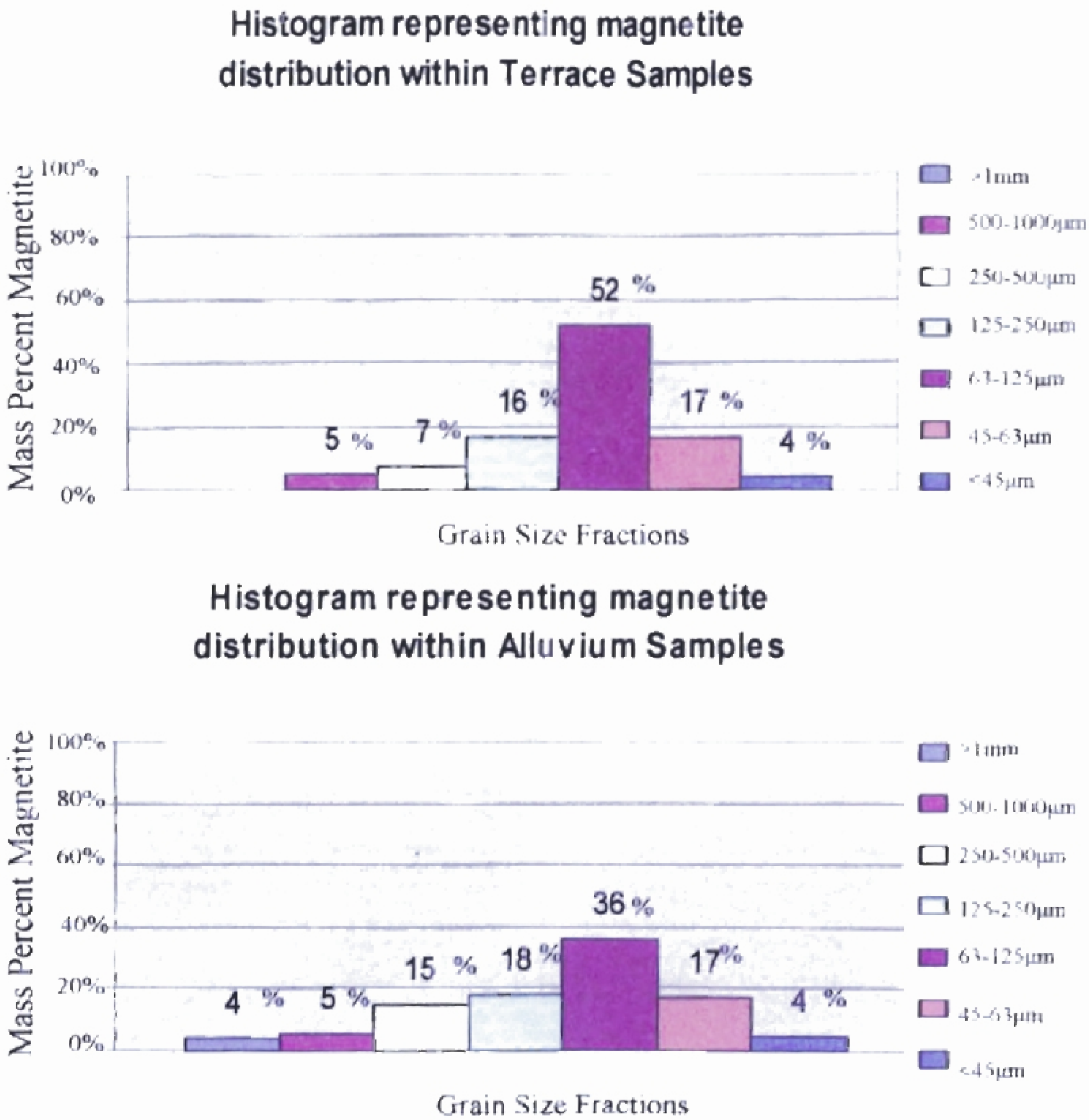


Figure 26. Magnetite distribution in alluvium and terrace samples

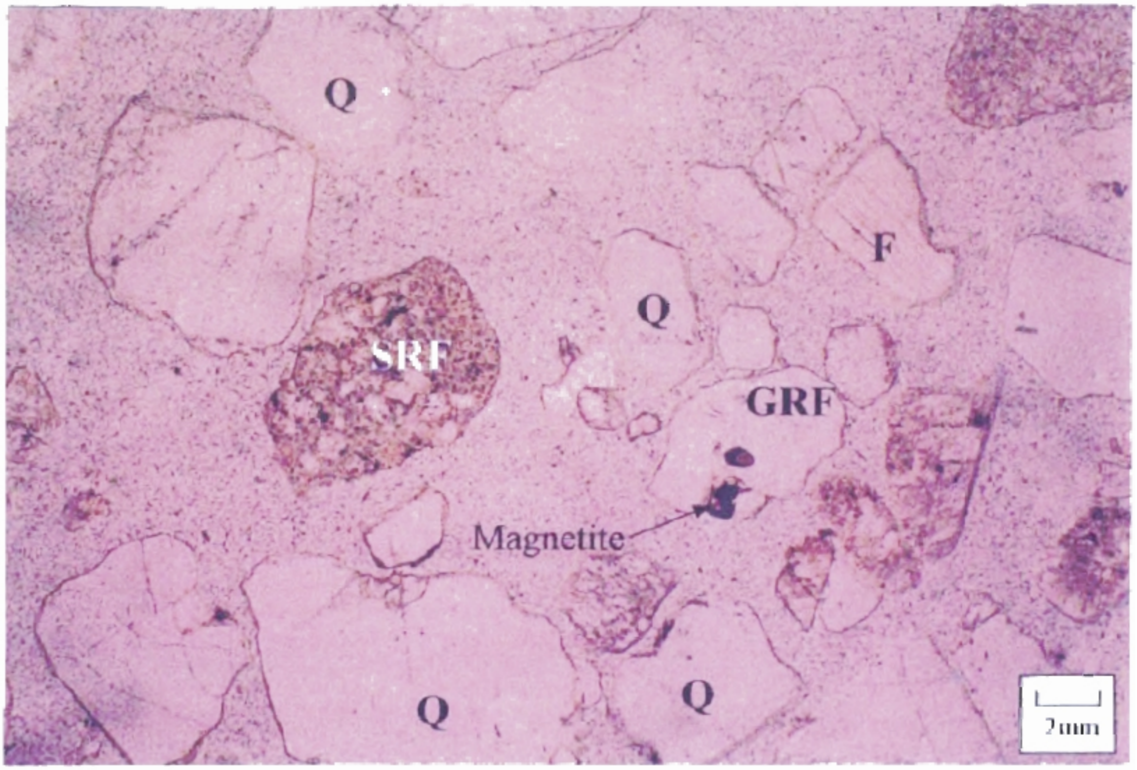


Figure 27. Photomicrograph of Quaternary sediment. Magnetite (M) in granitic rock fragment (GRF). Rock fragment is > 600 microns, (.6mm), in length, magnetite is approximately 100 microns. Magnetite grains were found most frequently in the 63-125 micron fraction. Other grains include sedimentary rock fragments (SRF), plagioclase feldspar (F) and quartz (Q). Core 071A, PPL.

CHAPTER V

CONCLUSION

Analysis of sedimentary features in cores and properties of the sediments they contain indicate distinct differences between terrace and alluvium deposits along the Arkansas River, Osage County Oklahoma. These differences suggest the alluvium is predominately fluvial in origin. No evidence was found suggesting that the terrace deposits were fluvial in origin. Significant evidence was found suggesting that the terrace deposits are eolian and were formed from sediment that was transported by prevailing southerly winds from the nearby river valley to the adjacent upland areas to the north. This interpretation is supported by the following findings:

- Alluvium sediments are coarser grained and more poorly sorted than terrace sediments.
- Alluvium cores contain a series of stacked fining-upward intervals that often contain pebble-granule sized particles at the base of each interval. These graded intervals indicate deposits were the result of waning current flow associated with a braided or meandering stream.
- Terrace cores have no apparent grading and are almost completely devoid of sedimentary structure.
- Terrace sediments have finely skewed grain-size distributions. In contrast, alluvium sediments have coarsely skewed grain-size distributions.

- Alluvium and terrace sediments have similar composition of sand and silt size particles that are dominated by quartz, feldspar and granitic rock fragments.
- Alluvium sediments contain pebbles of sedimentary rock fragments that are similar to local bedrock units.
- Magnetite grains, which are derived from granitic rock fragments, are present in both alluvium and terrace deposits. The majority of these magnetite grains are present in the 63-125 micrometer fraction of both deposits.

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APPENDIX A

GRAIN-SIZE STATISTICAL FORMULAS

Appendix A
Grain Size Statistical Parameters

Graphic Mean (M_z) (Folk)

$$M_z = \frac{\Phi 16 + \Phi 50 + \Phi 84}{3}$$

Inclusive Graphic Standard Deviation (σ_I) (Folk)

$$\sigma_I = \frac{\emptyset\Phi 84 - \Phi 16}{4} + \frac{\Phi 95 - \Phi 5}{6.6}$$

$\sigma_I =$ <.35Φ, very well sorted
.35-.50Φ , well sorted
.50-.71Φ , moderately well sorted
.71-1.0Φ , moderately sorted
1.0-2.0Φ , poorly sorted
2.0-4.0Φ , very poorly sorted
>4.0Φ, extremely poorly sorted

Inclusive Graphic Skewness (Sk_I) (Folk)

$$Sk_I = \frac{\Phi 16 + \Phi 84 - 2(\Phi 50)}{2(\Phi 84 - \Phi 16)} + \frac{\Phi 5 + \Phi 95 - 2(\Phi 50)}{2(\Phi 95 - \Phi 5)}$$

Sk_I= .00, symmetrical
= +1.00 to +.30, strongly fine-skewed
+.30 to +.10, fine-skewed
+.10 to - .10, near-symmetrical
-.10 to - .30, coarse-skewed
-.30 to −1.00, strongly coarse-skewed

APPENDIX B

RAW SIEVE DATA

	grain size(phi)	5	4.47	3.99	3	2	1	0	-1	-2	-2.58	-3	-4
	grain size (micron)	<45	45	63	125	250	500	1000	2000	4000	6000	8000	16000
core 001T	depth (ft.)												
	28	34	38	20	12	1	tr	0	0	0	0	0	0
	24	29	32	23	15	8	tr	0	0	0	0	0	0
	23	24	28	26	25	7	1	tr	0	0	0	0	0
	20	20	24	24	25	9	0	tr	0	0	0	0	0
	19	25	28	21	20	7	1	tr	0	0	0	0	0
	17	19	23	24	29	8	1	tr	0	0	0	0	0
	15	24	22	24	23	7	1	tr	0	0	0	0	0
	13	12	19	23	27	16	2	tr	0	0	0	0	0
	11	6	10	23	44	22	5	tr	0	0	0	0	0
	10	3	4	17	53	23	3	tr	0	0	0	0	0
	7	16	19	27	29	11	1	tr	0	0	0	0	0
	5	5	5	19	49	33	2	tr	0	0	0	0	0
	3	6	7	18	43	25	2	tr	0	0	0	0	0
	1	16	13	15	40	23	2	tr	0	0	0	0	0
core009T	30.5	2	1	7	51	33	7	tr					
	26.5	2	tr	5	26	68	13	tr					
	24	6	3	9	37	56	15	tr					
	22	3	3	12	36	68	9	tr					
	16	2	tr	4	25	52	16	tr					
	12	1	1	3	37	82	7	tr					
	8	tr	tr	3	27	57	10	tr					
	1.5	17	10	13	19	34	9	tr					
	0.5	17	9	10	17	35	6	tr					

	grain size(phi)	5	4.47	3.99	3	2	1	0	-1	-2	-2.58	-3	-4
	grain size (micron)	<45	45	63	125	250	500	1000	2000	4000	6000	8000	16000
core 011T	**depth(feet)**												
	28	4	1	3	12	82	17	tr					
	24	5	3	7	24	48	22	tr					
	20	8	8	20	47	26	2	tr					
	19	21	13	20	33	25	3	tr					
	14	16	10	18	29	28	5	tr					
	9	15	10	18	33	32	3	tr					
	5	31	16	19	28	27	3	tr					
	3	28	19	24	36	28	3	tr					
	1	9	6	11	37	42	4	tr					
core 027T	28	14	16	27	31	35	3	0	0				
	23	2	3	11	43	45	15	0	0				
	17	1	1	8	49	60	4	0	0				
	12	2	2	6	39	69	7	tr	0				
	8	3	3	11	50	61	4	tr	0				
	4	8	7	13	35	53	4	tr	0				
	1	20	12	18	44	38	3	0	0				
core 028T	39.7	1	tr	2	4	10	33	43	32	3	tr		
	38	tr	tr	2	4	8	23	38	41	9	0		
	35.7	27	18	9	13	20	33	15	8	1	0		
	27.7	6	5	16	60	32	tr	tr	0	0	0		
	27	24	19	22	22	8	1	tr	0	0	0		
	24	1	tr	8	59	73	10	0	0	0	0		
	16	4	2	11	49	56	9	tr	0	0	0		
	12	10	6	11	40	65	9	0	0	0	0		
	4	2	1	4	30	77	12	tr	0	0	0		
	1	18	8	8	31	51	5	tr	0	0	0		

	grain size(phi)	5	4.47	3.99	3	2	1	0	-1	-2	-2.58	-3	-4
	grain size (micron)	<45	45	63	125	250	500	1000	2000	4000	6000	8000	16000
core 035T	depth(feet)												
	50	1	tr	8	63	33	9	tr	0				
	47	7	4	14	58	28	6	tr	0				
	44	4	3	8	47	46	9	tr	0				
	40	16	12	18	44	28	12	tr	0				
	38	25	15	18	35	27	18	2	0				
	32	10	9	17	43	29	12	tr	0				
	28	12	11	24	69	38	3	tr	0				
	24	7	6	16	56	30	3	tr	0				
	23	7	7	17	56	36	4	tr	0				
	16	9	8	20	56	24	3	tr	0				
	12	7	4	9	33	57	24	tr	0				
	8	2	1	5	39	57	20	tr	0				
	4	1	1	3	28	59	33	3	tr				
	1	19	10	7	21	52	20	tr	0				
core 039T	40	tr	tr	tr	11	43	34	22	11				
	36	1	tr	7	40	50	8	1	0				
	32	1	1	7	34	42	22	1	0				
	28	8	5	12	45	47	5	tr	0				
	24	2	tr	5	22	60	25	tr	0				
	20	7	7	19	60	25	1	tr	0				
	17	15	5	8	16	31	21	3	0				
	13	10	4	8	38	41	10	tr	0				
	8	27	11	15	30	29	7	tr	0				
	4	15	10	15	38	39	5	tr	0				
core 053T	40	51	32	25	12	15	13	tr					
	32	43	42	21	7	7	9	tr					
	24	16	89	21	5	8	4	tr					
	16	6	90	19	3	3	tr	tr					
	12	18	79	32	7	7	tr	tr					
	4	21	59	30	4	2	5	tr					

	grain size(phi)	5	4.47	3.99	3	2	1	0	-1	-2	-2.58	-3	-4
	grain size (micron)	<45	45	63	125	250	500	1000	2000	4000	6000	8000	16000
core 082T	depth(feet)												
	42	49	36	29	20	6	tr	tr					
	36	27	15	23	35	18	1	0					
	32	4	2	10	78	36	0	0					
	28	2	tr	4	73	67	tr	tr					
	24	4	4	8	28	44	7	0					
	16	21	9	15	39	52	12	tr					
	12	14	8	13	44	58	12	tr					
	8	14	10	15	51	57	11	tr					
	4	8	8	11	31	50	16	tr					
	1	9	7	10	35	50	8	tr					
core 094T	16	48	28	22	18	2	0	0					
	12	38	28	18	10	0	1	tr					
	8	51	33	23	11	0	0	0					
	4	47	36	30	12	3	0	0					
	1	49	27	22	12	10	4	tr					
core 002A	29	tr	tr	1	2	13	23	21	17	8	5	12	
	28	tr	1	1	9	40	34	16	4	0	0	0	
	24	tr	tr	1	2	4	12	14	13	5	0	6	
	23	tr	tr	tr	1	5	28	36	26	8	3	6	
	22.5	tr	tr	1	4	27	30	28	9	4	0	0	
	22	tr	1	2	6	37	35	20	3	tr	0	0	
	20	0	tr	1	4	39	50	15	0	0	0	0	
	16	2	3	8	13	46	29	1	0	0	0	0	
	15	0	tr	2	9	27	40	22	15	4	0	0	
	13	tr	1	4	17	31	25	13	6	3	11	6	
	9.5	3	7	49	46	tr	tr	tr	0	0	0	0	
	6	25	32	31	10	2	0	0	0	0	0	0	
	2	20	20	33	25	7	tr	0	0	0	0	0	

	grain size(phi)	5	4.47	3.99	3	2	1	0	-1	-2	-2.58	-3	-4
	grain size (micron)	<45	45	63	125	250	500	1000	2000	4000	6000	8000	16000
core 007A	depth(feet)												
	24	tr	tr	tr	tr	6	40	52	14	tr			
	20	5	4	13	56	27	tr	tr	0	0			
	16	1	2	6	57	57	1	tr	0	0			
	12.5	42	13	tr	29	12	12	tr	0	0			
	4.5	13	11	tr	63	8	tr	tr	0	0			
	1.5	32	18	tr	35	7	1	tr	0	0			
core 010A	31	2	tr	1	3	7	8	22	29	15	2	10	
	28	tr	tr	tr	3	4	19	28	17	4	1	11	
	26.5	3	6	28	47	15	3	2	0	0	0	0	
	24	tr	tr	3	13	38	24	10	3	tr	0	8	
	22	tr	tr	tr	4	6	26	34	27	10	1	6	
	20	tr	tr	2	15	37	33	19	14	8	3	2	
	16	tr	1	3	17	34	37	16	2	tr	0	0	
	14	3	6	14	59	29	8	tr	0	0	0	0	
	12	37	42	28	4	tr	tr	0	0	0	0	0	
	8	36	44	18	4	4	tr	tr	0	0	0	0	
	5	36	31	27	14	3	tr	tr	0	0	0	0	
	2	42	35	9	9	14	3	0	0	0	0	0	
core 022A	44	tr	tr	tr	2	17	17	16	19	11	4	60	
	40	tr	tr	tr	2	19	54	21	8	tr	1	17	
	35	tr	tr	tr	t	1	9	20	25	16	10	59	
	28	tr	tr	tr	3	12	37	45	26	4	3		
	24	tr	tr	3	7	42	55	27	13	2	tr	1	
	20	tr	tr	2	7	17	58	34	26	tr			
	16	tr	tr	2	15	23	35	25	23	9	4	5	
	15	1	1	7	56	54	4	1	tr	0	0	0	
	12	5	4	12	22	45	11	0	0	0	0	0	
	8	tr	tr	7	43	64	6	0	0	0	0	0	
	4	17	28	46	18	8	1	tr	0	0	0	0	
	3	39	36	23	10	9	1	tr	0	0	0	0	

	grain size(phi)	5	4.47	3.99	3	2	1	0	-1	-2	-2.58	-3	-4
	grain size (micron)	<45	45	63	125	250	500	1000	2000	4000	6000	8000	16000
	depth(feet)												
core 026A	38	tr	1	1	4	22	43	32	20	7	1	16	
	32	1	tr	2	5	10	24	32	28	10	tr	7	
	28	tr	tr	2	5	27	35	20	13	3	tr	2	
	20		1	5	42	45	12	6	5	2	0	0	
	14	tr	tr	4	17	34	44	20	12	1	1	tr	
	6	tr	tr	10	75	30	1	tr	0	0	0	0	
	1	6	5	12	48	27	6	tr	0	0	0	0	
core 045A	41.9	tr	tr	tr	2	11	43	26	23	9	5	5	
	32	1	tr	tr	3	6	21	41	41	10	1	1	
	28	tr	tr	tr	3	31	36	25	18	2	0	0	
	22	tr	tr	tr	4	73	20	2	tr	0	0	0	
	20	tr	tr	3	19	33	21	14	16	5	tr	tr	
	16	tr	tr	3	9	13	22	33	38	12	4	4	
	8	tr	tr	7	69	12	5	8	0	0	0	0	
	4	tr	tr	tr	42	47	12	2	tr	0	0	0	
	1.5	6	4	6	16	46	29	tr	0	0	0	0	
core 047A	47.8	tr	1	1	4	15	29	25	19	9	tr	0	
	44	tr	tr	1	9	32	46	21	11	3	tr	2	
	42	tr	tr	tr	1	6	18	21	25	13	4	36	
	39	1	tr	1	2	9	23	31	35	13	2	3	
	35.5	1	1	5	16	12	15	15	18	7	3	7	
	26	tr	tr	tr	5	20	36	28	15	3	tr	4	
	20	0	tr	8	55	25	20	10	0	0	0	0	
	16	tr	tr	tr	21	11	23	30	10	0	0	0	
	8	1	4	29	64	6	5	3	tr	0	0	0	
	5	67	21	9	11	11	2	tr	0	0	0	0	
	1	14	14	25	28	13	4	tr	0	0	0	0	

	grain size(phi)	5	4.47	3.99	3	2	1	0	-1	-2	-2.58	-3	-4
	grain size (micron)	<45	45	63	125	250	500	1000	2000	4000	6000	8000	16000
core 056A	depth(feet)												
	37	5	1	3	7	13	24	20	19	7	5	5	
	33	tr	2	7	18	14	13	14	27	15	4	15	
	24	2	2	6	17	41	31	11	4	0	0	0	
	23	1	tr	tr	tr	1	3	11	34	23	8	41	
	16	tr	tr	2	12	38	23	15	12	4	2	0	
	12	3	1	12	87	27	7	3	3	0	0	0	
	8	1	1	5	77	43	1	tr	0	0	0		
	3	24	9	12	15	26	21	1	0	0	0	0	
core 071A	38	tr	tr	tr	5	16	32	44	31	9	0	11	
	28	tr	tr	3	14	23	48	28	7	0	1	0	
	24	1	tr	5	22	80	22	3	tr	0	0	0	
	20	tr	tr	3	14	56	45	24	14	5	2	0	
	16	2	2	16	56	37	12	2	2	tr	0	0	
	12	41	32	30	11	tr	1	tr	0	0	0	0	
	4	19	31	40	15	8	tr	tr	0	0	0	0	
	1	7	9	16	43	50	tr	tr	0	0	0	0	
Well 092A	16	22	23	42	25	1	0						
	11	35	28	21	7	9	8						
	7	39	15	7	6	9	10						
	3	50	37	24	3	0	0						
	1	35	19	16	9	11	11						

APPENDIX C

GRAIN SIZE STATISTICS

well	depth	thickness (ft)	sample mean	sorting	skewness	well mean
001T	28	3.0	4.1	0.77	-0.37	3.25
	24	1.5	3.8	1.03	-0.43	
	23	1.5	3.6	1.04	-0.31	
	20	1.5	3.5	1.01	-0.29	
	19	1.5	3.7	1.06	-0.38	
	17	3.0	3.5	1.07	-0.12	
	15	2.0	3.6	1.07	-0.27	
	13	2.0	3.1	1.18	-0.10	
	11	2.0	2.7	1.09	0.11	
	10	1.0	2.5	0.91	0.04	
	7	3.0	3.3	1.10	-0.05	
	5	3.0	2.5	0.92	0.26	
	3	2.0	2.6	0.98	0.23	
	1	1.0	2.9	1.15	0.30	
009T	30.5	2.5	2.1	0.84	-0.05	2.01
	26.5	1.5	1.8	0.79	0.20	
	24	3.0	2.0	1.07	0.22	
	22	3.5	2.0	0.91	0.30	
	16	5.0	1.8	0.84	0.08	
	12	5.0	1.8	0.65	0.24	
	8	5.0	1.8	0.72	0.08	
	1.5	2.5	2.7	1.47	0.21	
	0.5	2.5	2.7	1.43	0.29	
011T	28	4.0	1.5	0.76	0.20	2.60
	24	2.0	1.8	1.15	0.22	
	20	2.0	2.7	1.08	0.12	
	19	3.0	3.0	1.29	0.09	
	14	5.0	2.8	1.30	0.18	
	9	4.0	2.8	1.29	0.18	
	5	4.0	3.2	1.35	-0.09	
	3	2.0	3.1	1.30	0.01	
	1	2.0	2.4	1.15	0.31	
027T	28	3.5	2.9	1.24	0.06	2.22
	23	5.5	2.0	0.98	0.04	
	17	7.0	2.0	0.74	0.18	
	12	4.0	1.9	0.78	0.31	
	8	4.0	2.1	0.84	0.22	
	4	4.5	2.3	1.12	0.35	
	1	2.5	2.8	1.29	0.22	
028T	27.7	4.5	2.5	0.91	0.16	2.20
	27	1.5	3.6	1.12	-0.23	
	24	2.0	2.0	0.74	0.06	
	16	10.0	2.0	0.88	0.13	
	12	6.0	2.2	1.13	0.39	
	4	5.0	1.8	0.76	0.12	
	1	3.0	2.6	1.35	0.45	

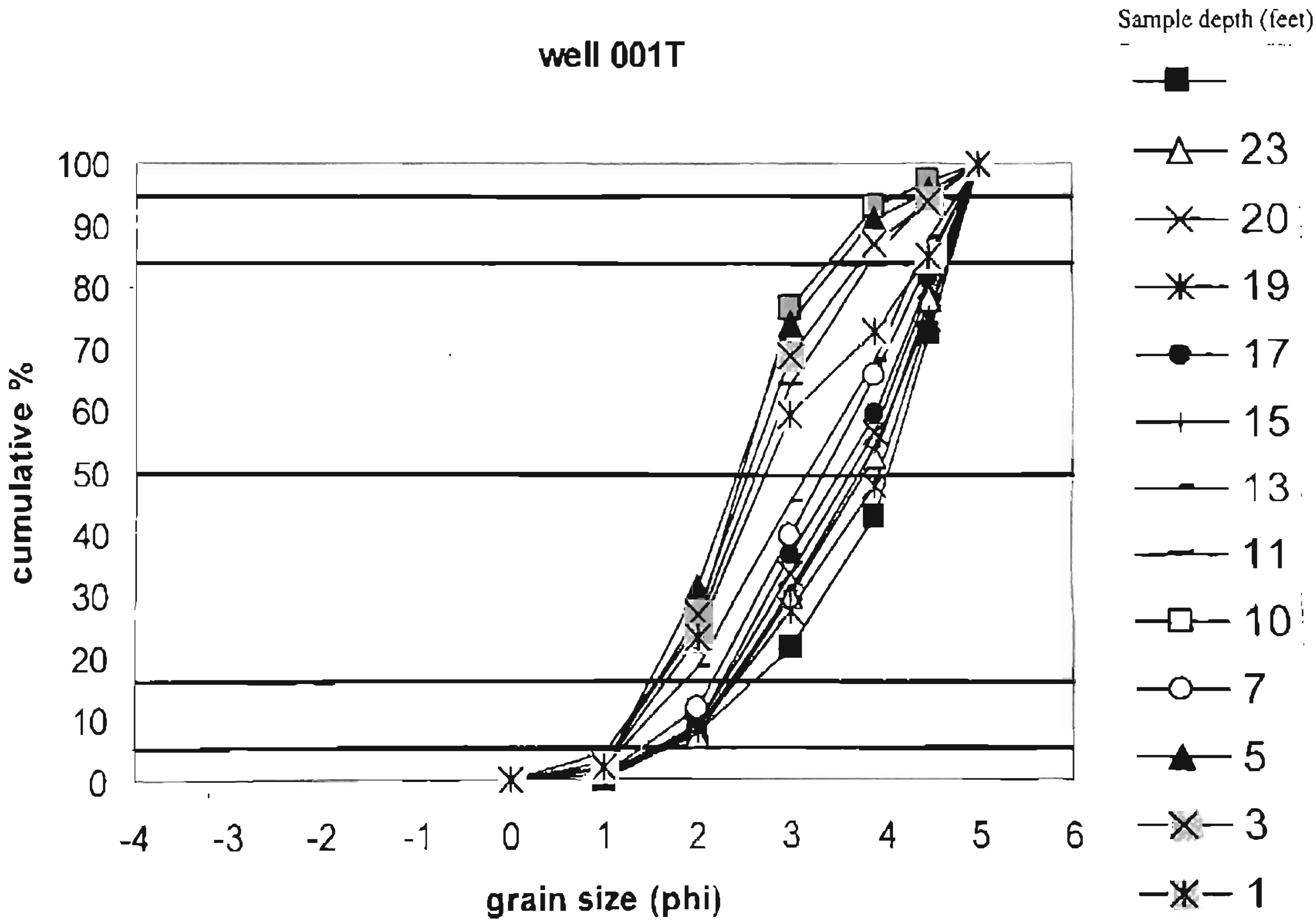
well	depth	thickness (ft)	sample mean	sorting	skewness	well mean
035T	50	3.0	2.1	0.81	-0.20	2.33
	47	3.0	2.4	1.01	0.13	
	44	4.0	2.1	0.95	0.07	
	40	3.0	2.7	1.17	-0.32	
	38	5.0	2.7	1.56	0.01	
	32	4.0	2.6	1.29	0.06	
	28	4.0	2.6	1.09	0.20	
	24	4.0	2.5	1.02	0.19	
	23	4.0	2.5	1.03	0.18	
	16	3.0	2.7	1.06	0.15	
	12	3.0	1.9	1 14	0.23	
	8	5.0	1.8	0.87	0.10	
	4	3.0	1.5	0.90	-0.03	
	1	2.0	2.4	1.53	0.41	
039T	36	4.0	1.9	0.82	0.03	2.06
	32	4.0	1.8	0.98	0.02	
	28	2.0	2.3	1.07	0.24	
	24	4.0	1.6	0.90	0.11	
	20	4.0	2.6	1.00	0.17	
	17	4.0	2.3	1.65	0.32	
	13	4.0	2.3	1.20	0.24	
	8	6.0	2.9	1.41	0.09	
053T	40	6.5	3.5	1.42	-0.58	3.89
	32	8.0	3.9	1.17	-0.56	
	24	4.0	4.0	0.81	-0.57	
	16	8.0	4.1	0.41	-0.33	
	12	4.0	3.9	0.72	-0.46	
	4	12.0	4.0	0.81	-0.49	
O82T	42	5.0	3.9	0.93	-0.42	2.54
	36	3.0	3.3	1.20	0.01	
	32	3.0	2.3	0.74	-0.02	
	28	4.0	2.0	0.65	0.03	
	24	7.0	2.2	0.99	0.20	
	16	5.0	2.6	1.40	0.28	
	12	4.0	2.4	1.23	0.37	
	8	3.0	2.4	1.23	0.27	
	4	4.0	2.2	1.26	0.32	
	1	4.0	2.3	1.17	0.32	
094T	16	4.5	4.0	0.88	-0.40	4.02
	12	4.0	4.1	0.79	-0.43	
	8	4.0	4.1	0.74	-0.44	
	4	4.0	4.1	0.82	-0.36	
	1	4.0	3.8	1.14	-0.54	

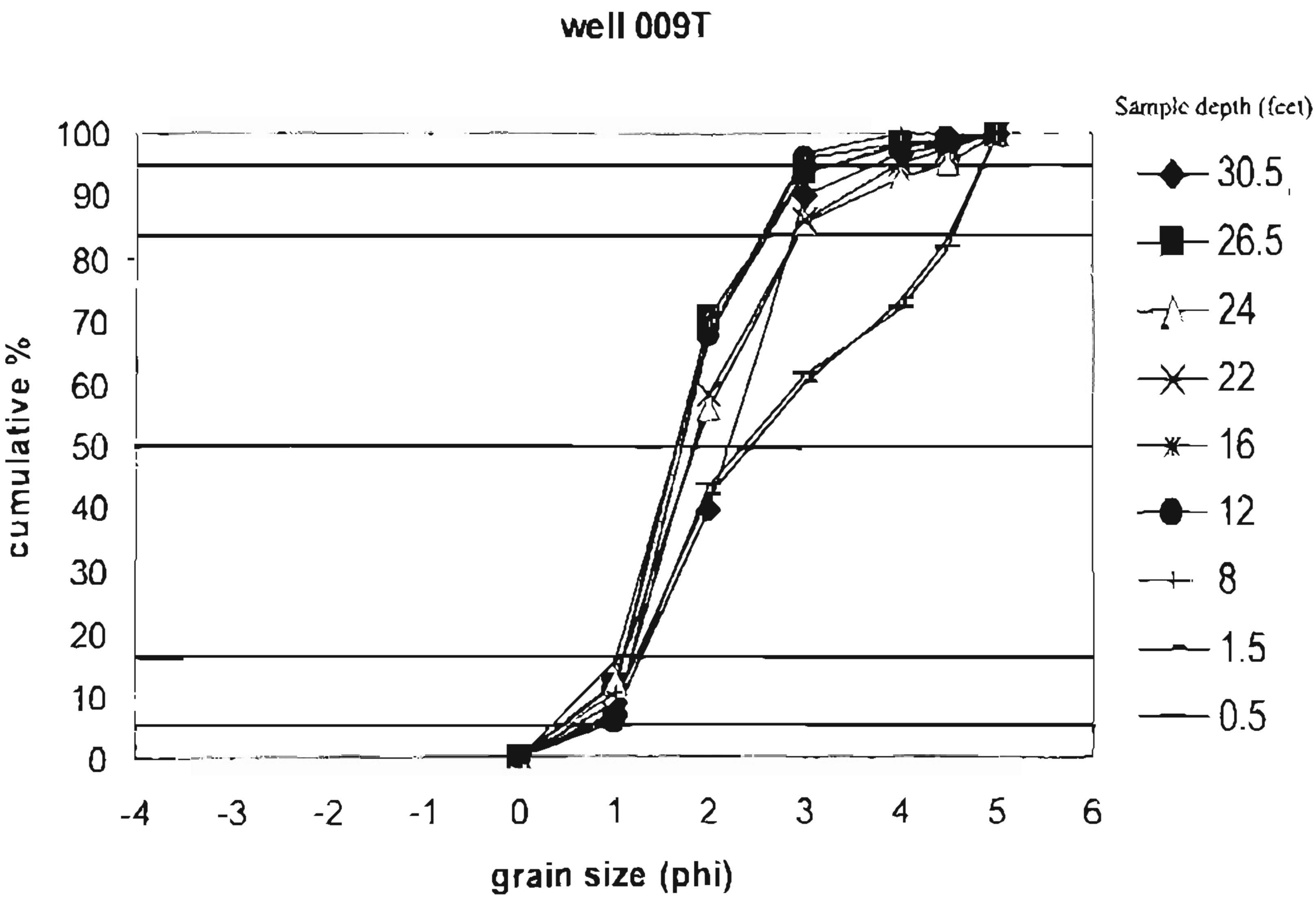
well	depth	thickness (ft)	sample mean	sorting	skewness	well mean
002A	29	2.0	1.2	1.72	-0.16	2.23
	28	1.0	0.7	1.04	-0.09	
	24	4.0	1.8	2.49	-1.02	
	23	1.0	0.5	2.15	-1.73	
	22.5	0.5	0.2	0.60	-0.59	
	22	1.5	0.8	1.06	-0.05	
	20	1.0	0.6	0.81	0.01	
	16	5.0	2.1	1.14	0.22	
	15	1.0	0.5	1.01	-0.57	
	13	2.0	1.3	2.14	-0.37	
	9.5	3.0	1.4	0.96	0.16	
	6	5.0	1.8	0.79	-0.32	
	2	4.0	1.6	1.01	-0.16	
007A	28	4.0	1.8	0.76	0.77	2.48
	24	2.0	0.9	0.78	0.04	
	20	2.5	1.2	0.93	0.14	
	16	3.5	1.4	0.73	0.08	
	12.5	5.0	2.0	1.52	-0.56	
	4.5	7.0	2.8	1.06	0.47	
	1.5	4.0	1.5	1.14	-0.50	
010A	31	2.0	1.3	1.64	0.19	1.95
	28	2.5	1.3	1.53	-0.15	
	26.5	2.0	1.0	1.00	0.01	
	24	2.0	1.1	1.56	-0.37	
	22	2.0	1.1	1.37	-0.02	
	20	2.0	1.1	1.61	-0.20	
	16	4.5	1.9	1 11	0.06	
	14	2.5	1.2	0.99	0.00	
	12	3.0	1.0	0.54	-0.46	
	8	3.0	1.1	0 70	-0.39	
	5	3.0	1.2	0.85	-0.39	
	2	3.0	1,2	1.23	-0.66	
022A	44	1.0	1.1	1.94	0.33	0.64
	40	5.0	2.0	1.55	-0.42	
	35	6.0	2.6	1.39	0.27	
	28	5.0	2.1	1.15	0.03	
	24	4.0	1.7	1.18	-0.12	
	20	4.0	1.7	1.18	-0.04	
	16	4.0	1.9	1.71	-0.05	
	15	2.5	1.1	0.75	0.04	
	12	1.5	1.0	1.19	0.33	
	8	5.0	2.0	0.69	0.16	
	4	4.0	1.6	0.95	-0.19	
	3	3.0	1.2	0.97	-0.45	
026A	38	5.0	2.1	1.62	-0.22	1,19
	32	5.0	2.2	1 57	0.06	
	28	2.0	1.1	1.34	-0.13	
	20	13.0	4.6	1.19	-0.27	
	14	3.0	1.4	1.33	-0.02	
	6	10.0	3.5	0.67	-0.11	
	1	2.0	1.1	1.09	0.09	

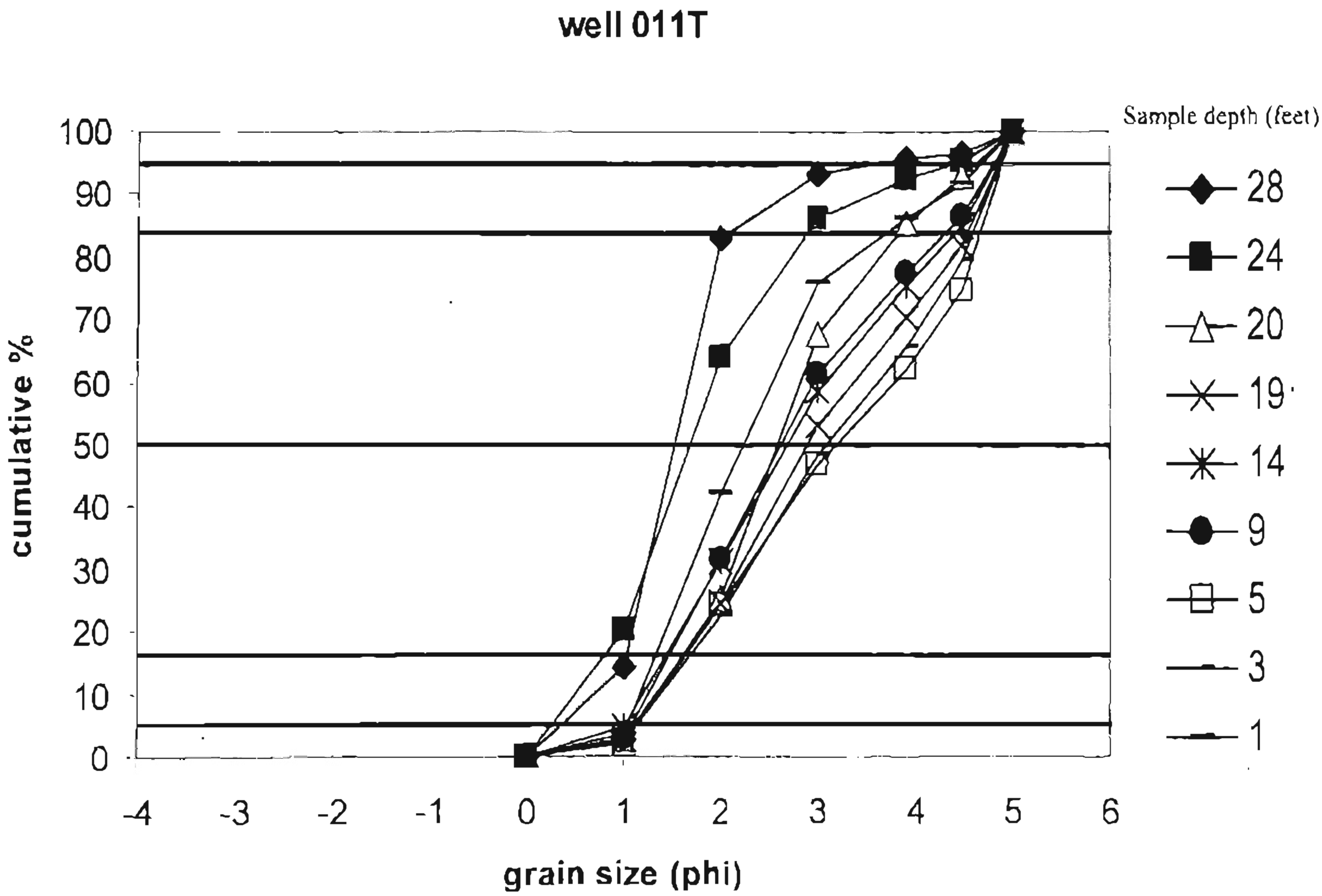
well	depth	thickness (ft)	sample mean	sorting	skewness	well mean
045A	41.9	9.0	3.4	1.37	-0.23	0.81
	32	2.0	1.1	1.17	0.17	
	28	4.0	1.7	1.23	-0.15	
	22	5.0	1.6	0.38	-0.49	
	20	2.0	1.1	1.59	-0.26	
	16	9.0	3.6	1.60	0.22	
	8	5.0	1.8	0.97	-0.45	
	4	4.0	1.6	0.79	-0.07	
	1.5	2.0	1.2	1.23	0.25	
047A	47.8	0.5	0.6	1.40	-0.01	1.00
	44	3.5	1.5	1.22	-0.10	
	42	2.5	1.3	1.28	0.13	
	39	4.5	2.0	1.30	0.14	
	35.5	2.0	1.3	1.93	0.10	
	26	13.0	4.7	1.20	-0.04	
	20	9.0	3.3	1.14	-0.38	
	16	4.0	1.9	1.43	0.23	
	8	3.0	1.3	0.88	0.05	
	5	3.0	1.1	1.10	-0.72	
	1	3.0	1.4	1.19	-0.05	
056A	37	4.5	2.2	2.06	0.11	1.01
	33	4.5	2.3	2.25	0.25	
	24	5.5	2.3	1.27	0.02	
	23	3.0	1.4	1.17	0.05	
	16	3.5	1.6	1.48	-0.29	
	12	8.0	2.9	0.91	-0.25	
	8	4.0	1.5	0.63	-0.15	
	3	4.0	1.9	1.66	0.11	
071A	38	6.0	3.2	1.47	2 16	1.68
	28	4.0	1.8	1.22	0.09	
	24	5.0	2.0	0.79	0.06	
	20	5.0	2.0	1.33	-0.22	
	16	2.0	0.9	1.02	-0.17	
	12	4.0	1.5	0.77	-0.37	
	4	10.0	3.6	0.93	-0.23	
	1	2.0	1.1	1.09	0.26	
092A	16	5.0	2.0	0.88	-0.01	3.69
	11	3.0	1.3	1.34	-0.56	
	7	3.0	1.3	1.53	-0.71	
	3	3.0	1.1	0.58	-0.24	
	1	2.0	1.0	1.52	-0.56	

APPENDIX D

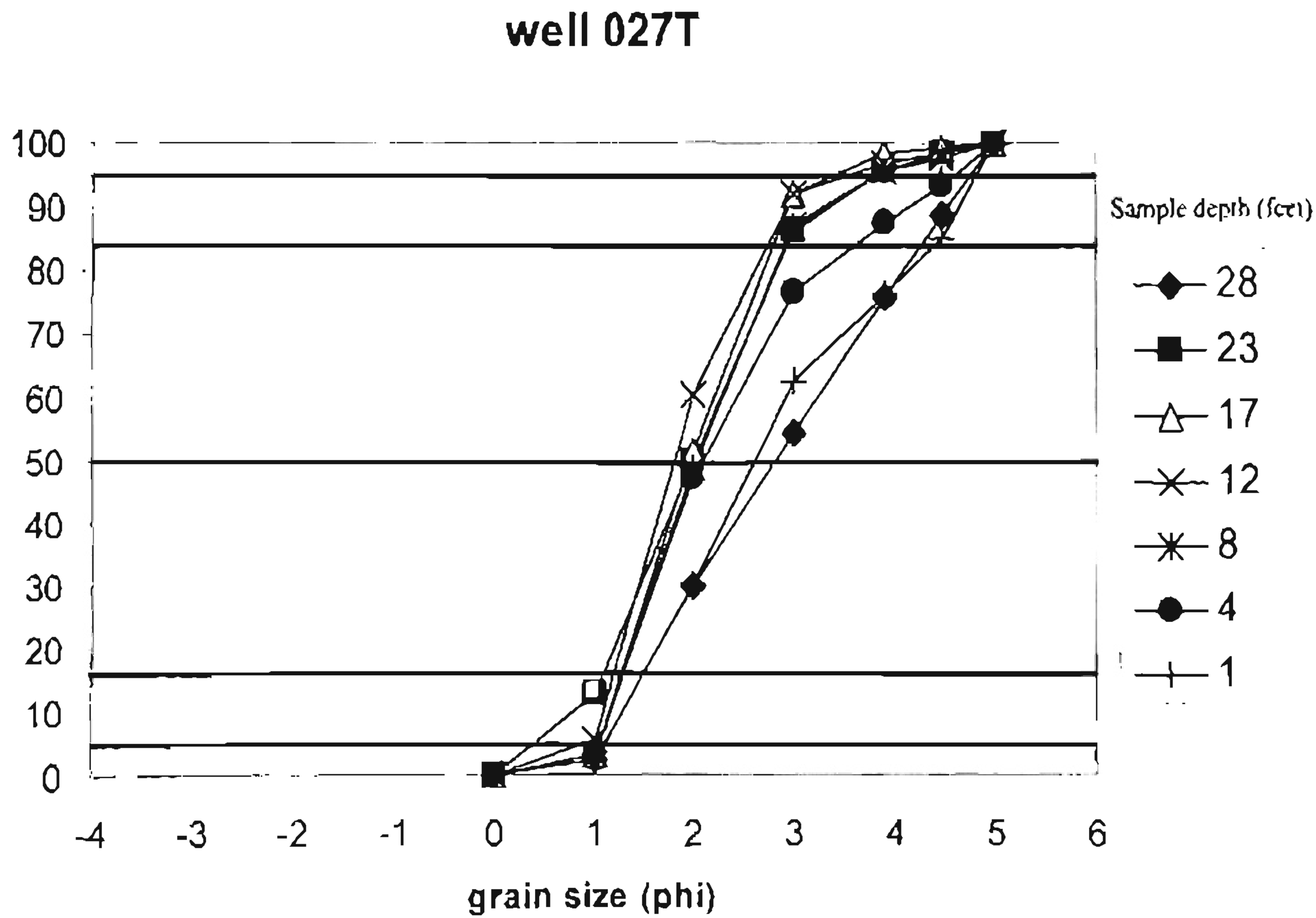
CUMULATIVE CURVES


well 001T
Sample depth (feet)
23
20
19
17
15
13
11
10
7
5
3
1
cumulative %
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)


well 009T
Sample depth (feet)
30.5
26.5
24
22
16
12
8
1.5
0.5
cumulative %
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)

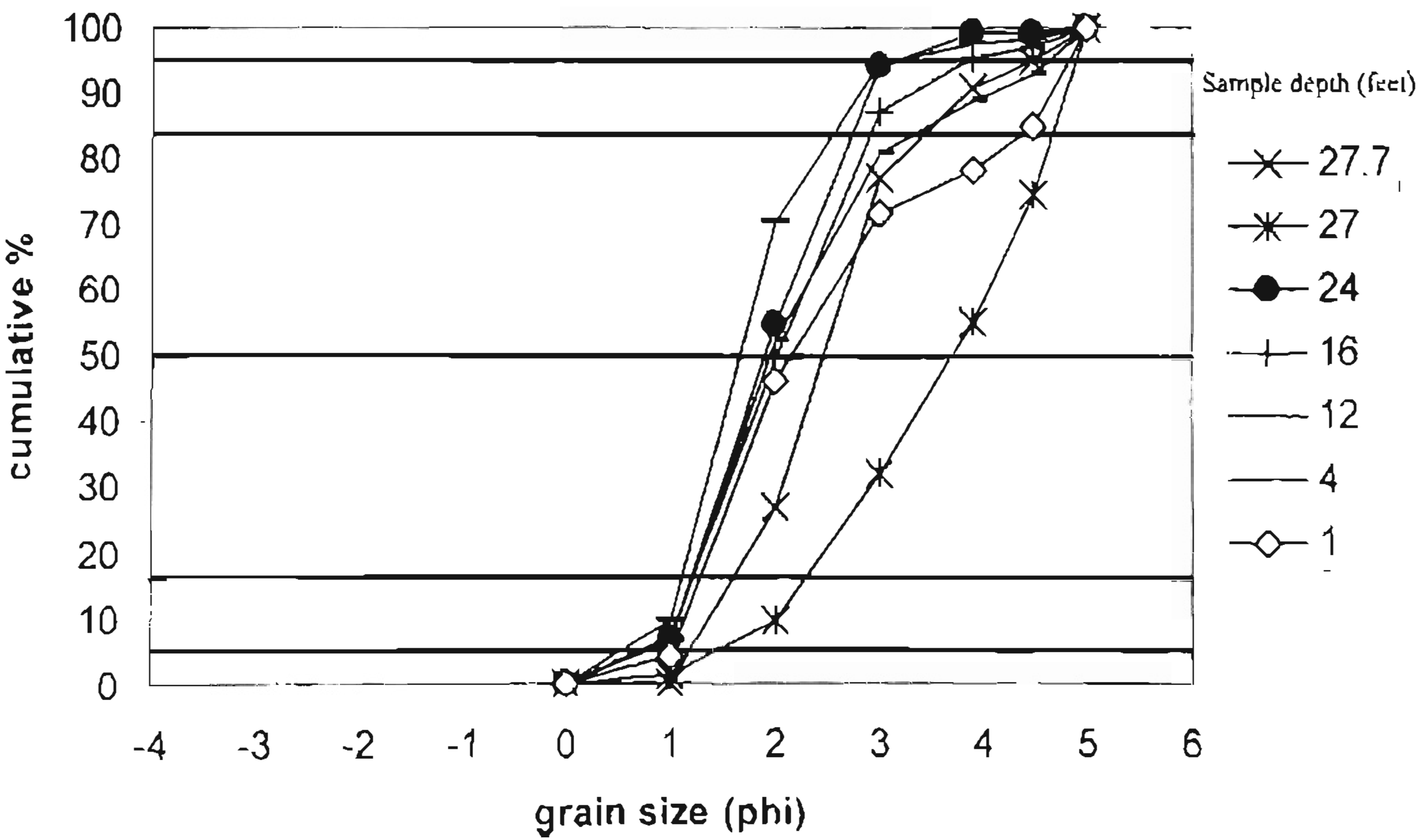


well 011T
cumulative %
grain size (phi)
Sample depth (feet)
28
24
20
19
14
9
5
3
1
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6

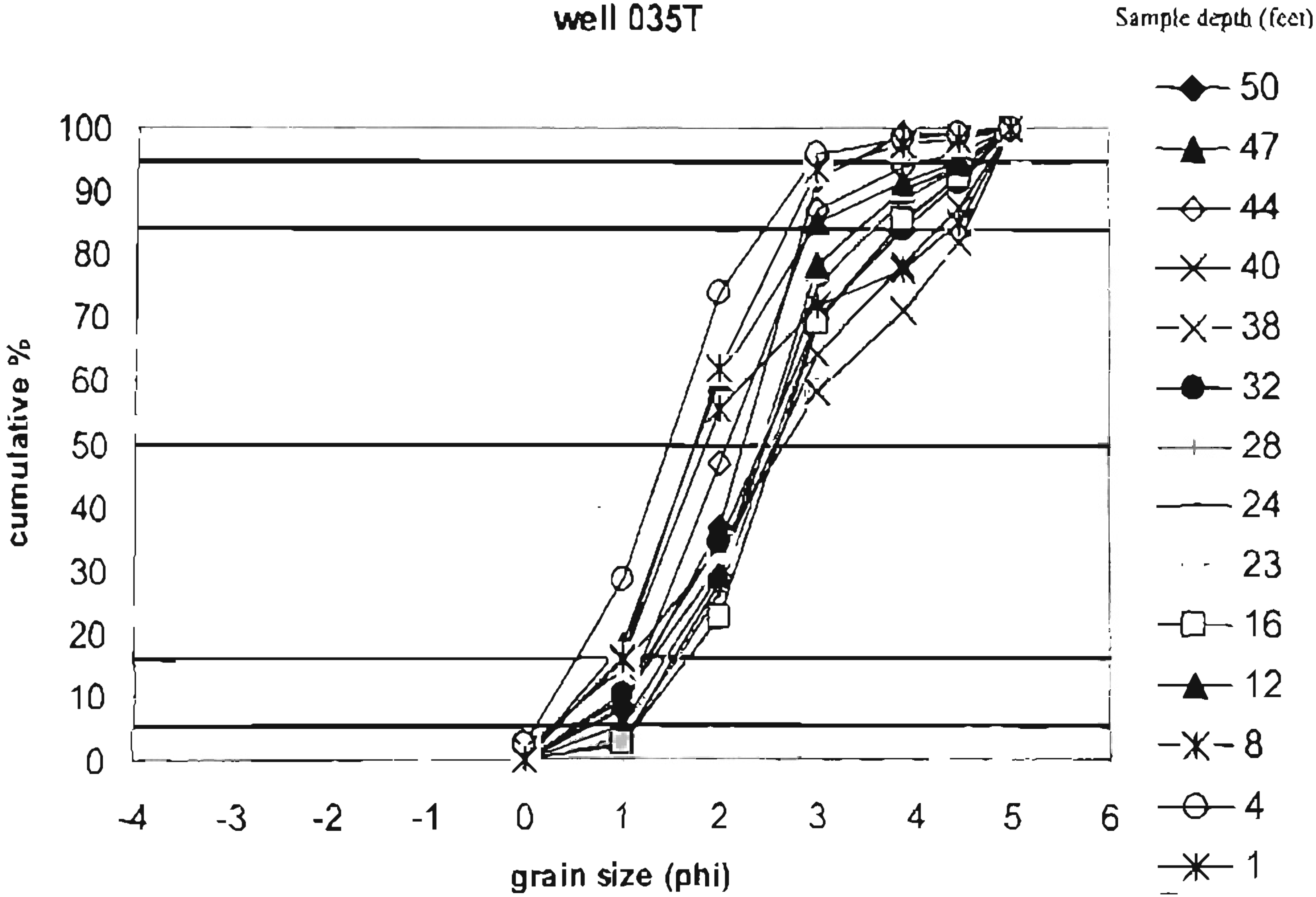


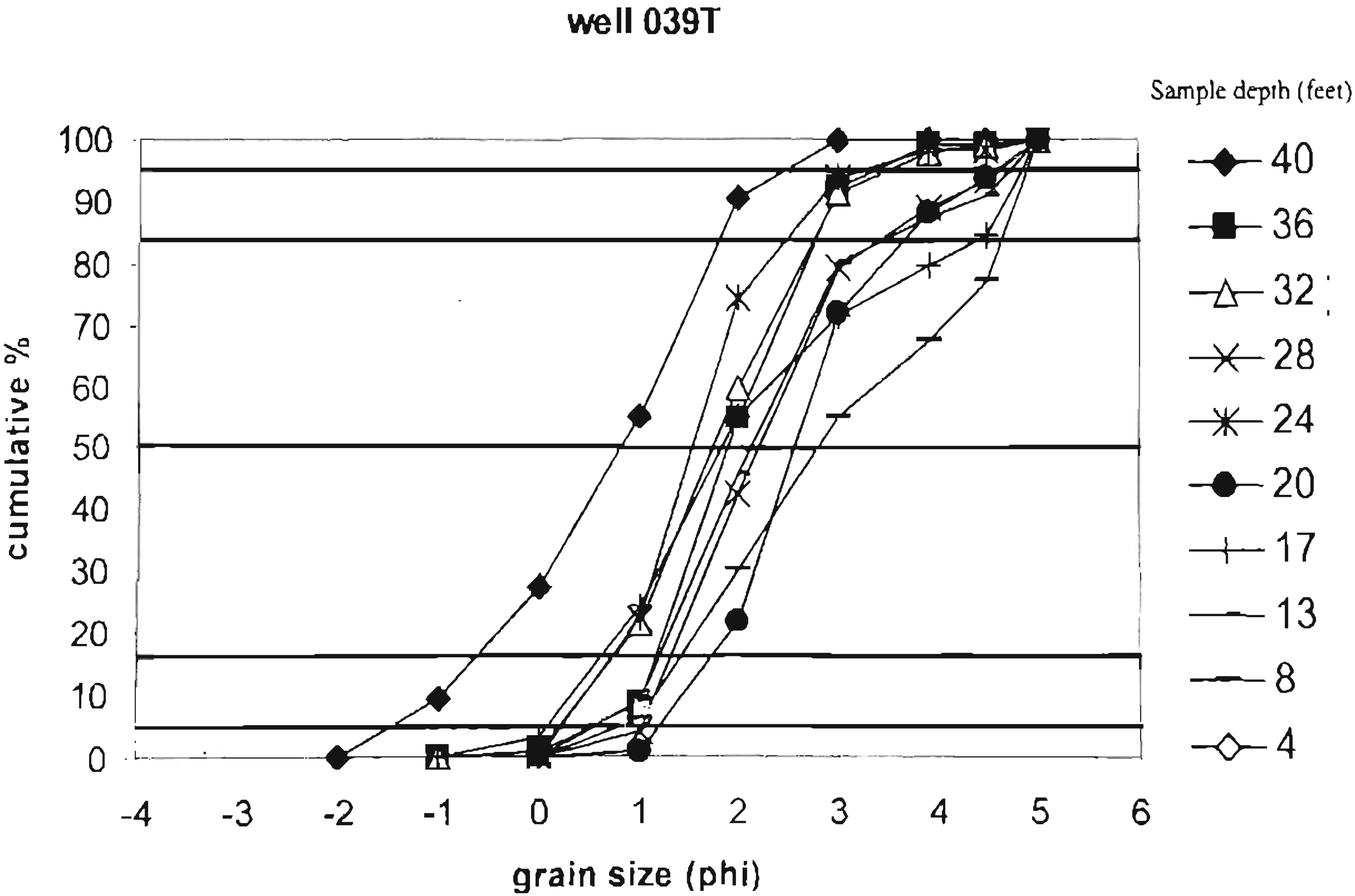
well 027T
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)
Sample depth (feet)
28
23
17
12
8
4
1

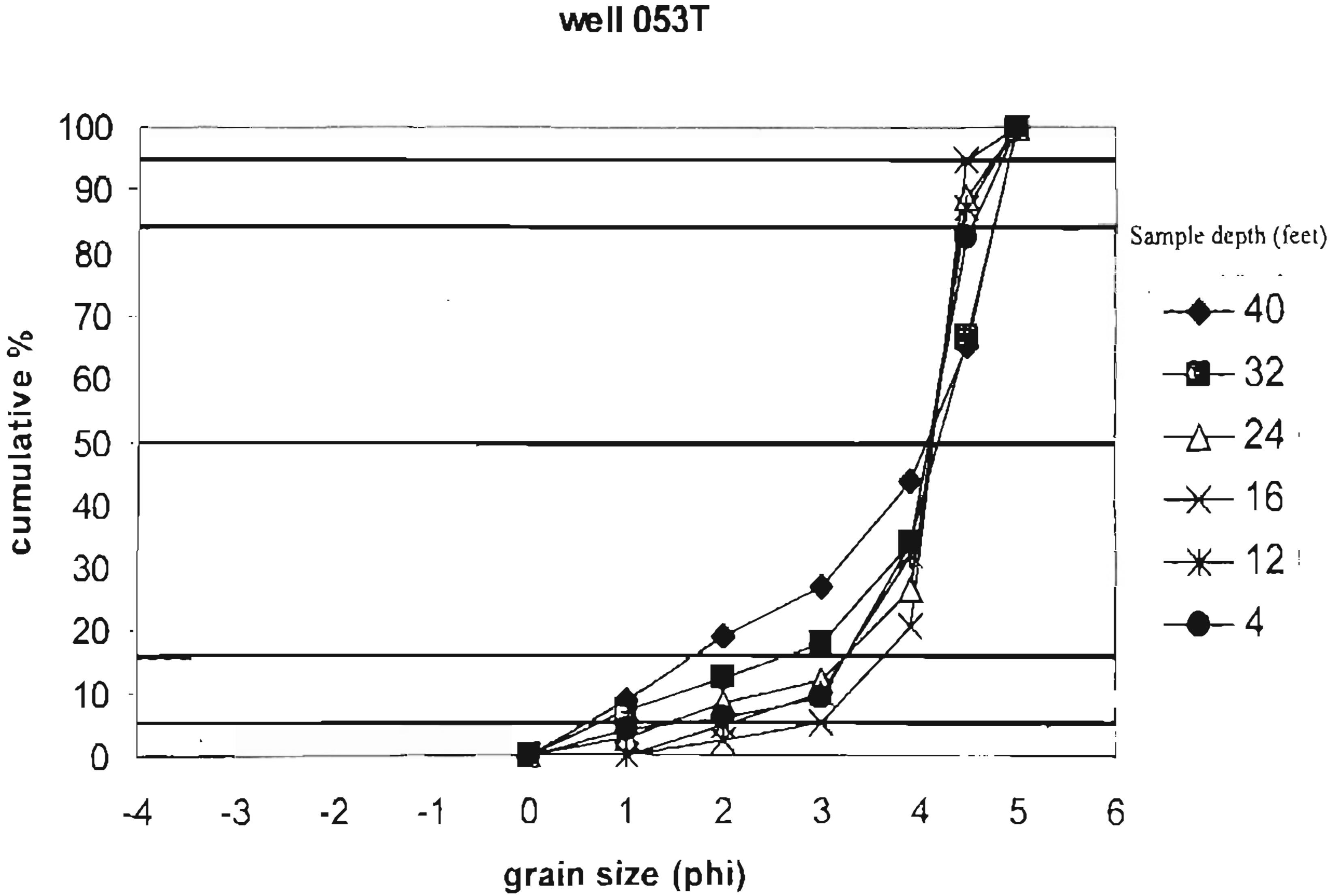
well 028T

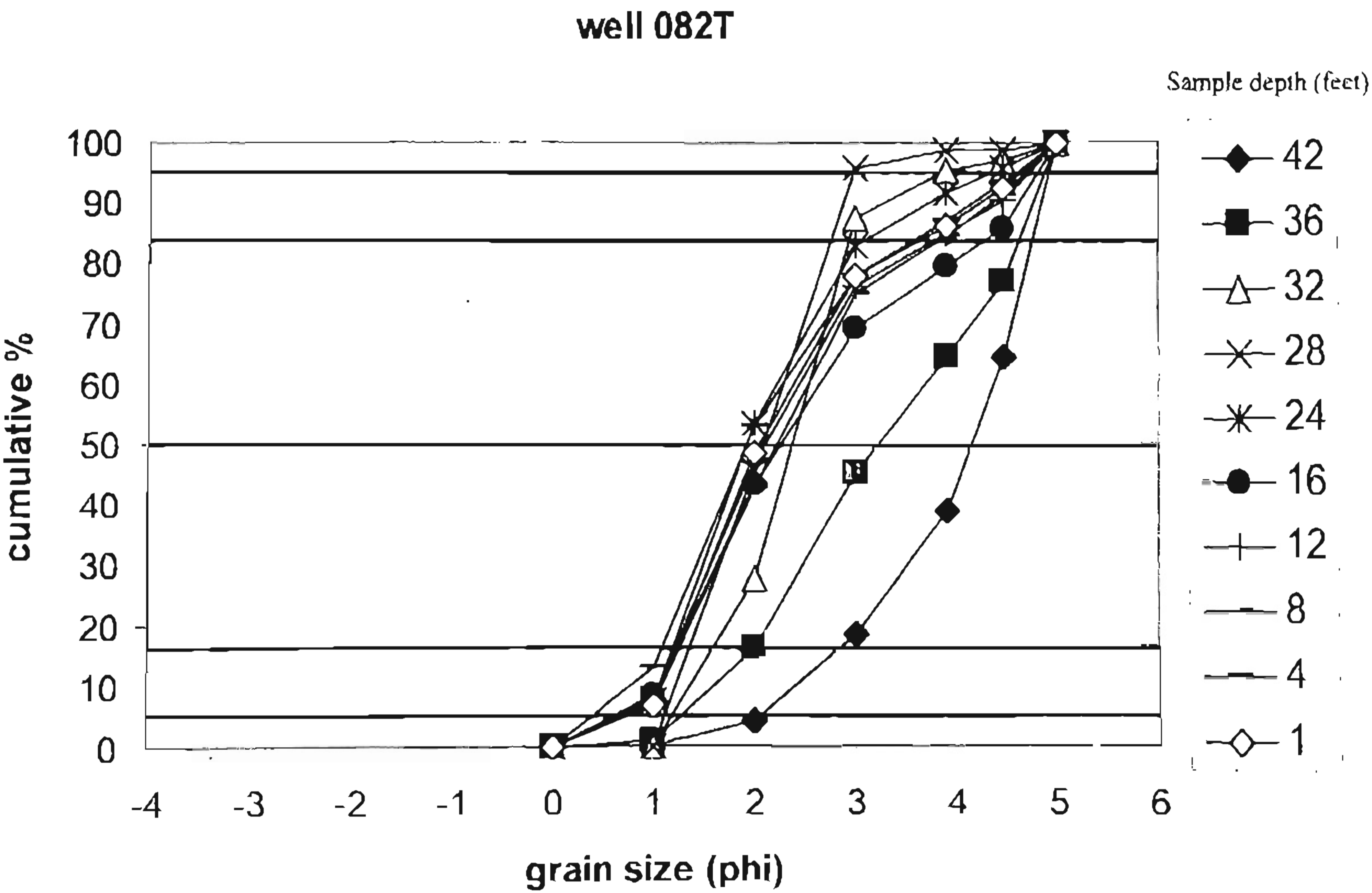


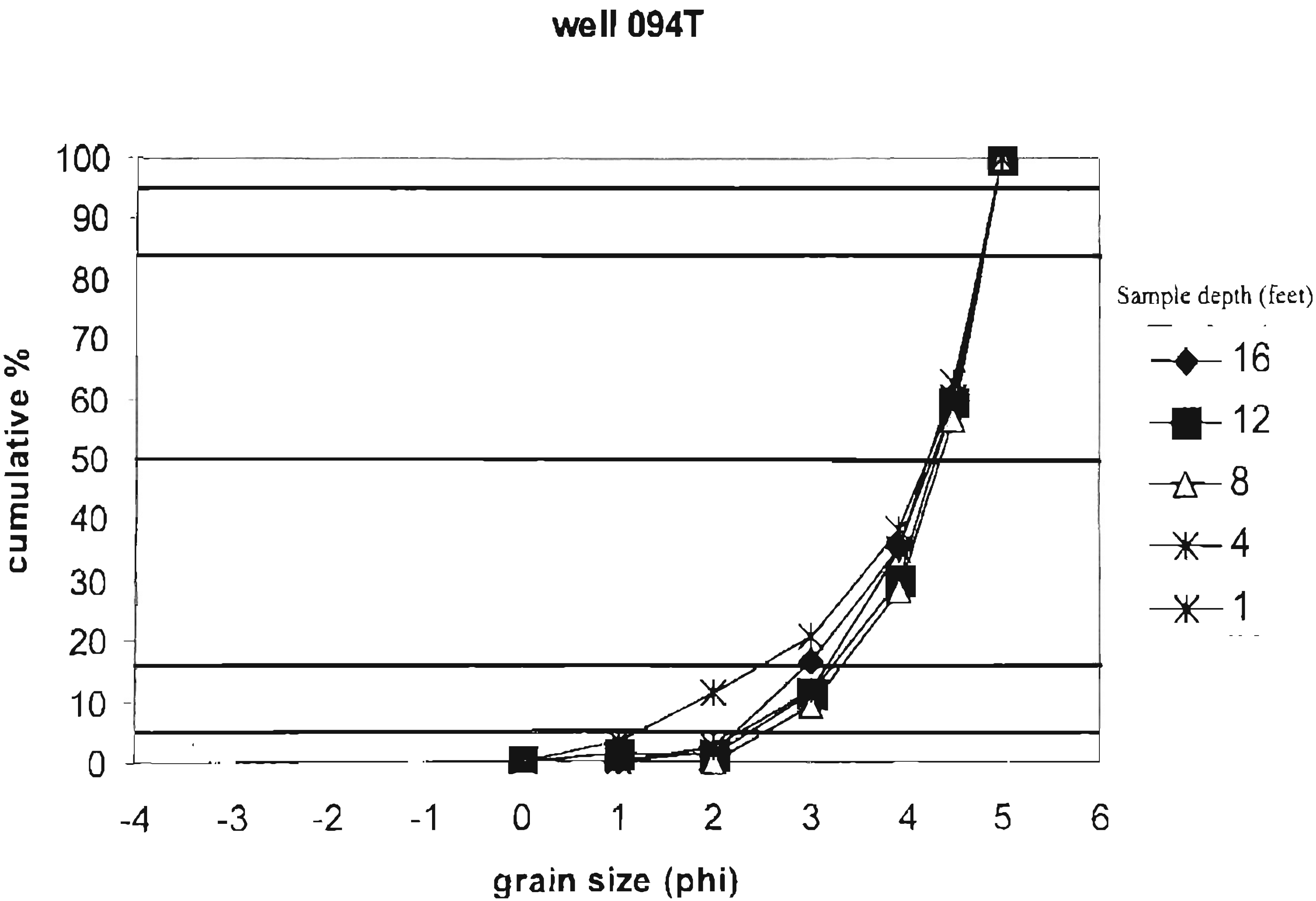
well 028T
cumulative %
grain size (phi)
Sample depth (feet)
27.7
27
24
16
12
4
1

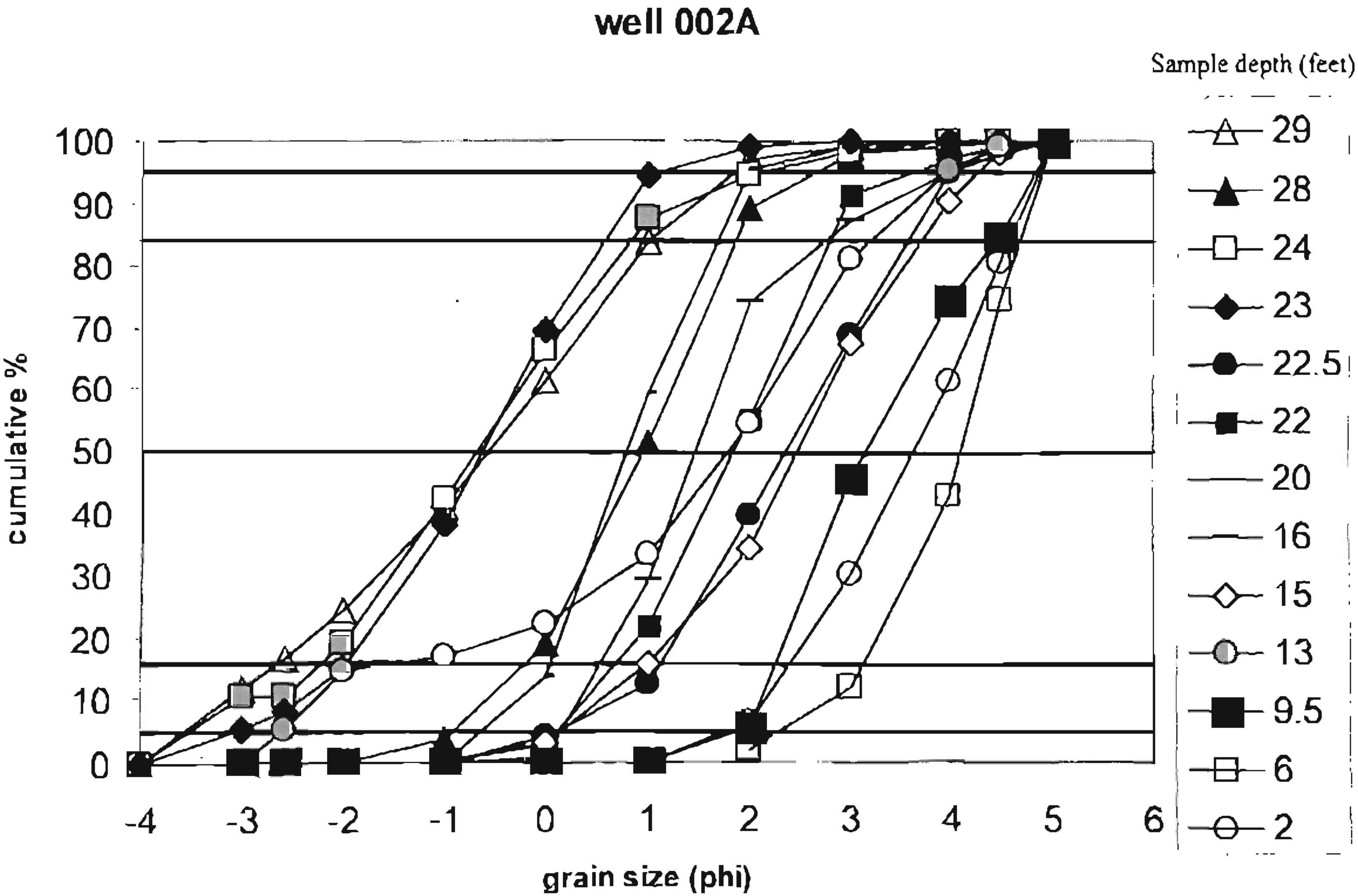

well 035T
Sample depth (feet)
cumulative %
grain size (phi)
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
50
47
44
40
38
32
28
24
23
16
12
8
4
1


well 039T
Sample depth (feet)
cumulative %
grain size (phi)
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
40
36
32
28
24
20
17
13
8
4

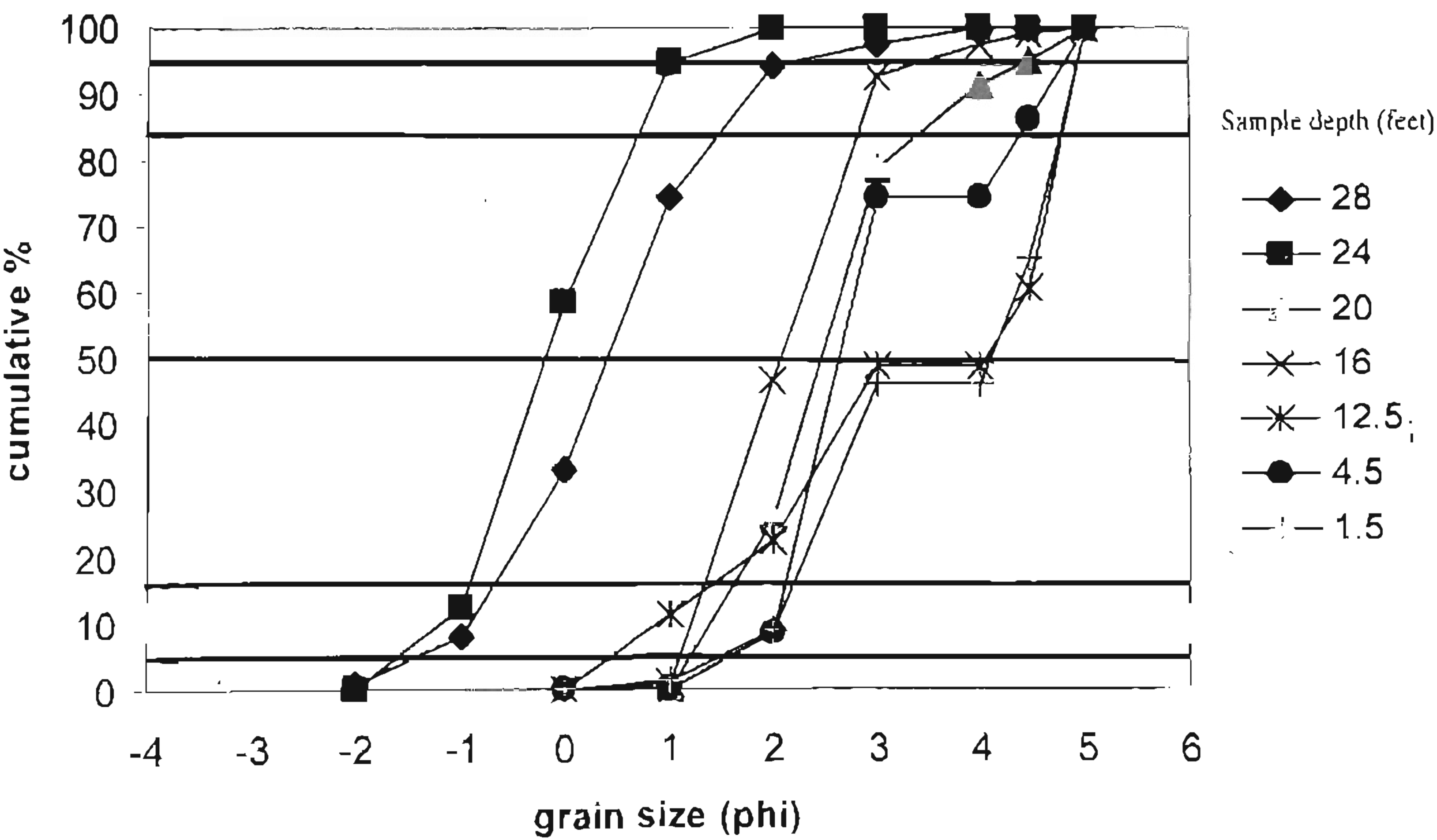

well 053T
cumulative %
grain size (phi)
Sample depth (feet)
40
32
24
16
12
4
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6


well 082T
Sample depth (feet)
42
36
32
28
24
16
12
8
4
1
cumulative %
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)

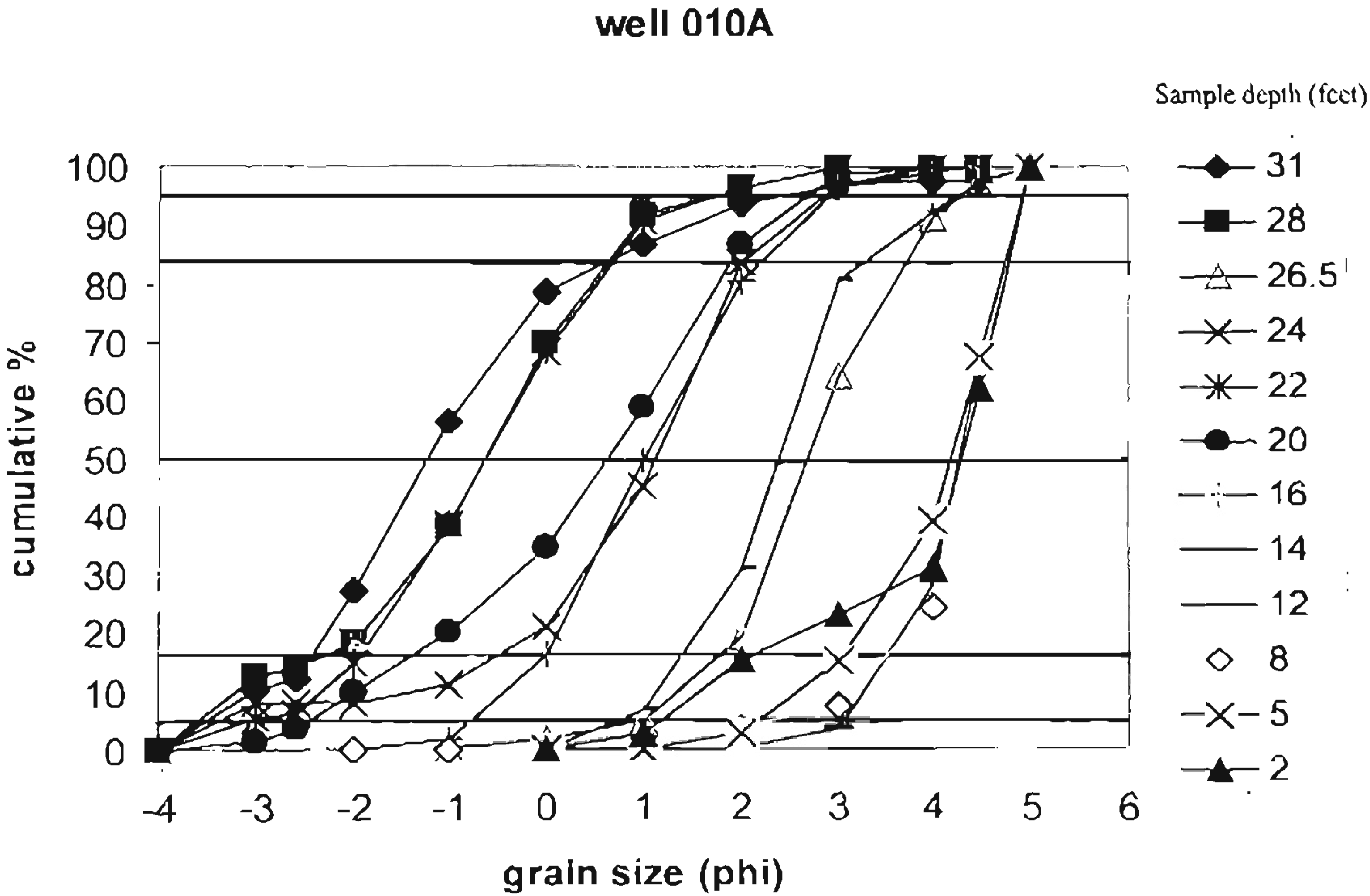

well 094T
cumulative %
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)
Sample depth (feet)
16
12
8
4
1

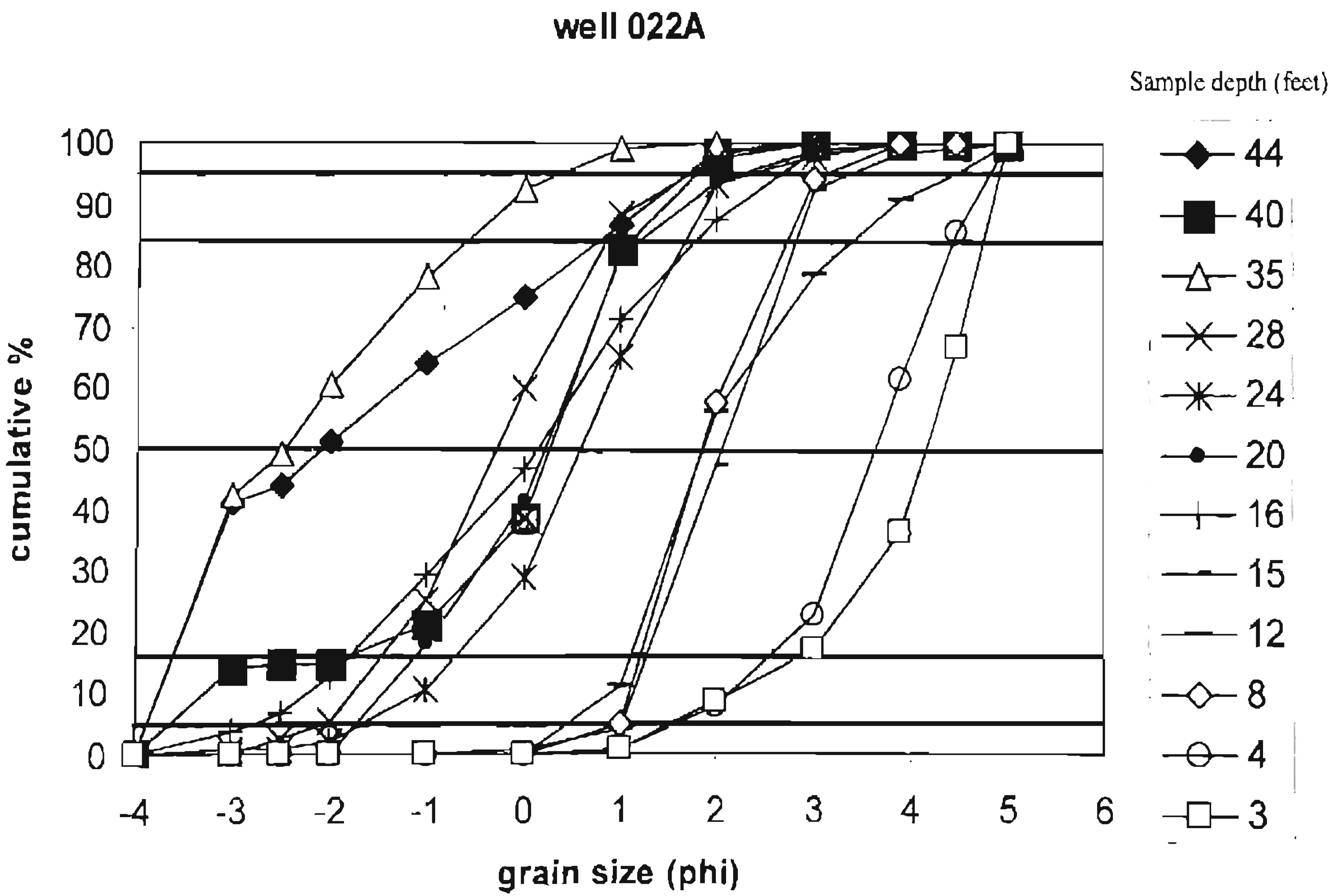

well 002A
Sample depth (feet)
29
28
24
23
22.5
22
20
16
15
13
9.5
6
2
cumulative %
0
10
20
30
40
50
60
70
80
90
100
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)

well 007A

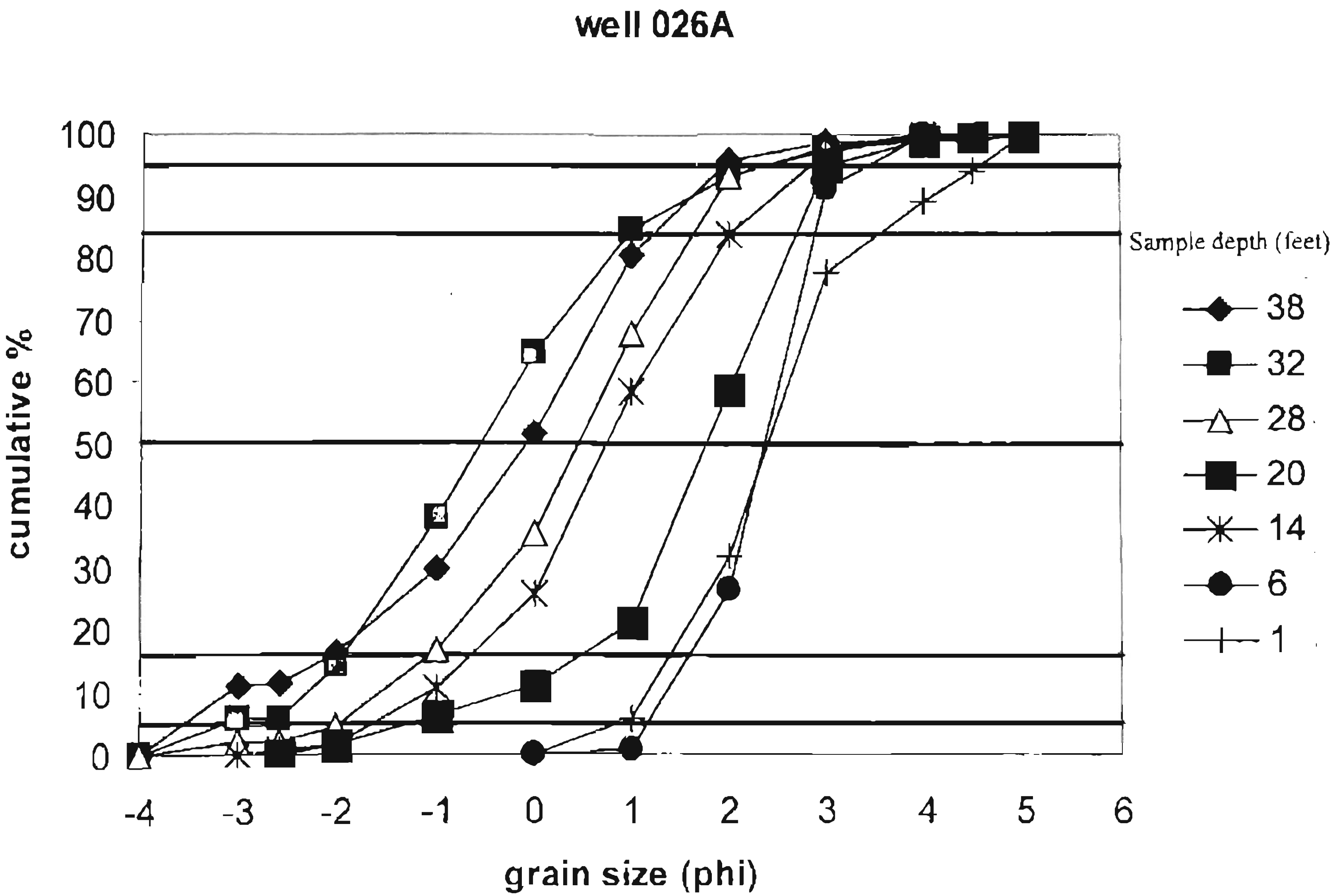


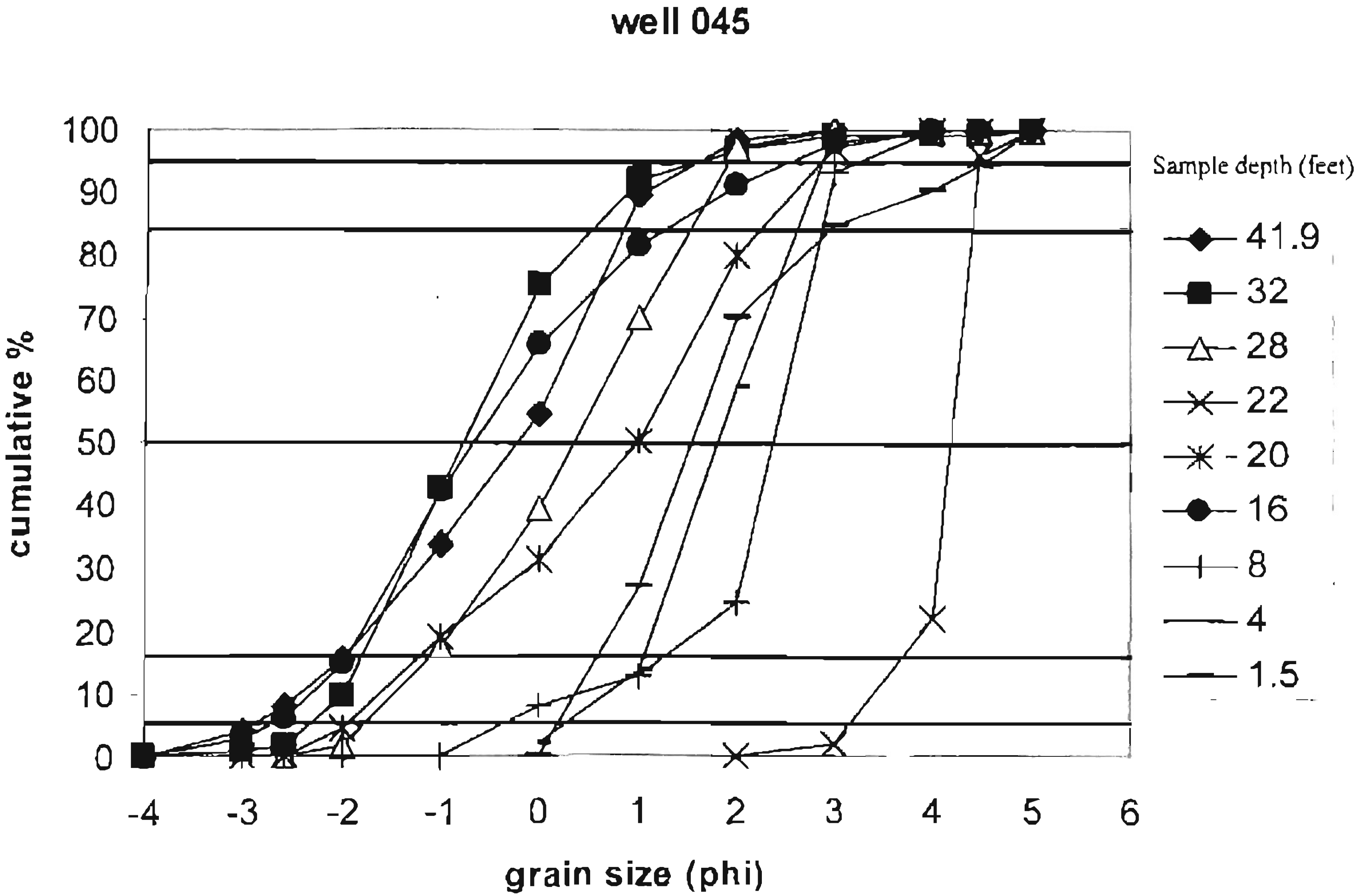
cumulative %
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)
Sample depth (feet)
28
24
20
16
12.5
4.5
1.5

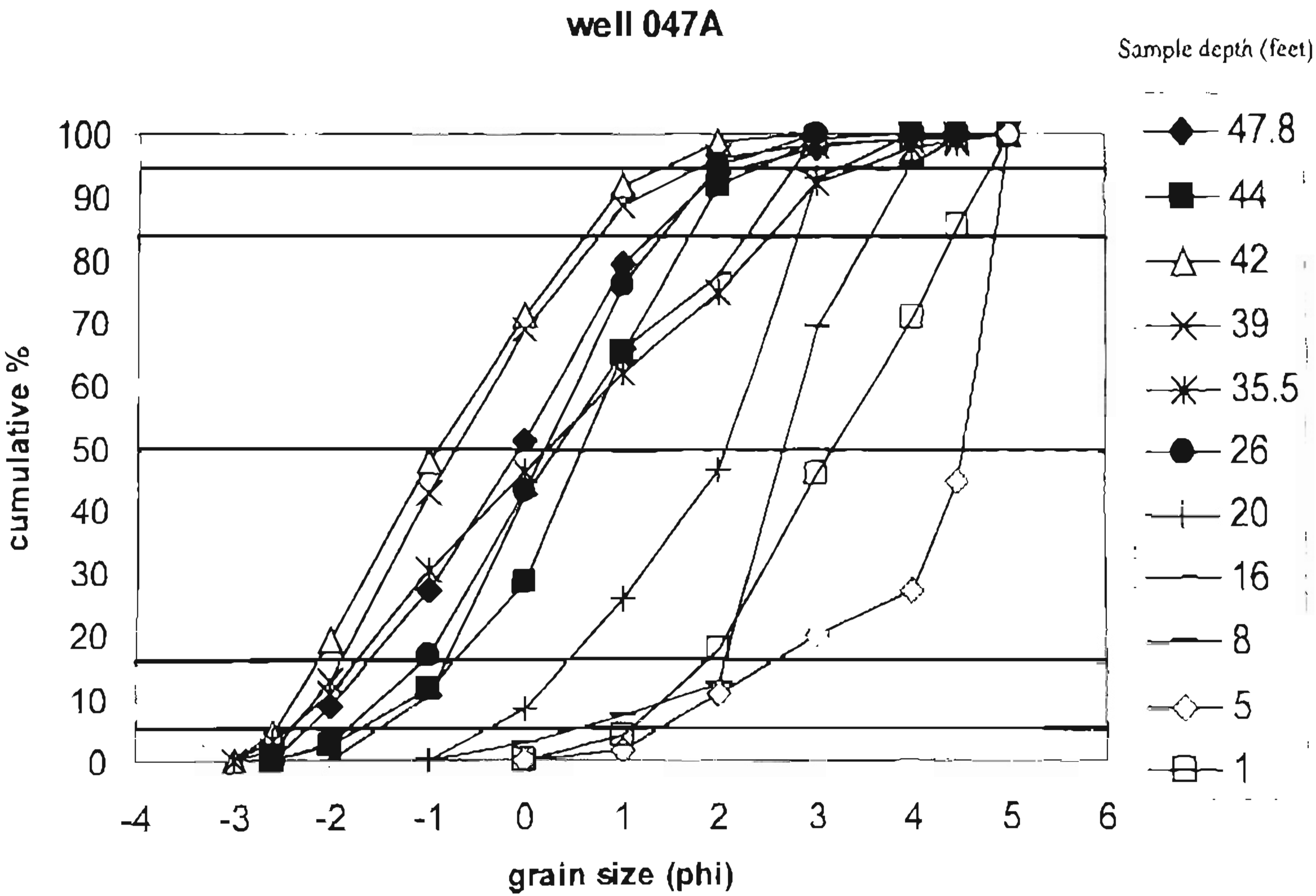

well 010A
cumulative %
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)
Sample depth (feet)
31
28
26.5
24
22
20
16
14
12
8
5
2

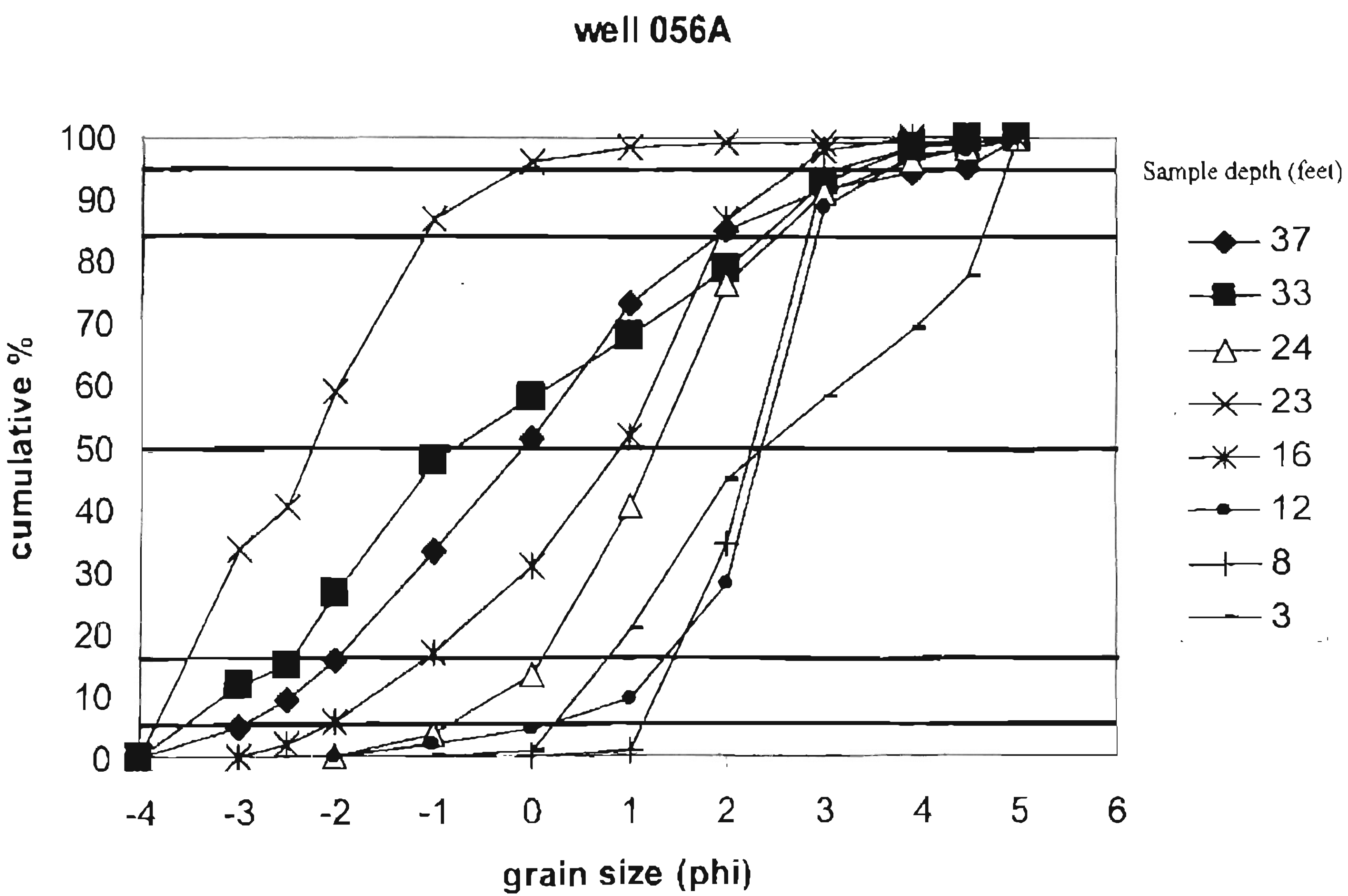


well 022A
Sample depth (feet)
cumulative %
grain size (phi)
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
44
40
35
28
24
20
16
15
12
8
4
3


well 026A
cumulative %
0
10
20
30
40
50
60
70
80
90
100
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)
Sample depth (feet)
38
32
28
20
14
6
1

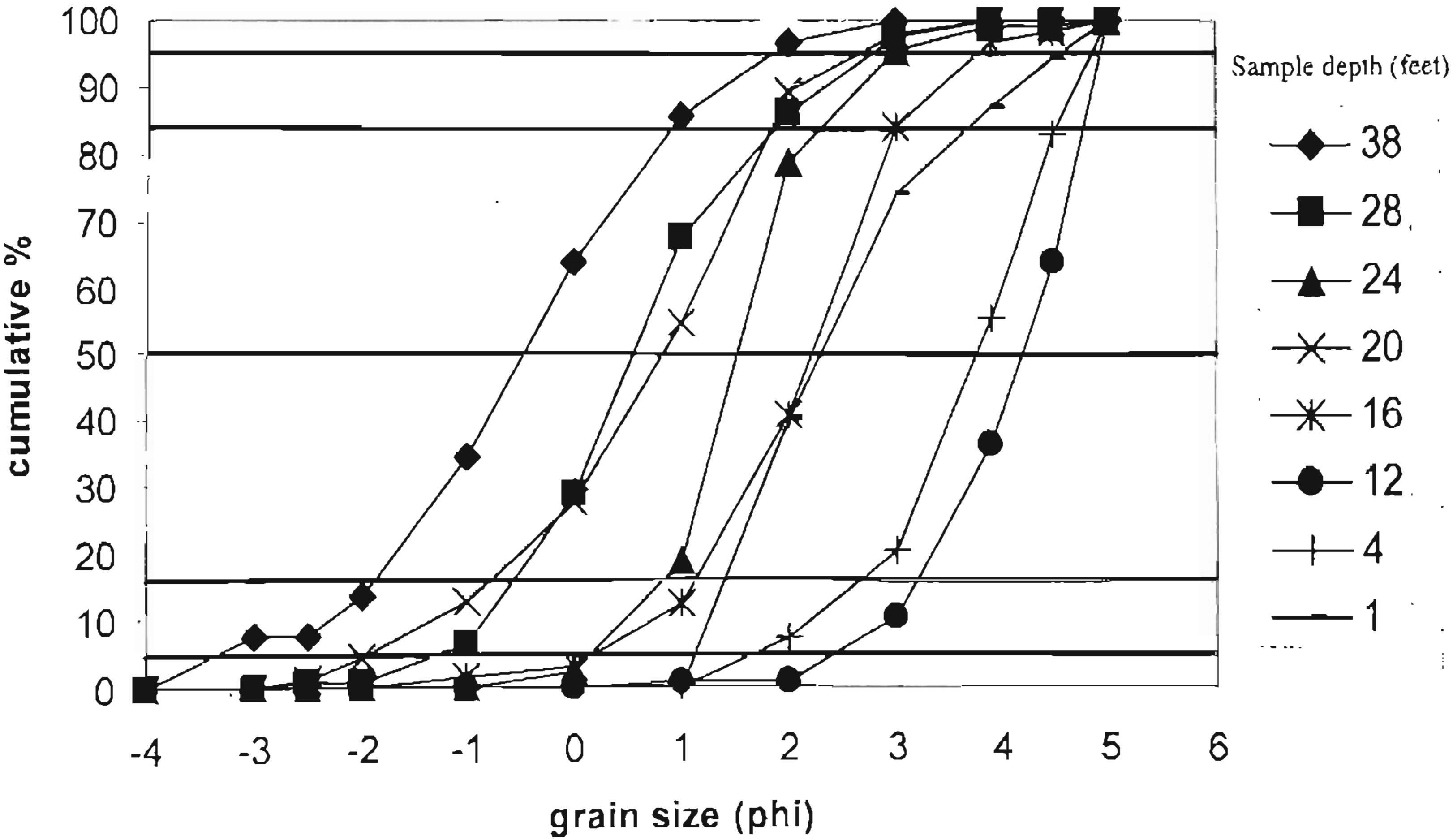

well 045
cumulative %
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6
grain size (phi)
Sample depth (feet)
41.9
32
28
22
- 20
16
8
4
1.5

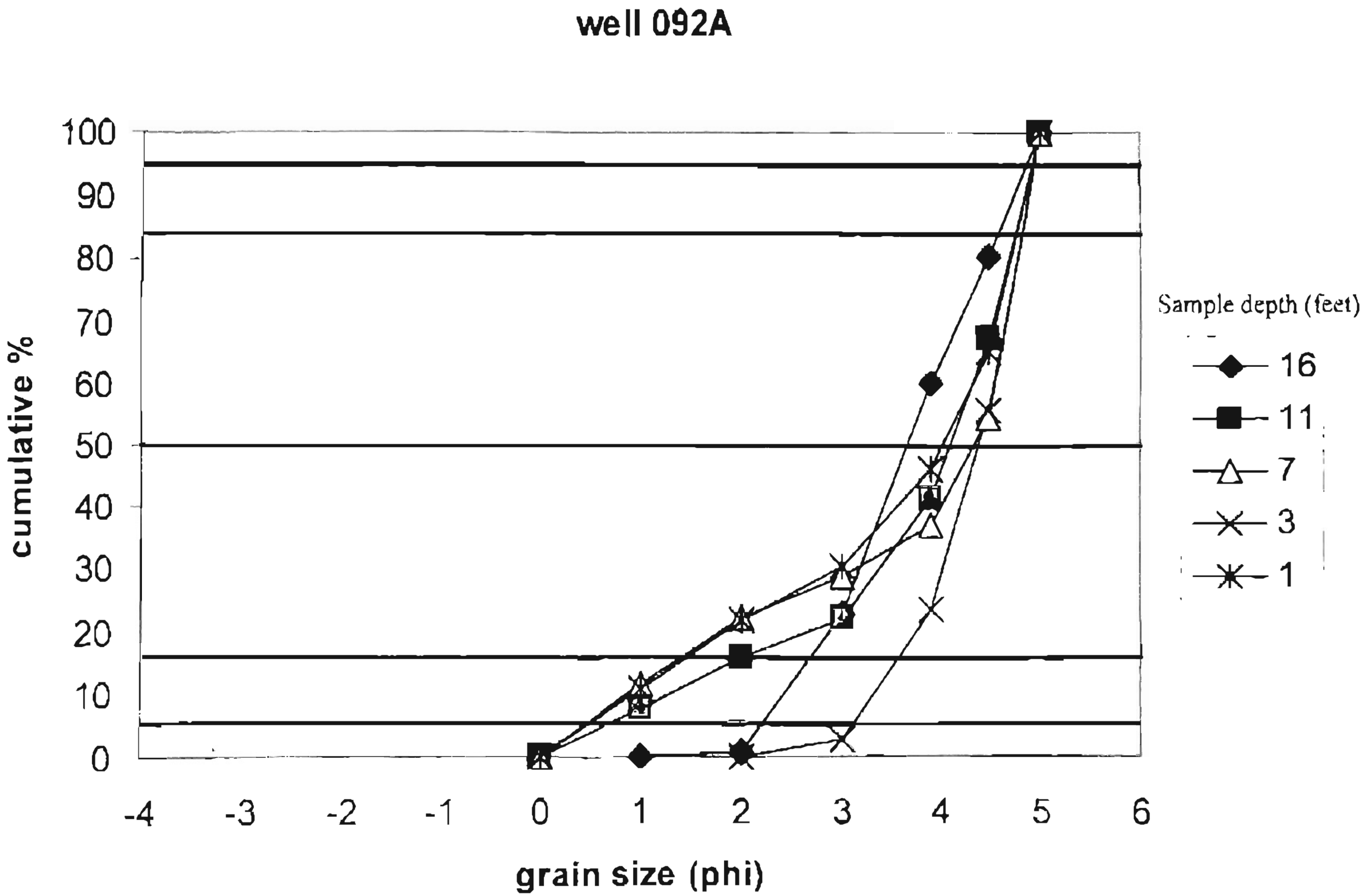

well 047A
Sample depth (feet)
47.8
44
42
39
35.5
26
20
16
8
5
1
cumulative %
grain size (phi)
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6



well 056A
cumulative %
grain size (phi)
Sample depth (feet)
37
33
24
23
16
12
8
3
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6

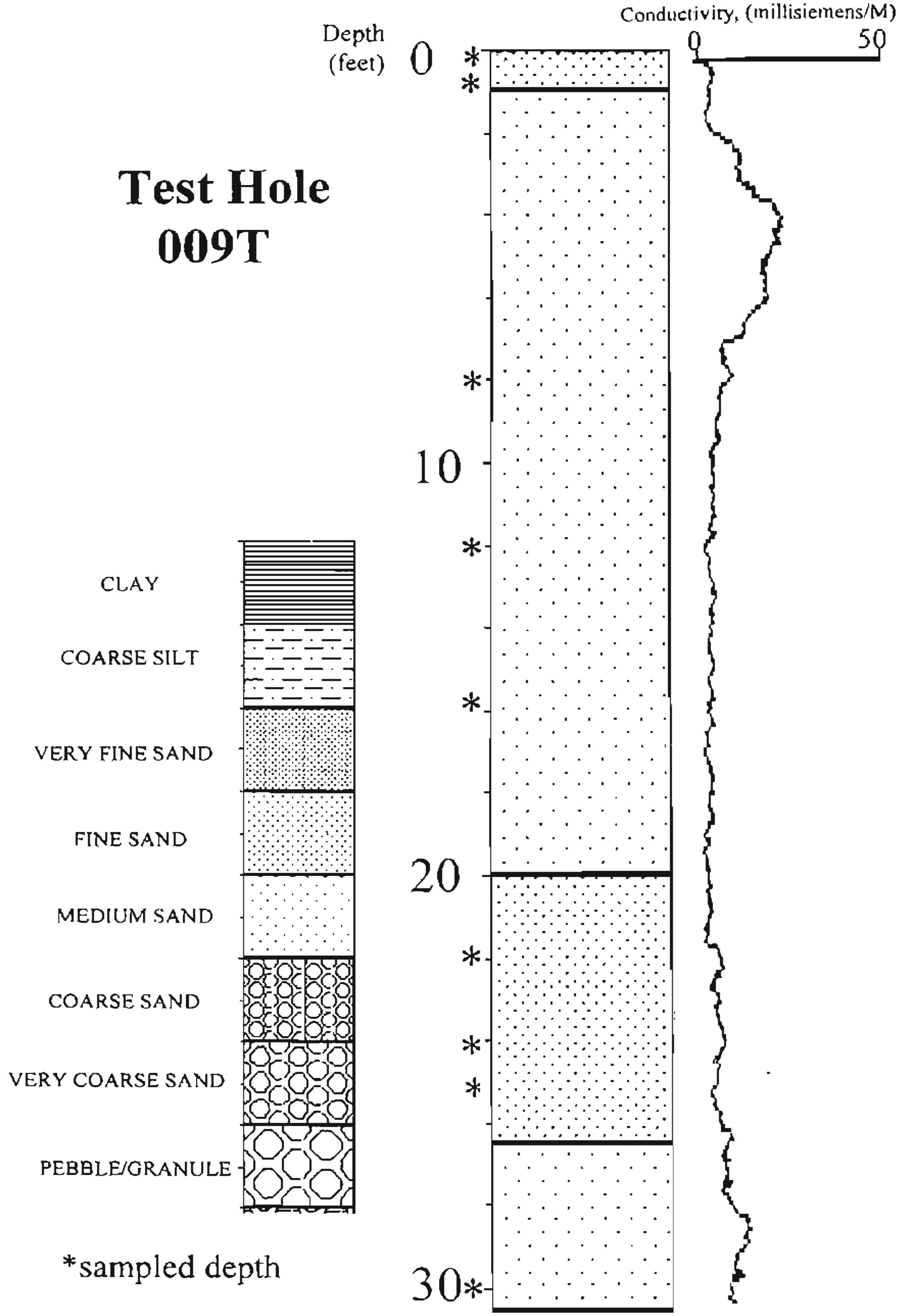
well 071A


cumulative %
grain size (phi)
Sample depth (feet)
38
28
24
20
16
12
4
1
0
10
20
30
40
50
60
70
80
90
100
-4
-3
-2
-1
0
1
2
3
4
5
6

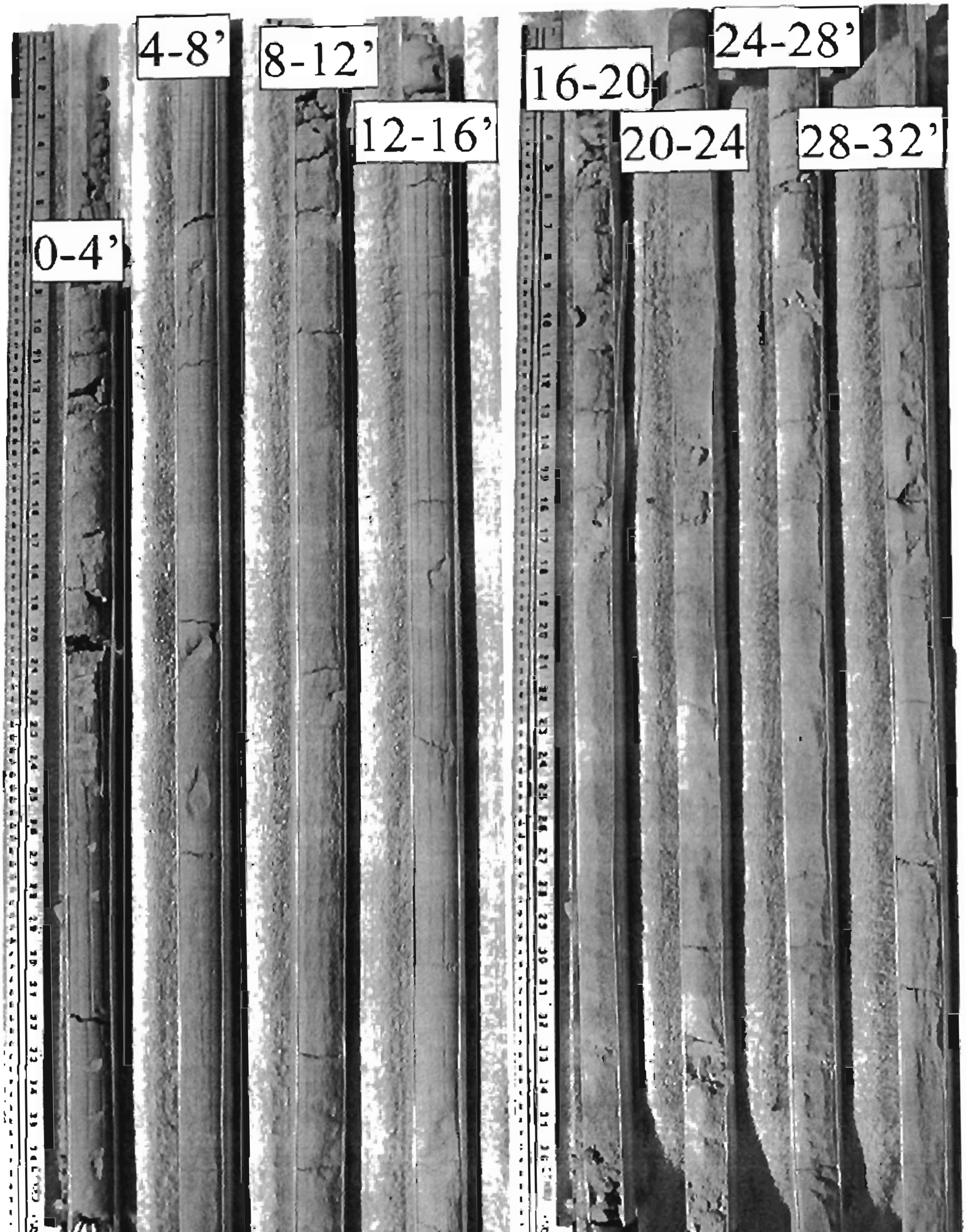

well 092A
cumulative %
grain size (phi)
Sample depth (feet)
16
11
7
3
1
100
90
80
70
60
50
40
30
20
10
0
-4
-3
-2
-1
0
1
2
3
4
5
6

APPENDIX E

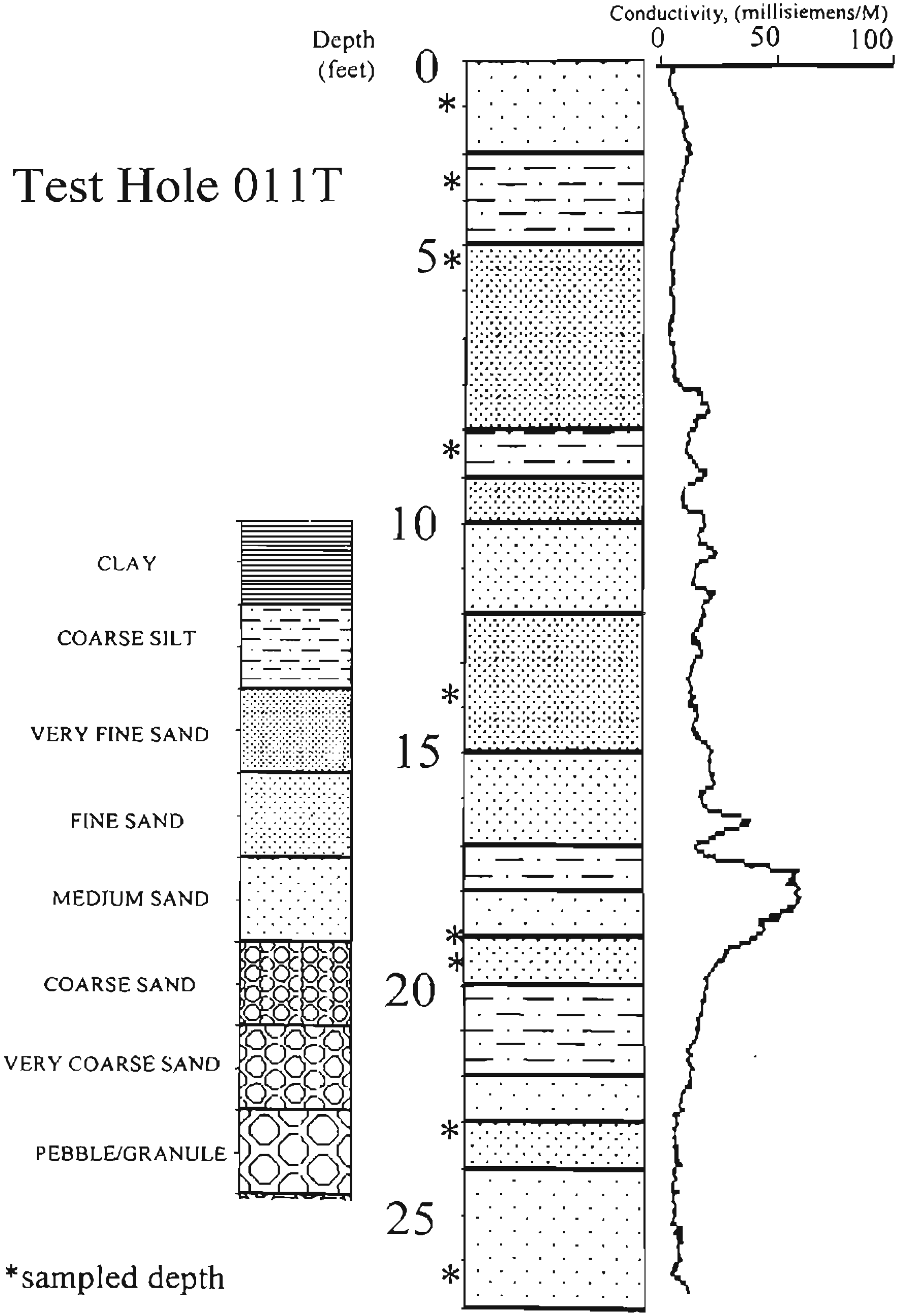
CORE STRIP LOGS AND PHOTOS


Test Hole
009T
Depth
(feet)
0
10
20
30
Conductivity, (millisiemens/M)
0
50
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
VERY COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 009T

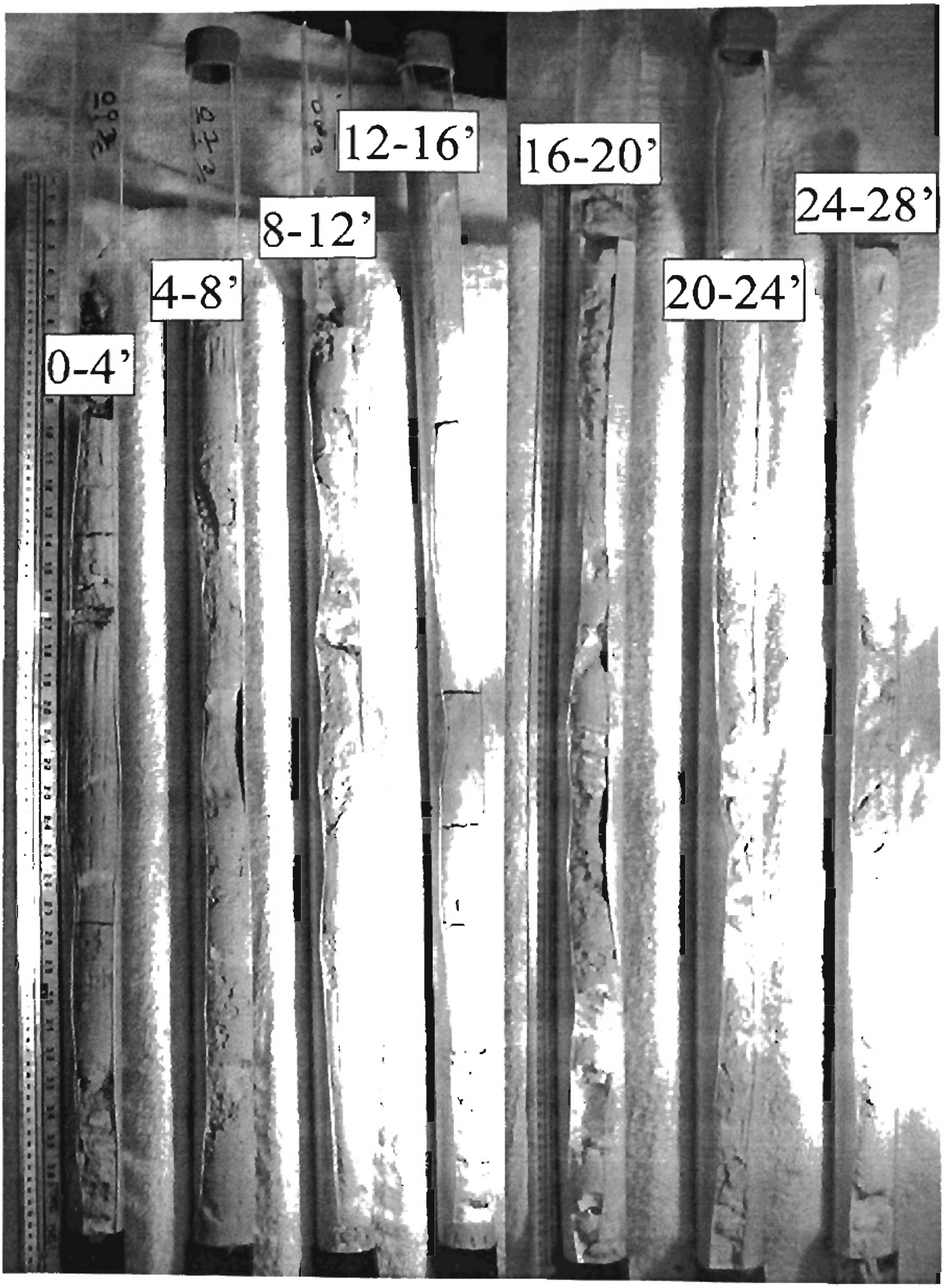


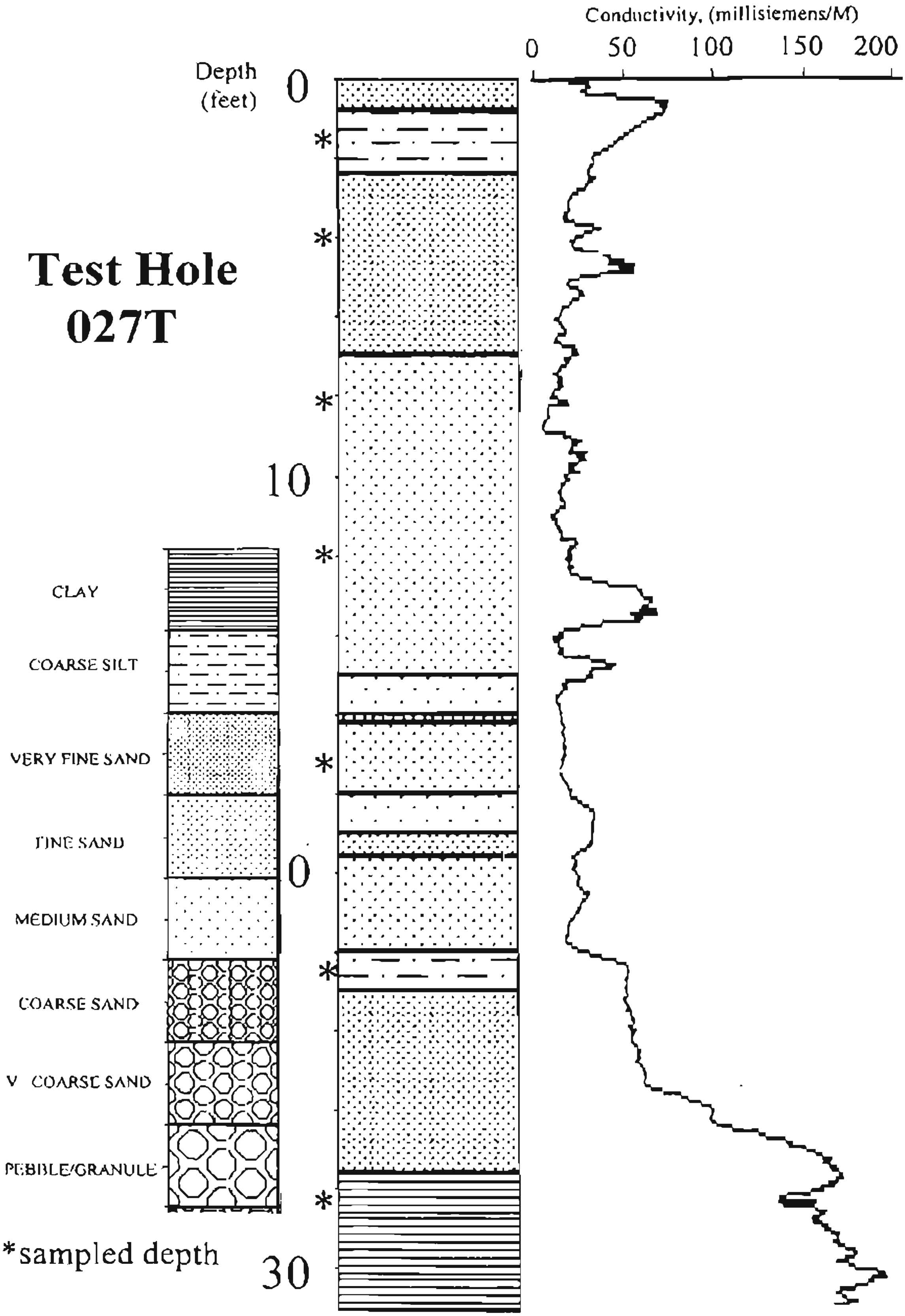
Test Hole 011T



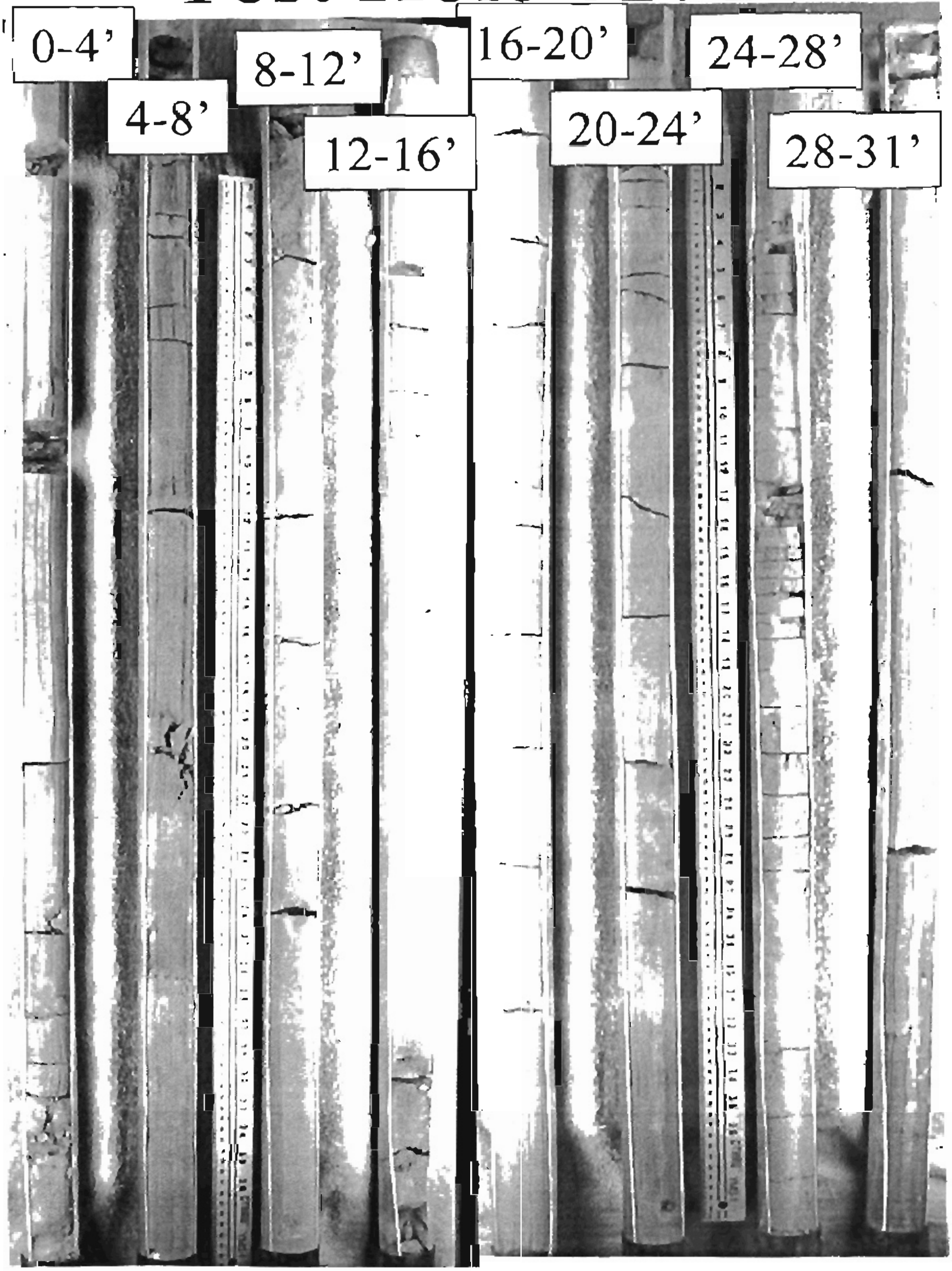
*sampled depth

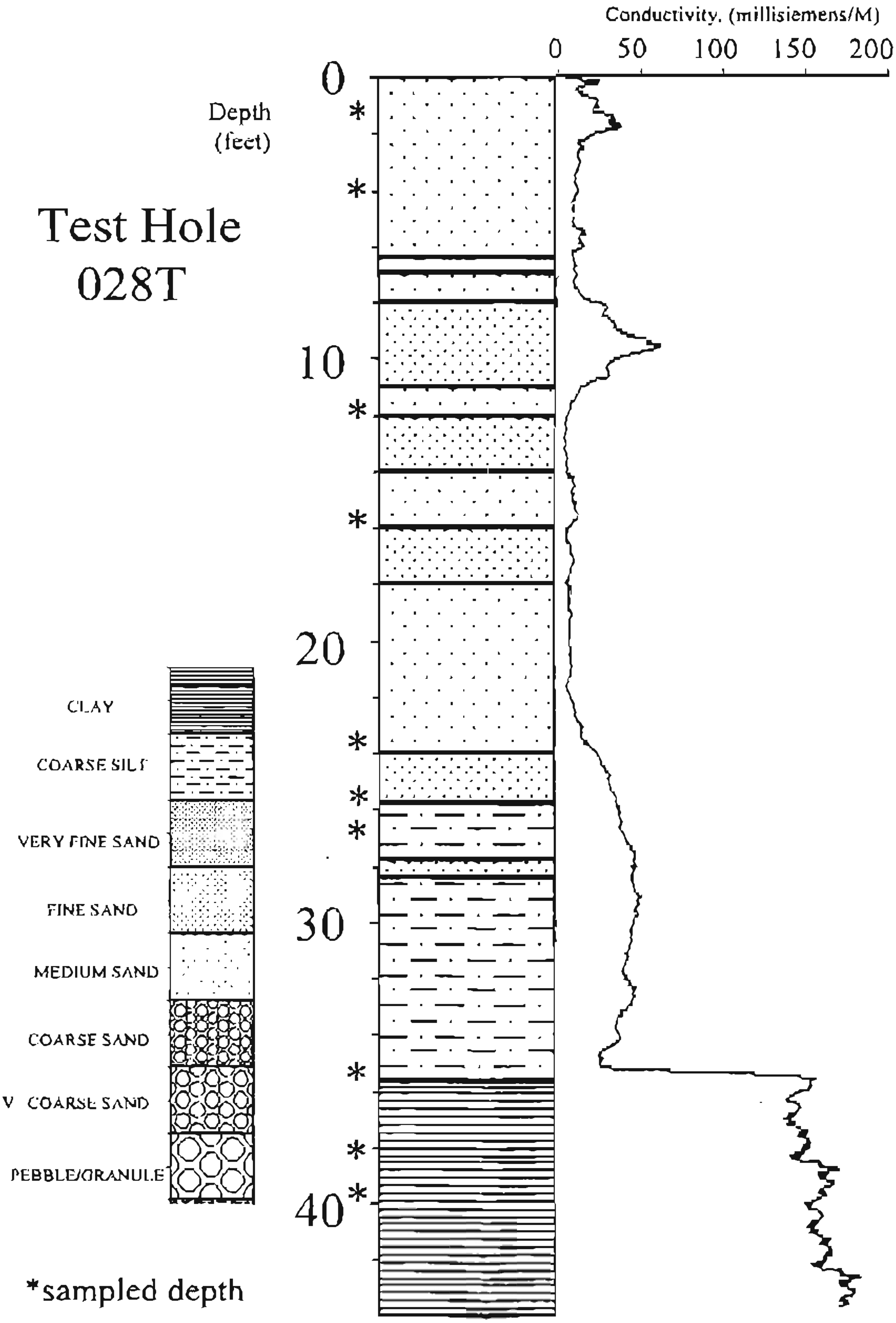
Test Hole 011T



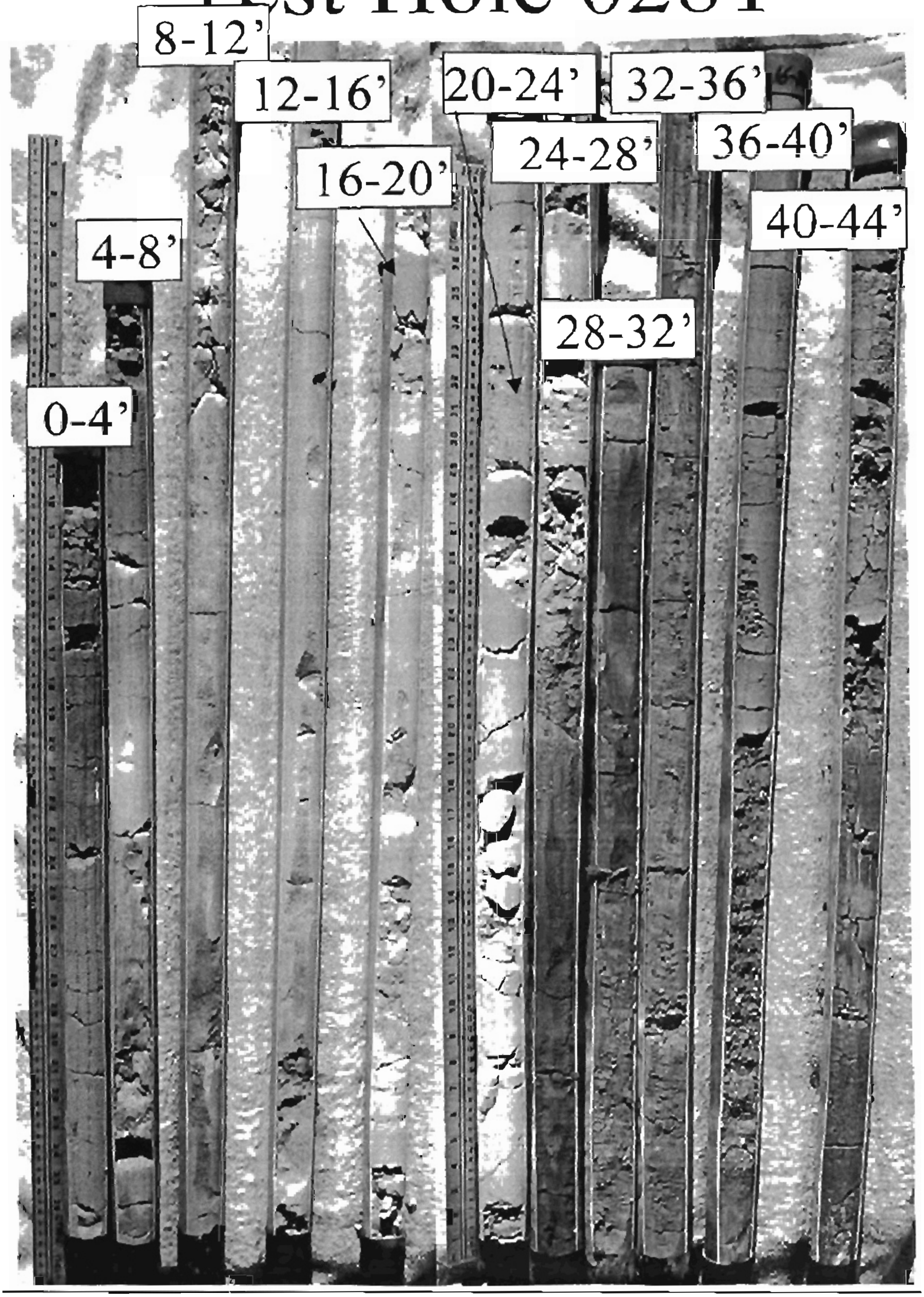

Test Hole 027T
Depth (feet)
0
10
0
30
Conductivity, (millisiemens/M)
0 50 100 150 200
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V COARSE SAND
PEBBLE/GRANULE
*sampled depth

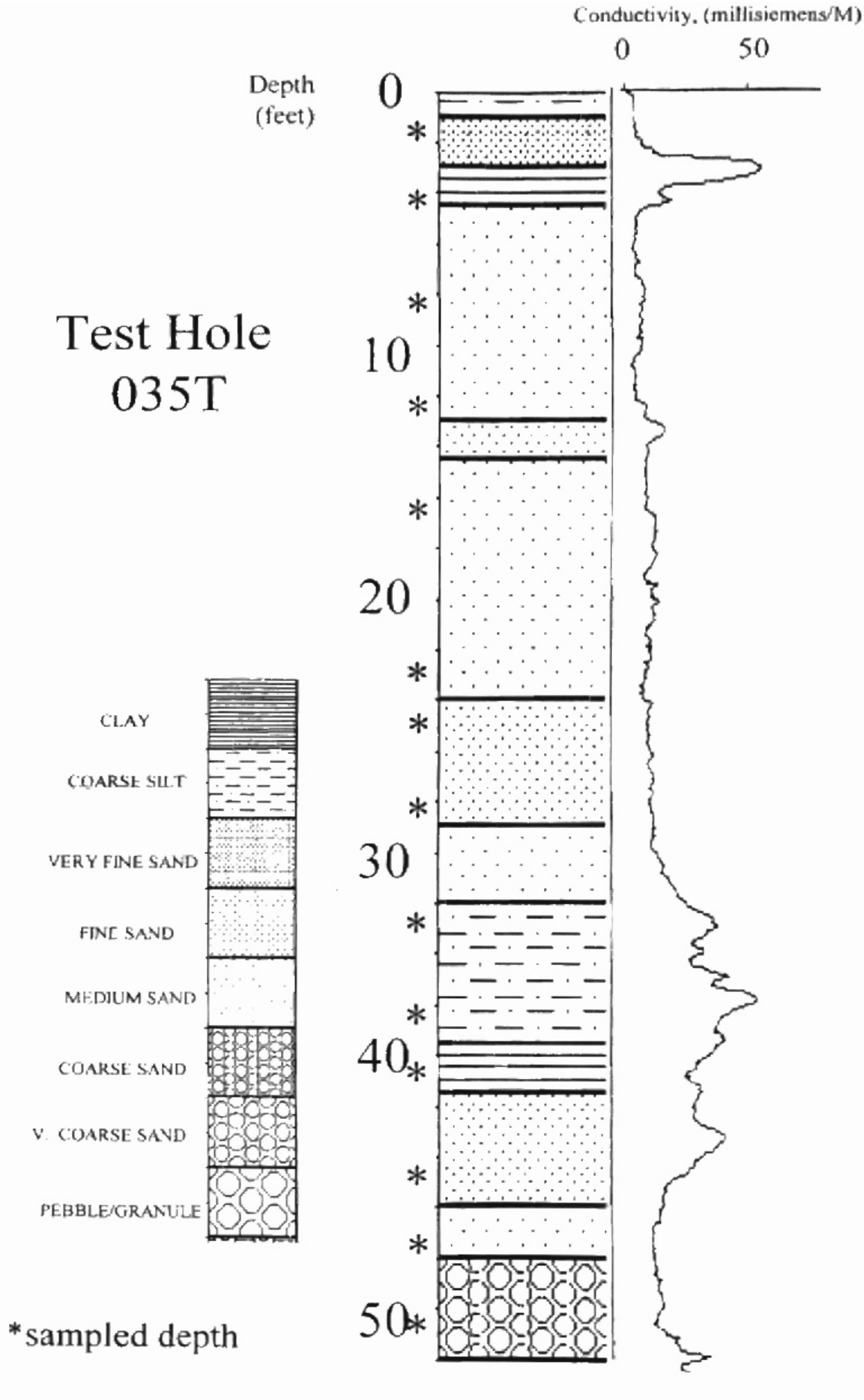
Test Hole 027T



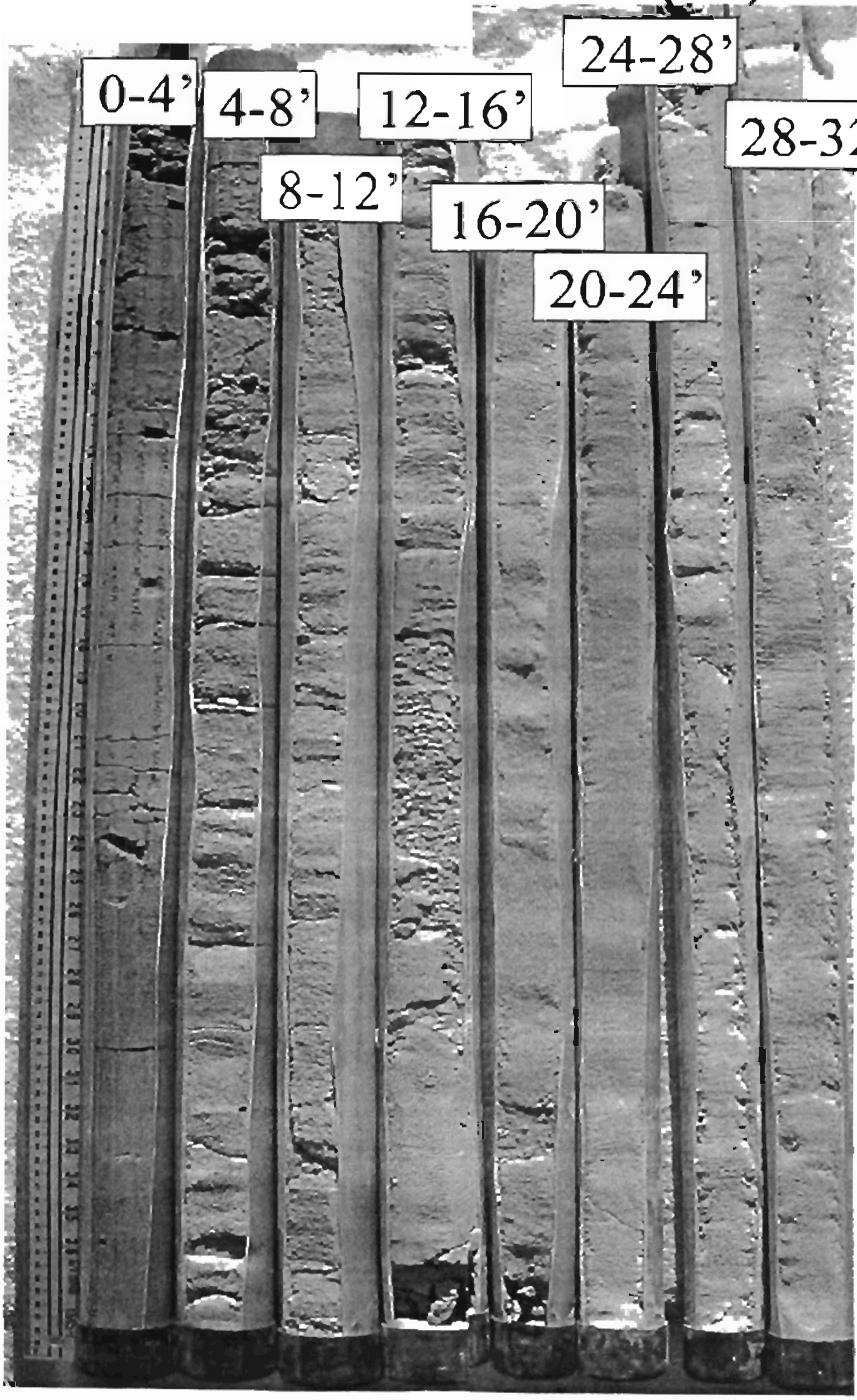

Conductivity, (millisiemens/M)
0
50
100
150
200
Depth
(feet)
0
10
20
30
40
*
Test Hole
028T
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 028T

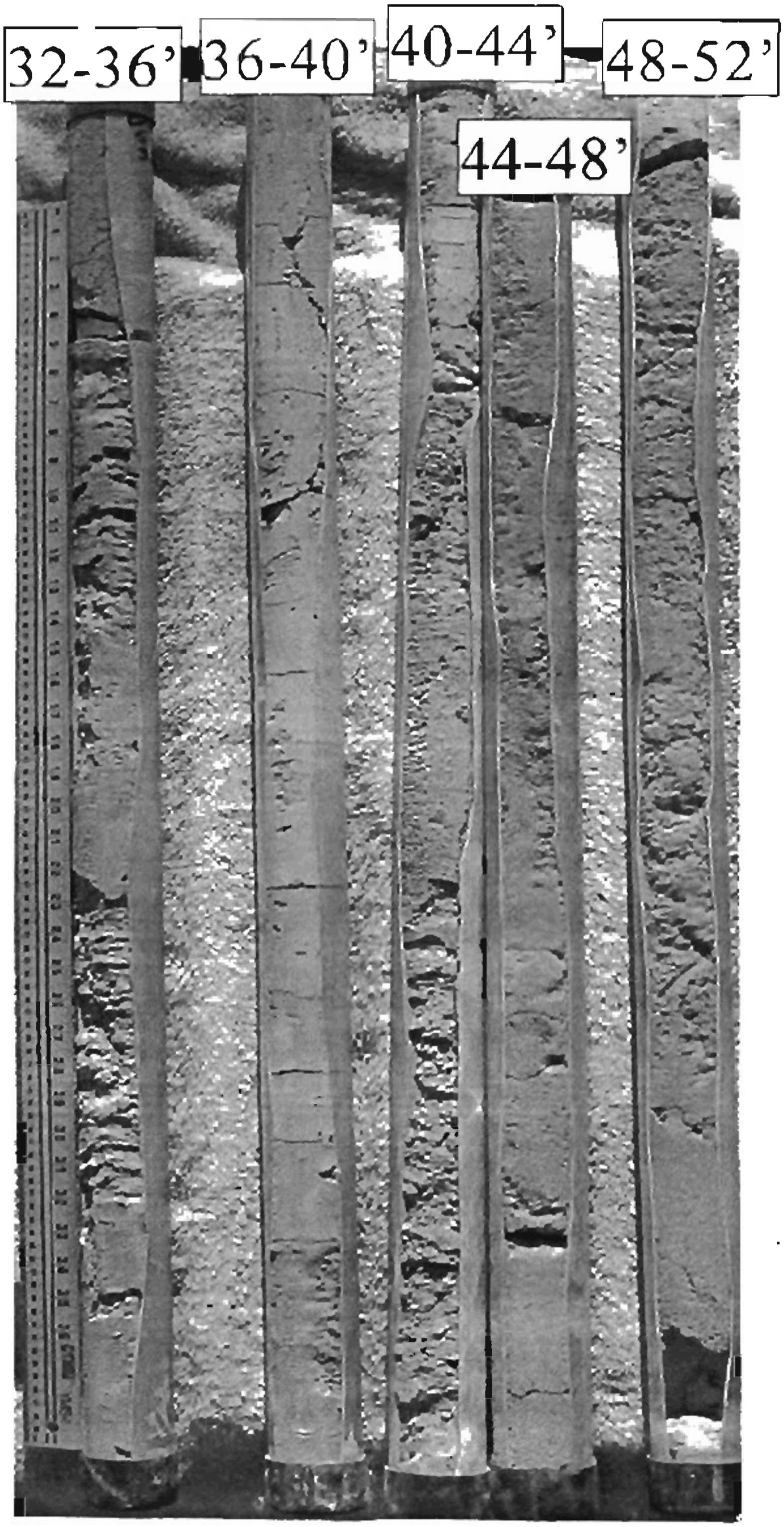


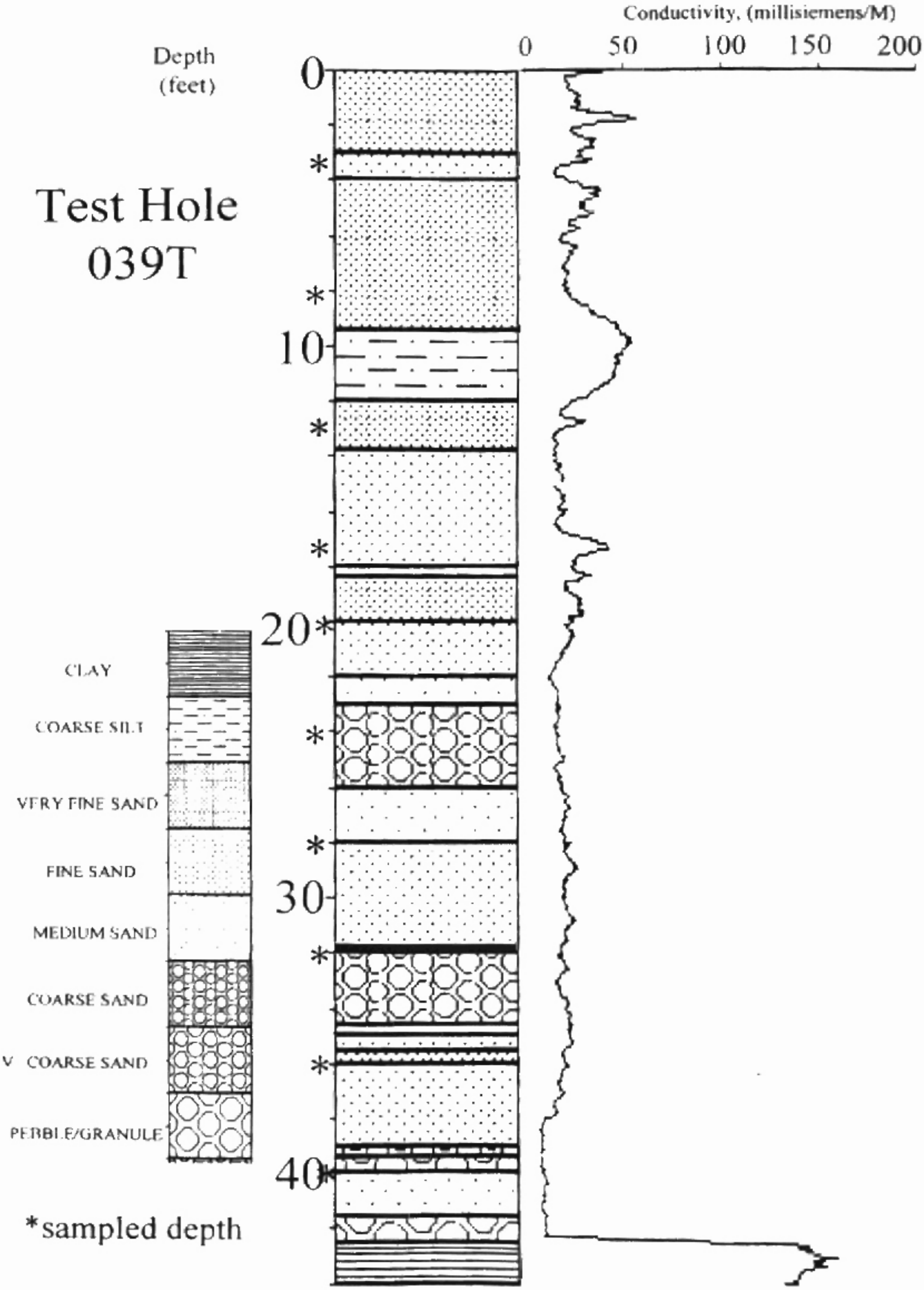

Conductivity, (millisiemens/M)
0
50
Depth (feet)
0
10
20
30
40
50
Test Hole 035T
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 035T(a)

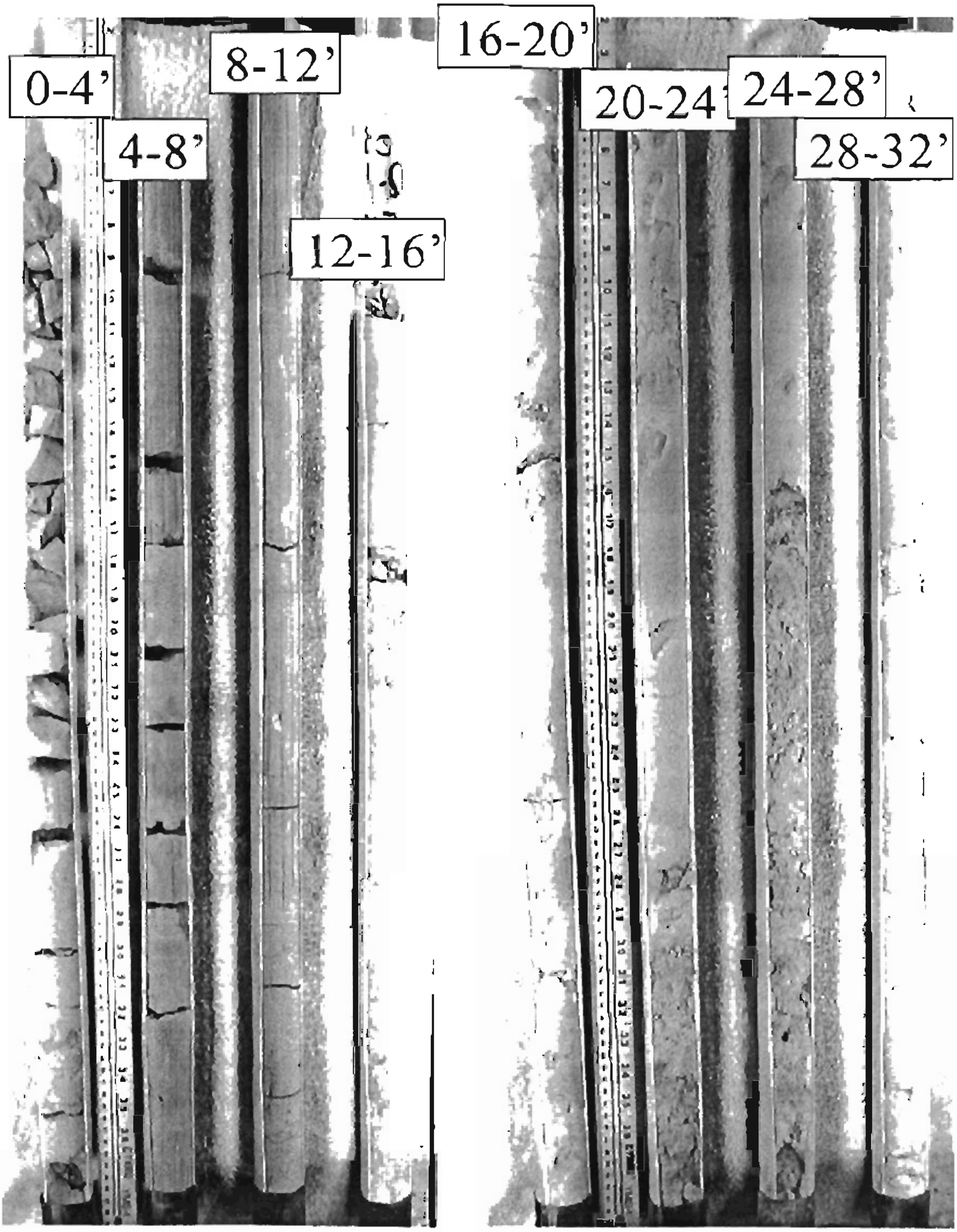


Well 035T(b)

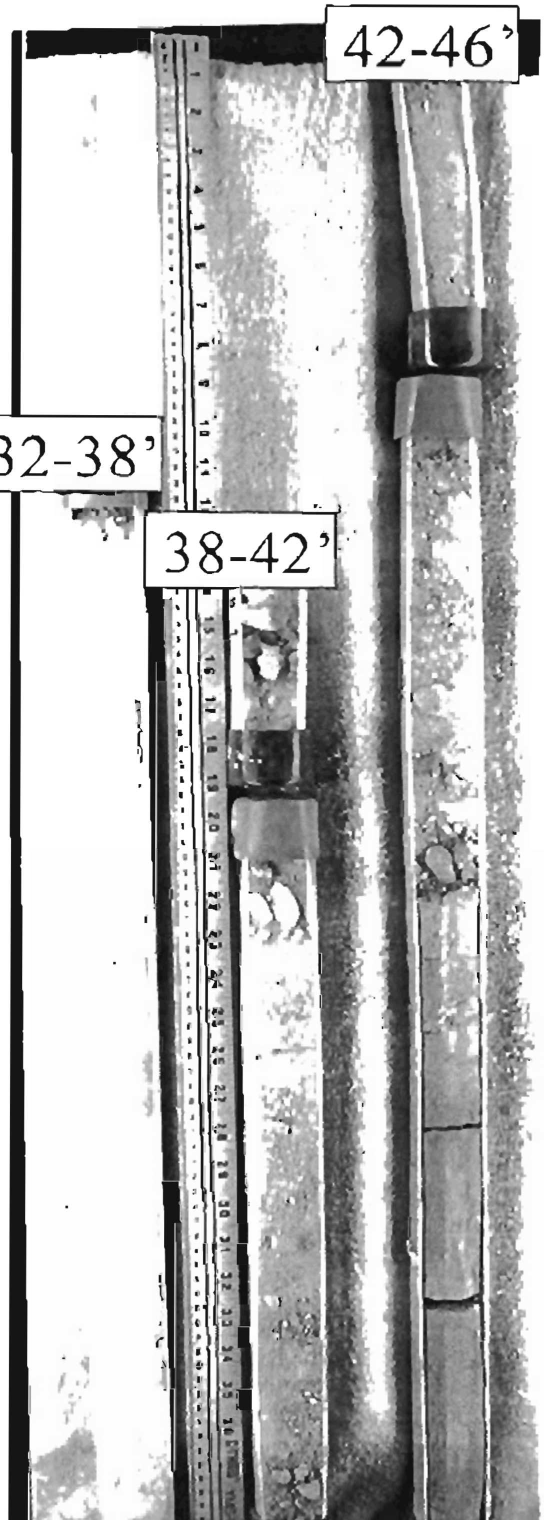


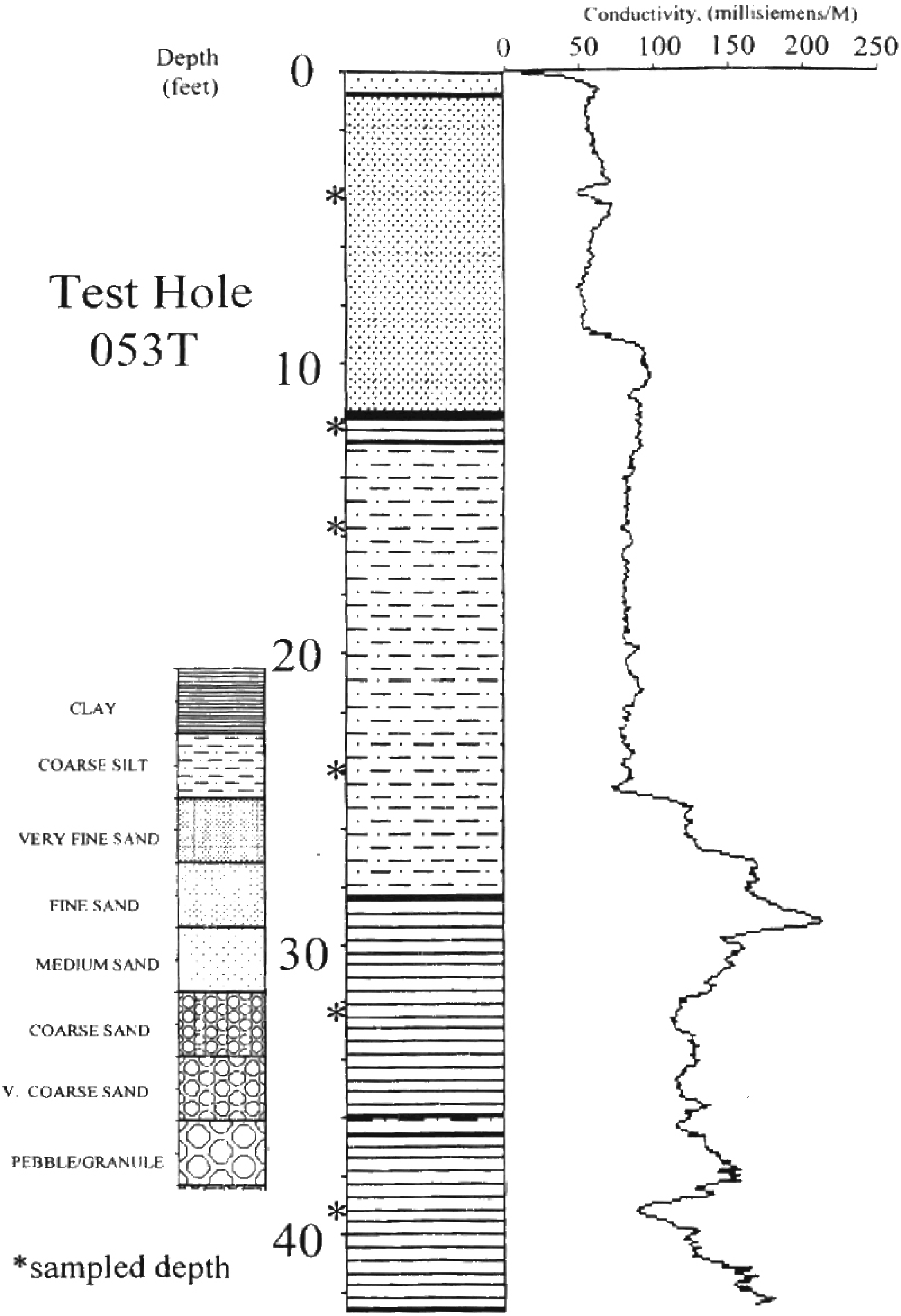

Test Hole
039T
Depth
(feet)
0
10
20
30
40
Conductivity, (millisiemens/M)
0
50
100
150
200
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 039T (a)

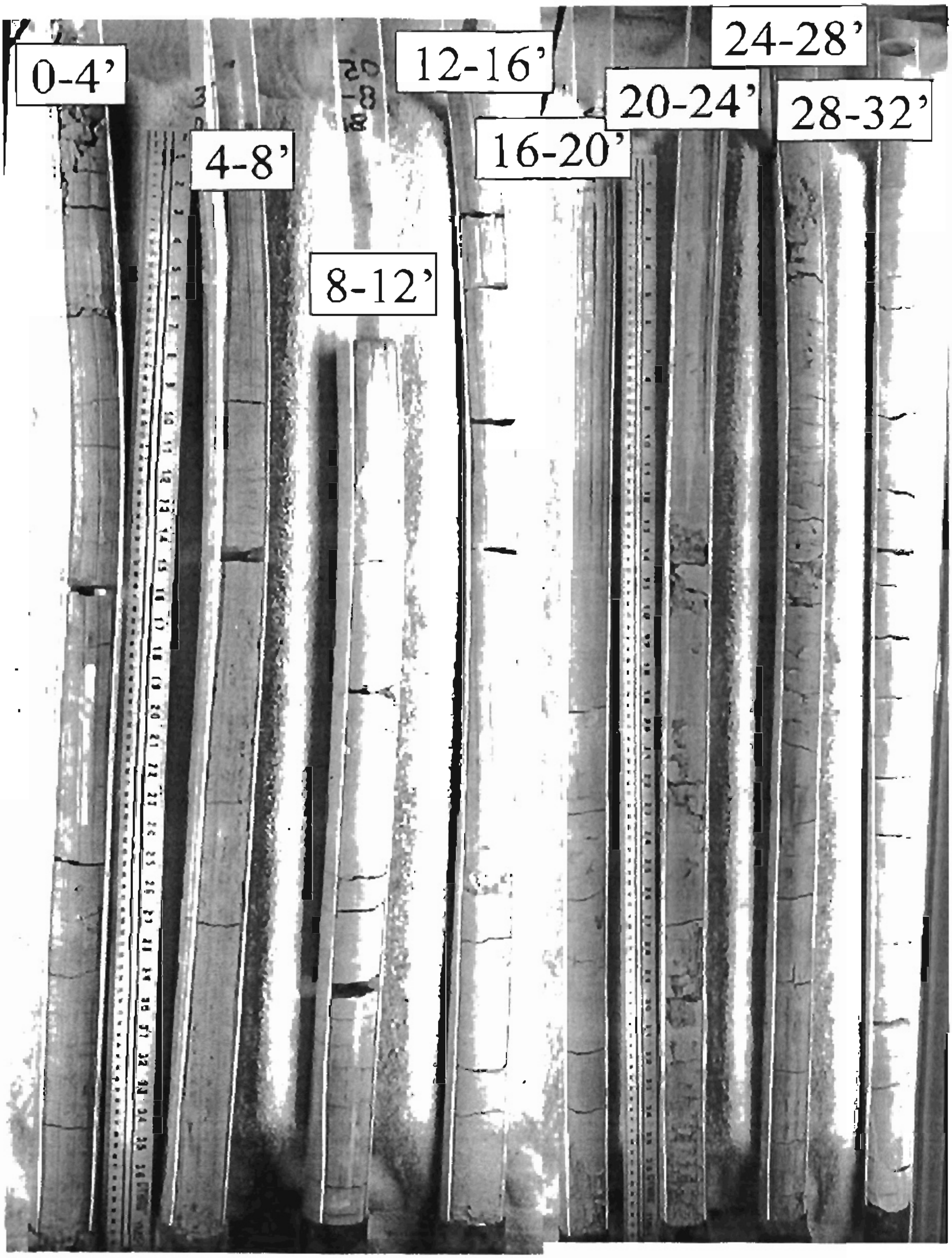


Test Hole 039T (b)

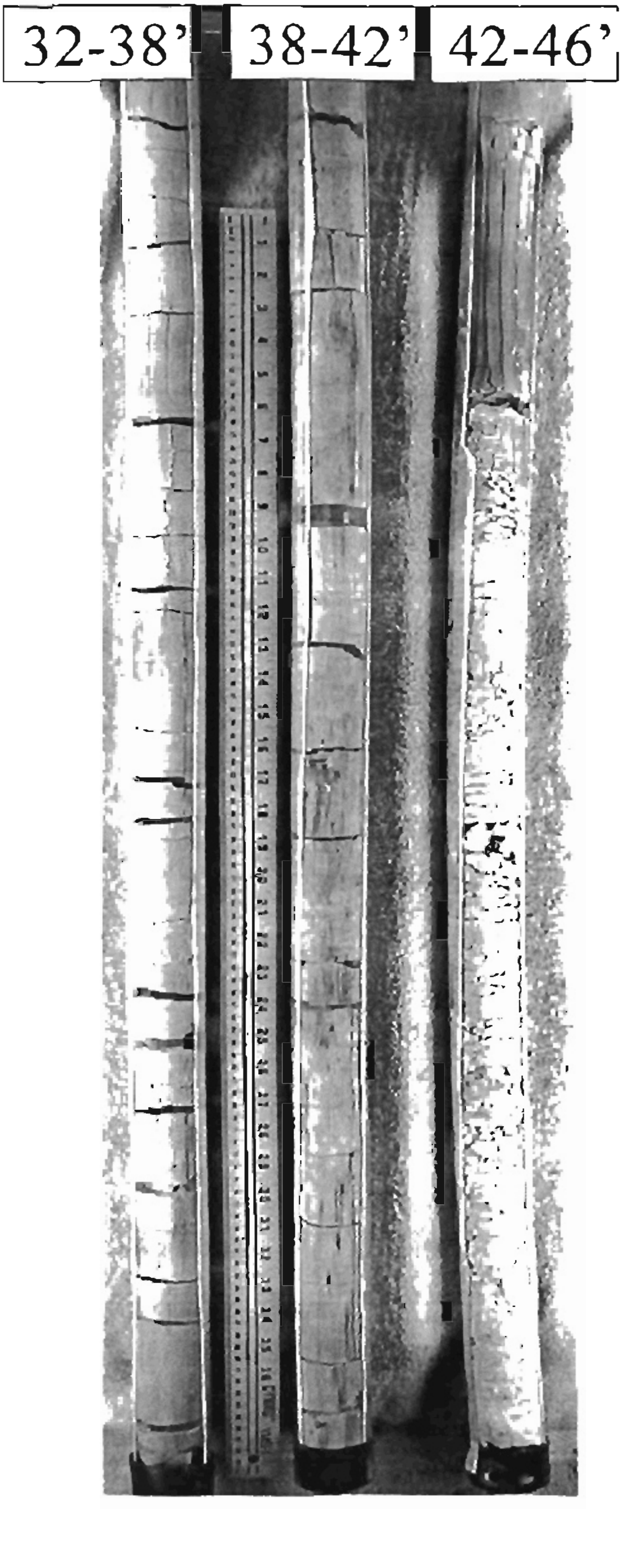


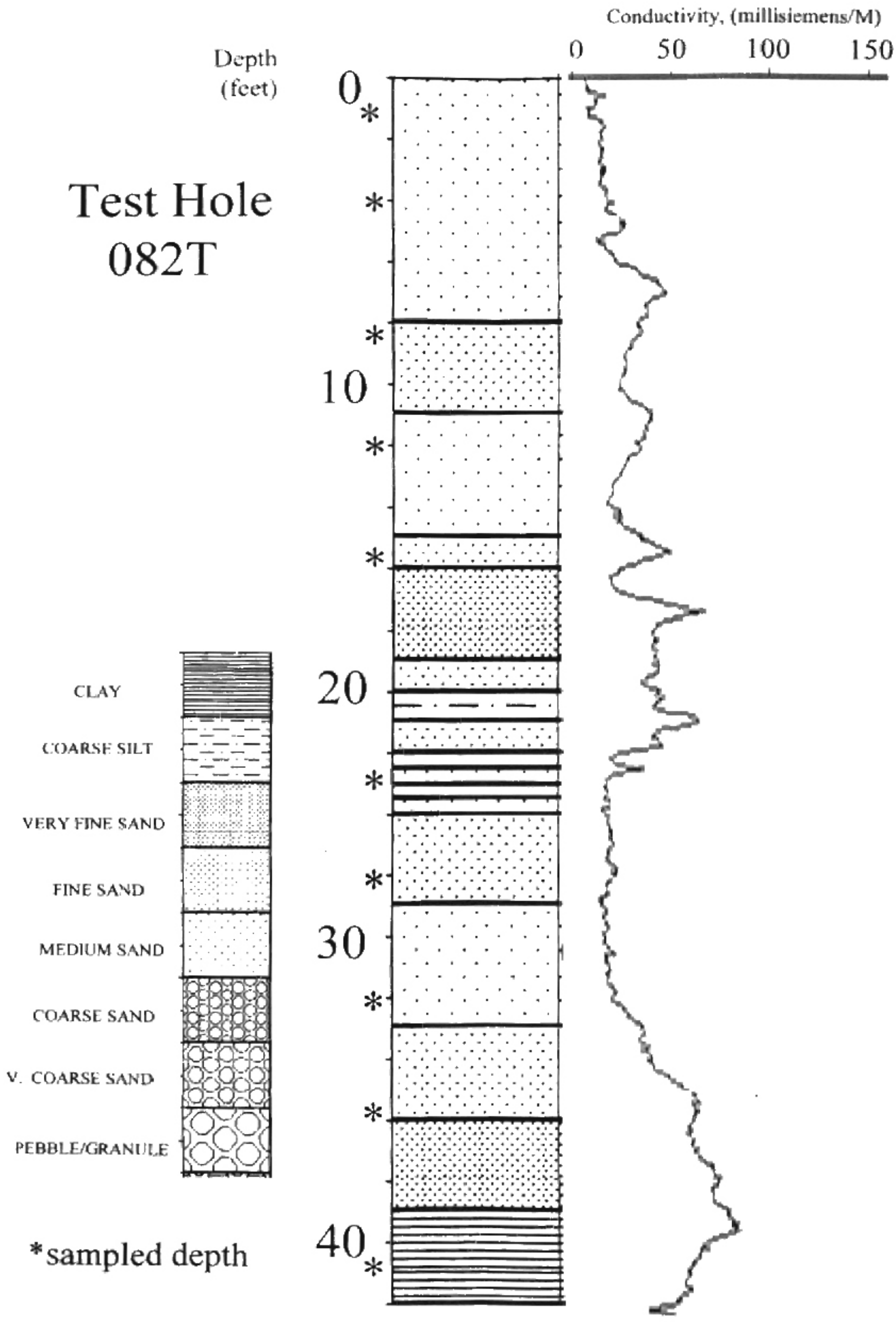

Conductivity, (millisiemens/M)
0
50
100
150
200
250
Depth
(feet)
0
10
20
30
40
Test Hole
053T
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 053T (a)



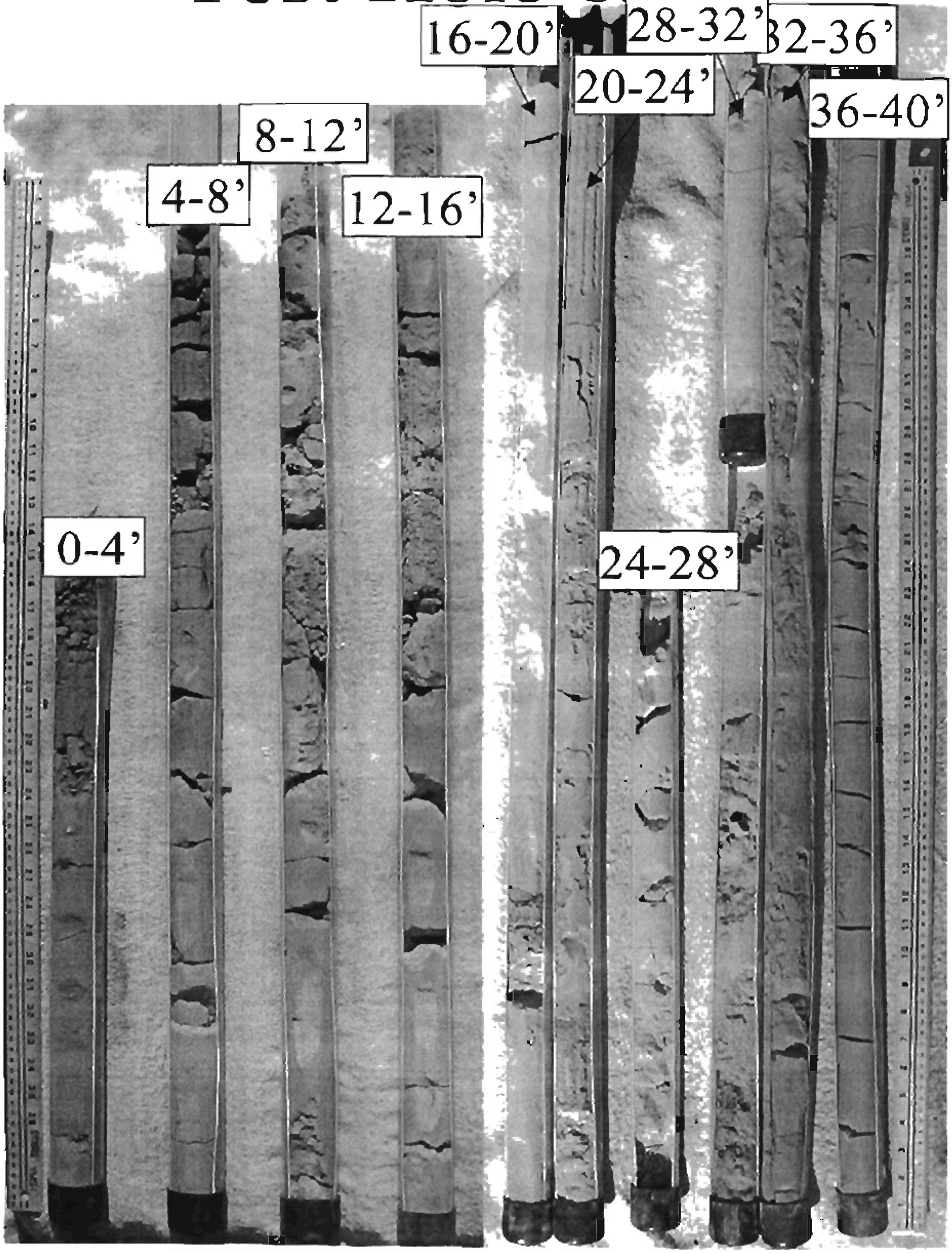
Well 053T (b)

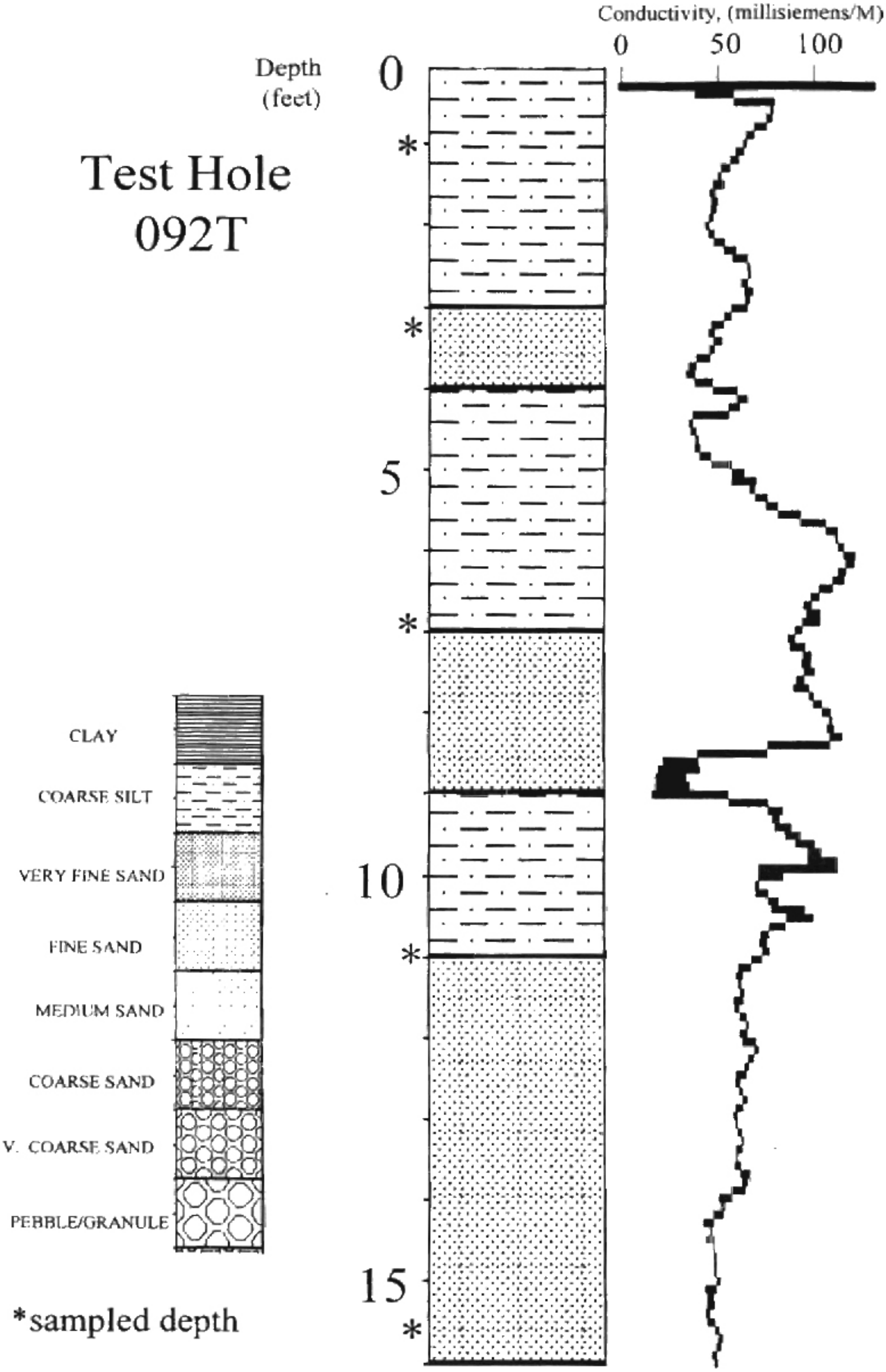




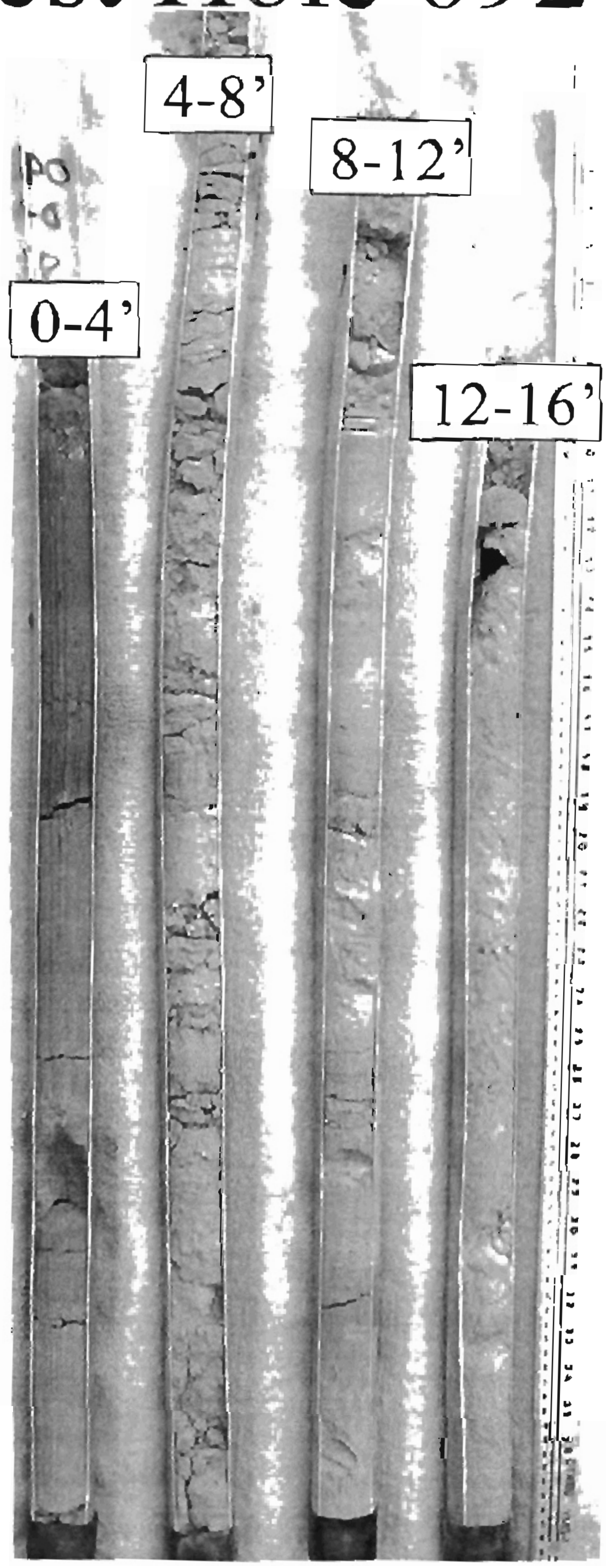
Conductivity, (millisiemens/M)
0
50
100
150
Depth
(feet)
0
10
20
30
40
Test Hole
082T
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

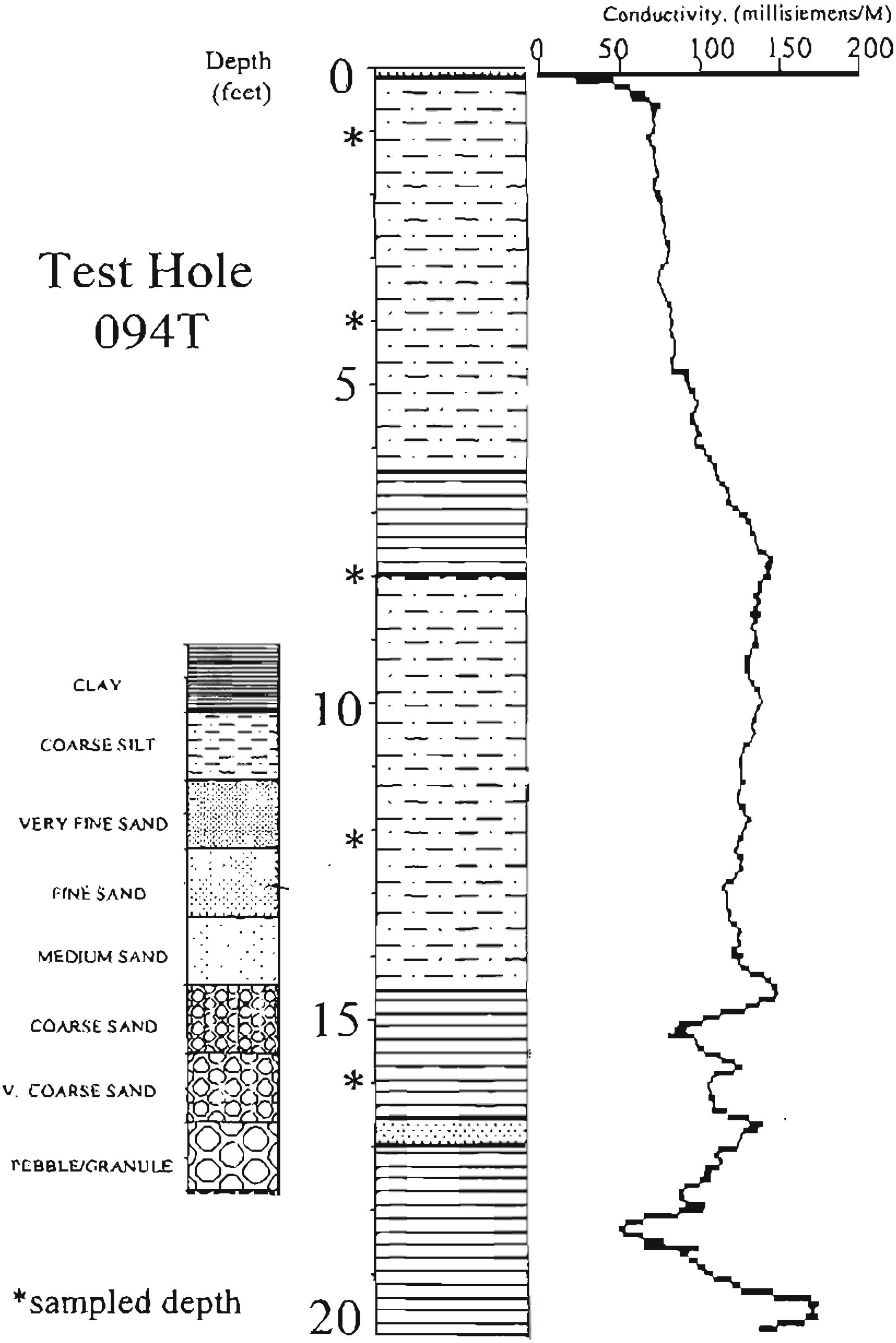
Test Hole 82T




Test Hole
092T
Depth
(feet)
0
5
10
15
Conductivity, (millisiemens/M)
0
50
100
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

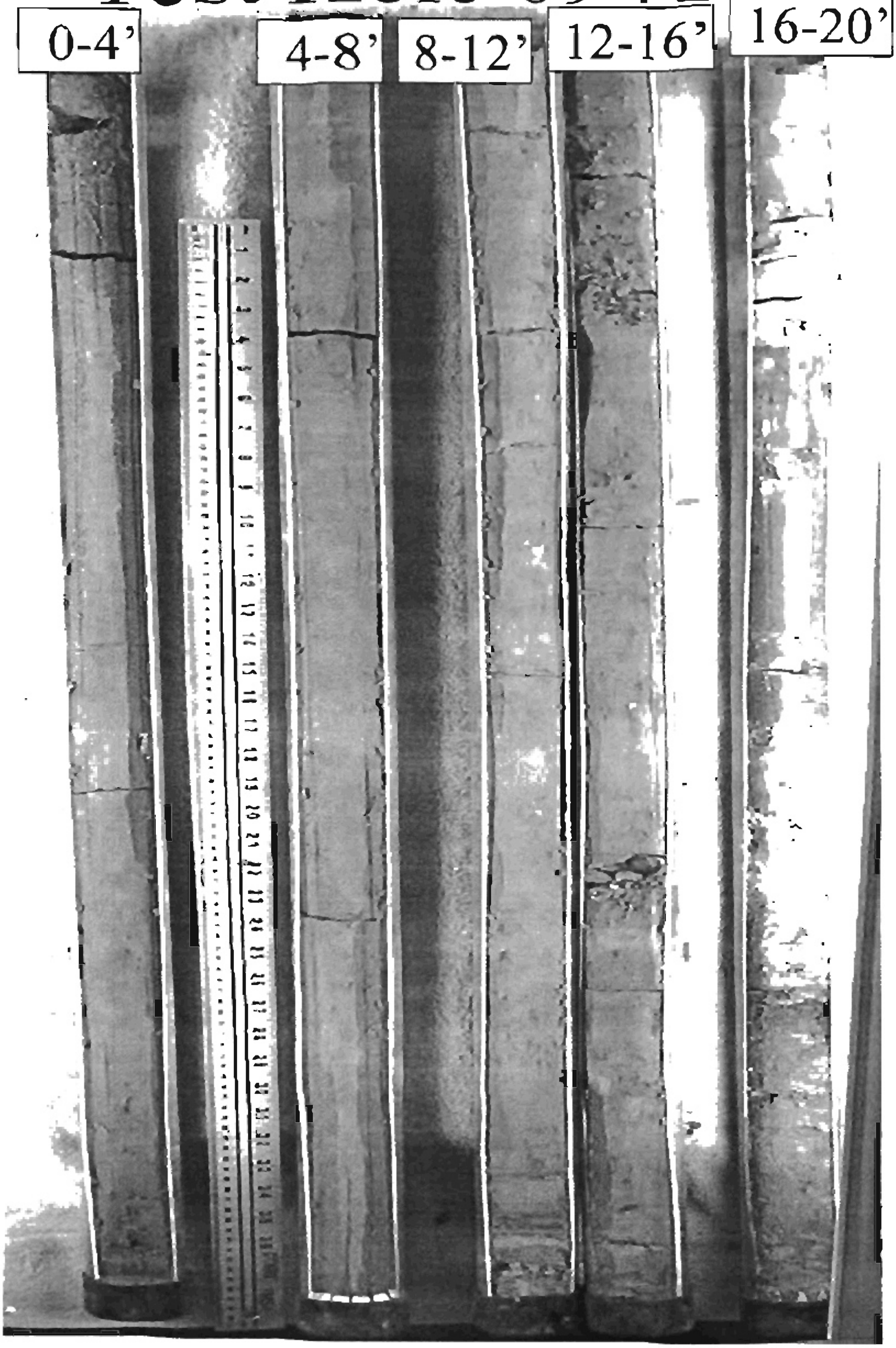
Test Hole 092T

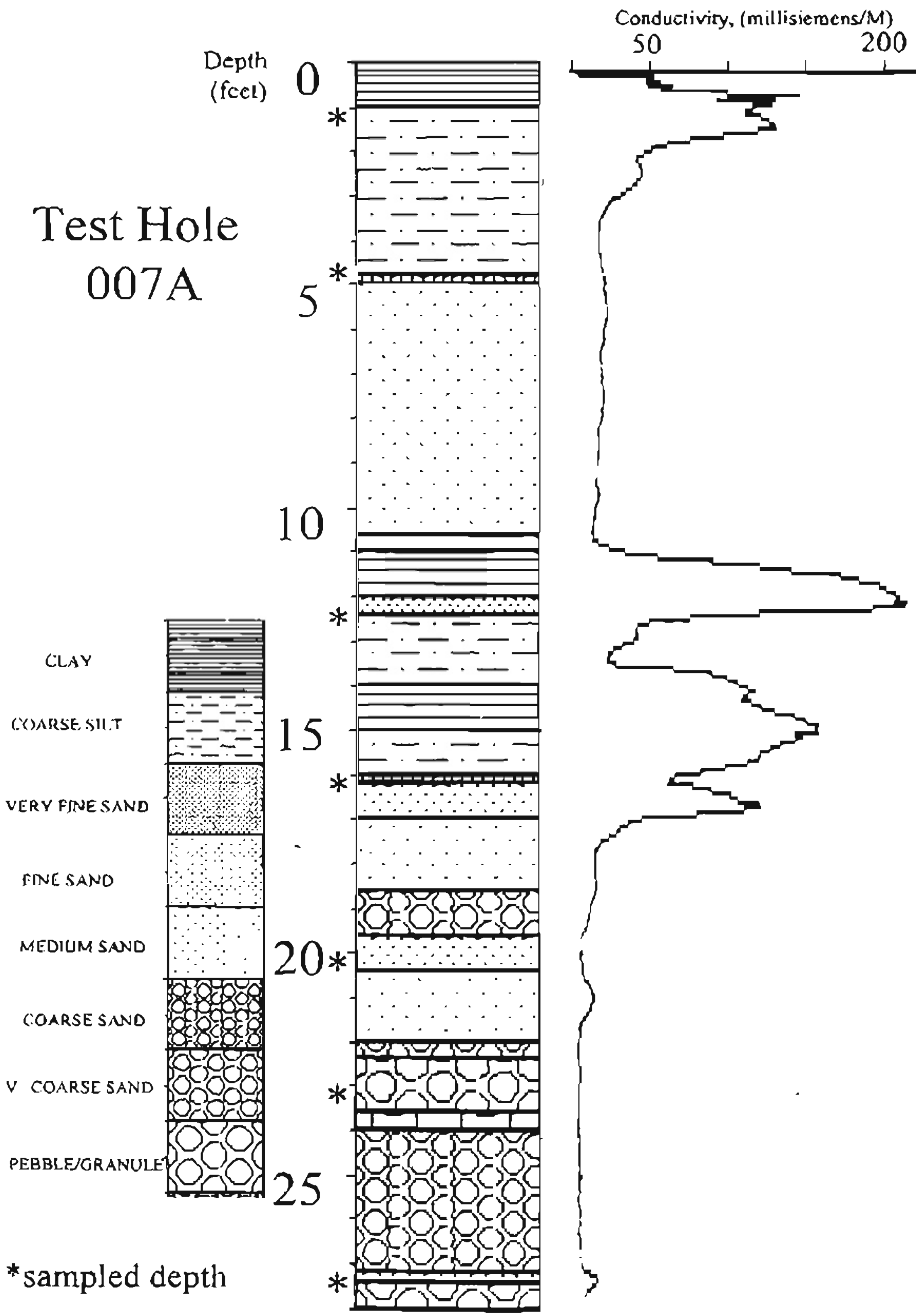




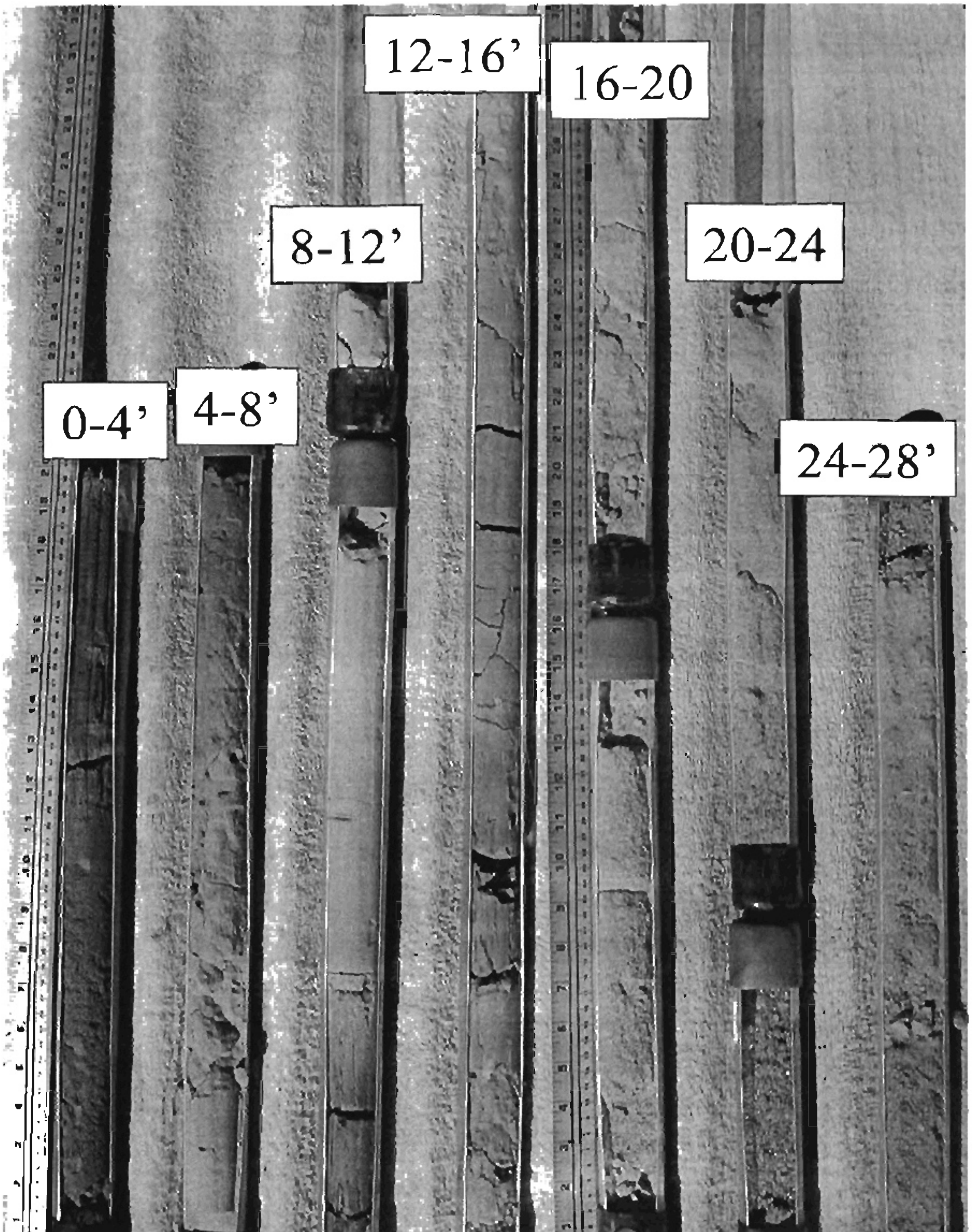
Conductivity, (millisiemens/M)
0
50
100
150
200
Depth
(feet)
0
5
10
15
20
Test Hole
094T
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 094T

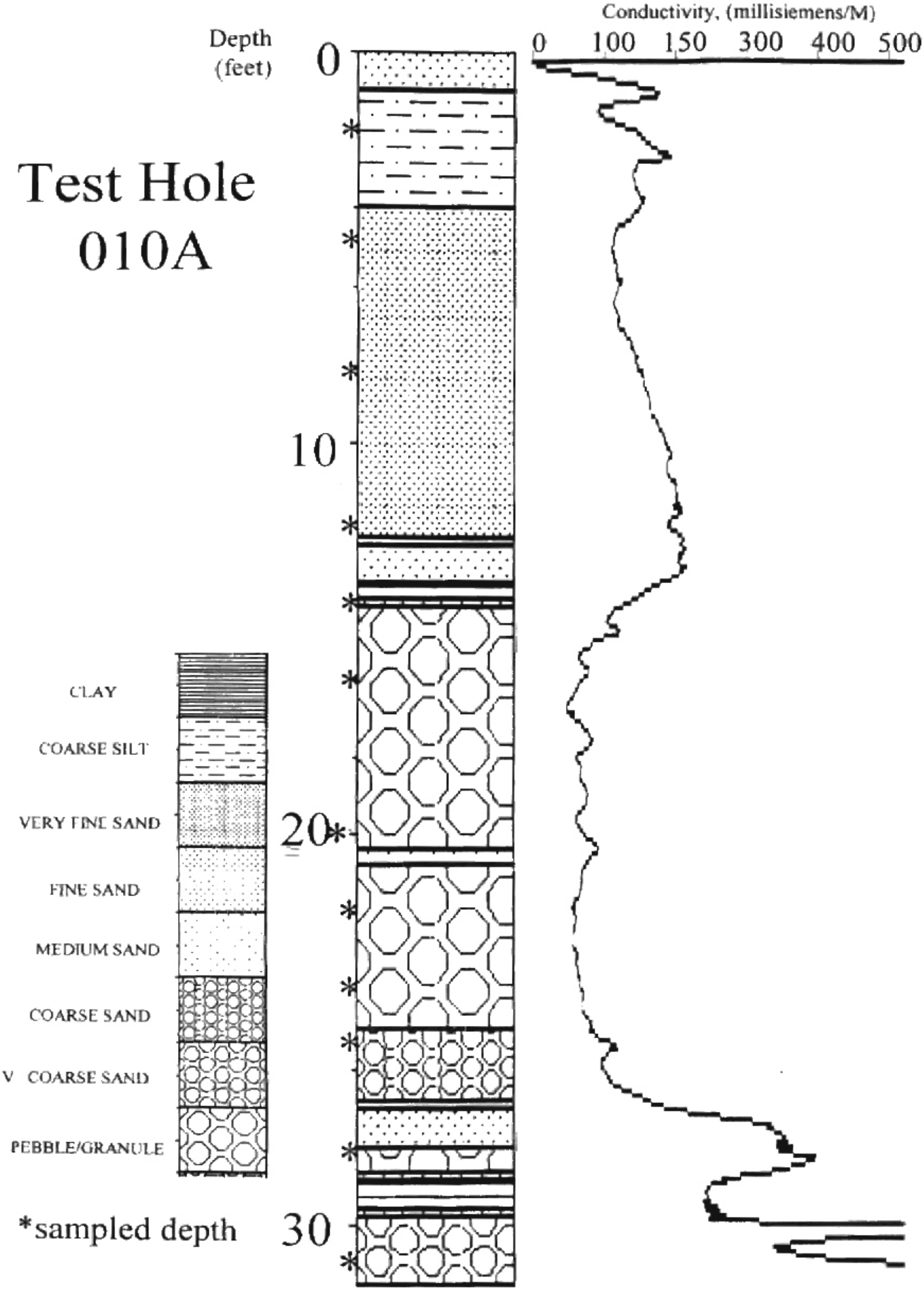



Test Hole
007A
Depth
(feet)
0
5
10
15
20
25
Conductivity, (millisiemens/M)
50
200
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V COARSE SAND
PEBBLE/GRANULE
*sampled depth

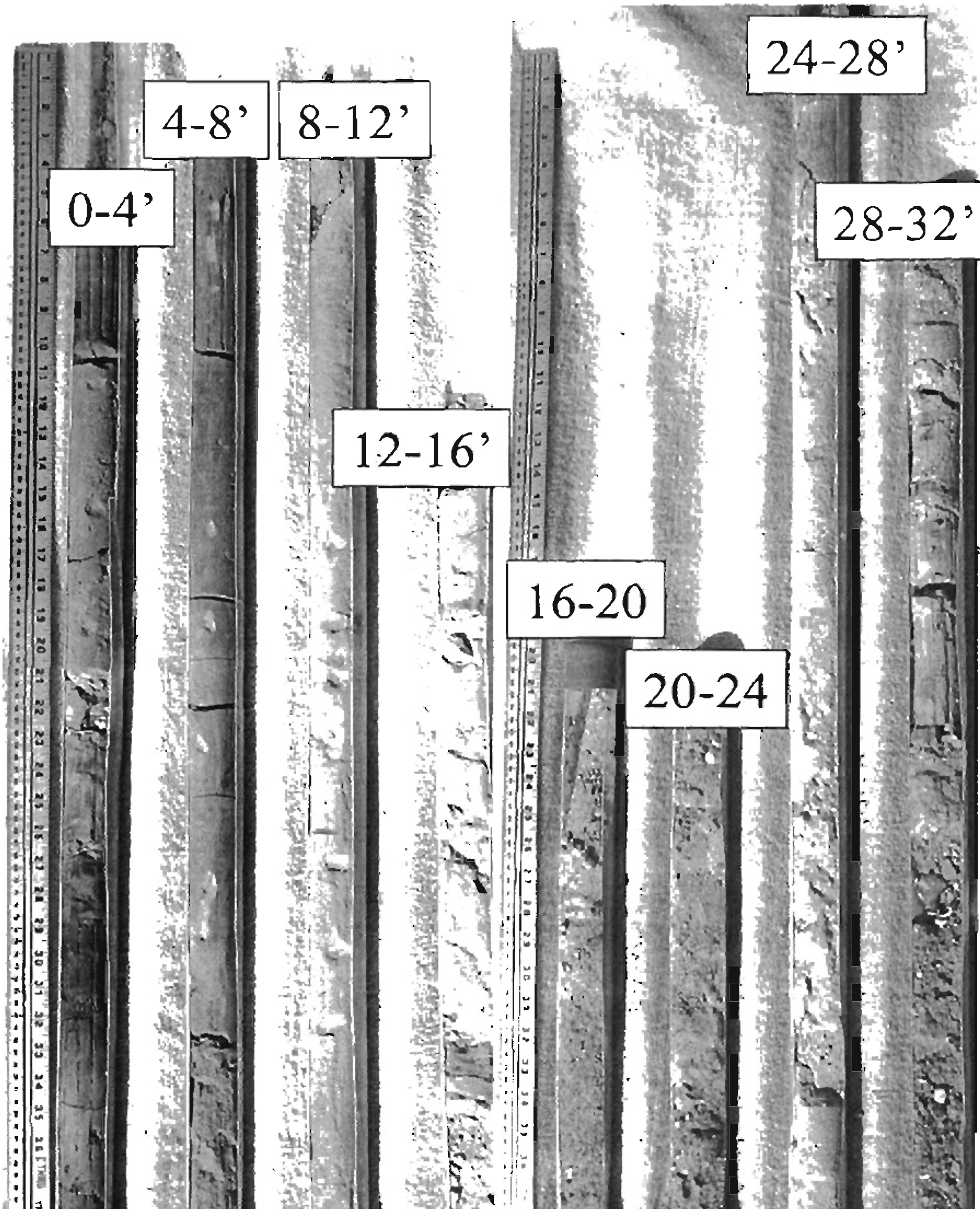
Test Hole 007A



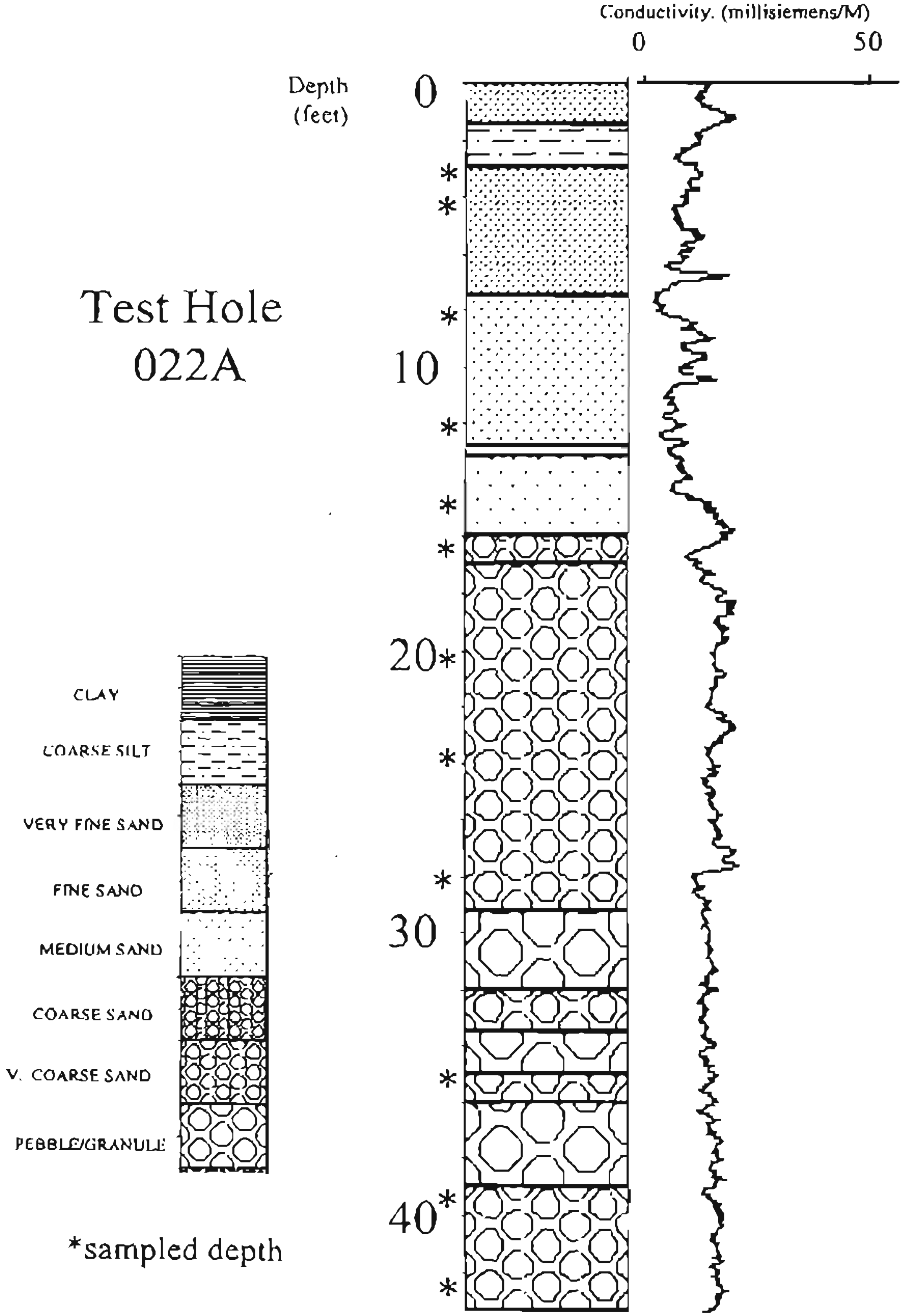
Test Hole 010A



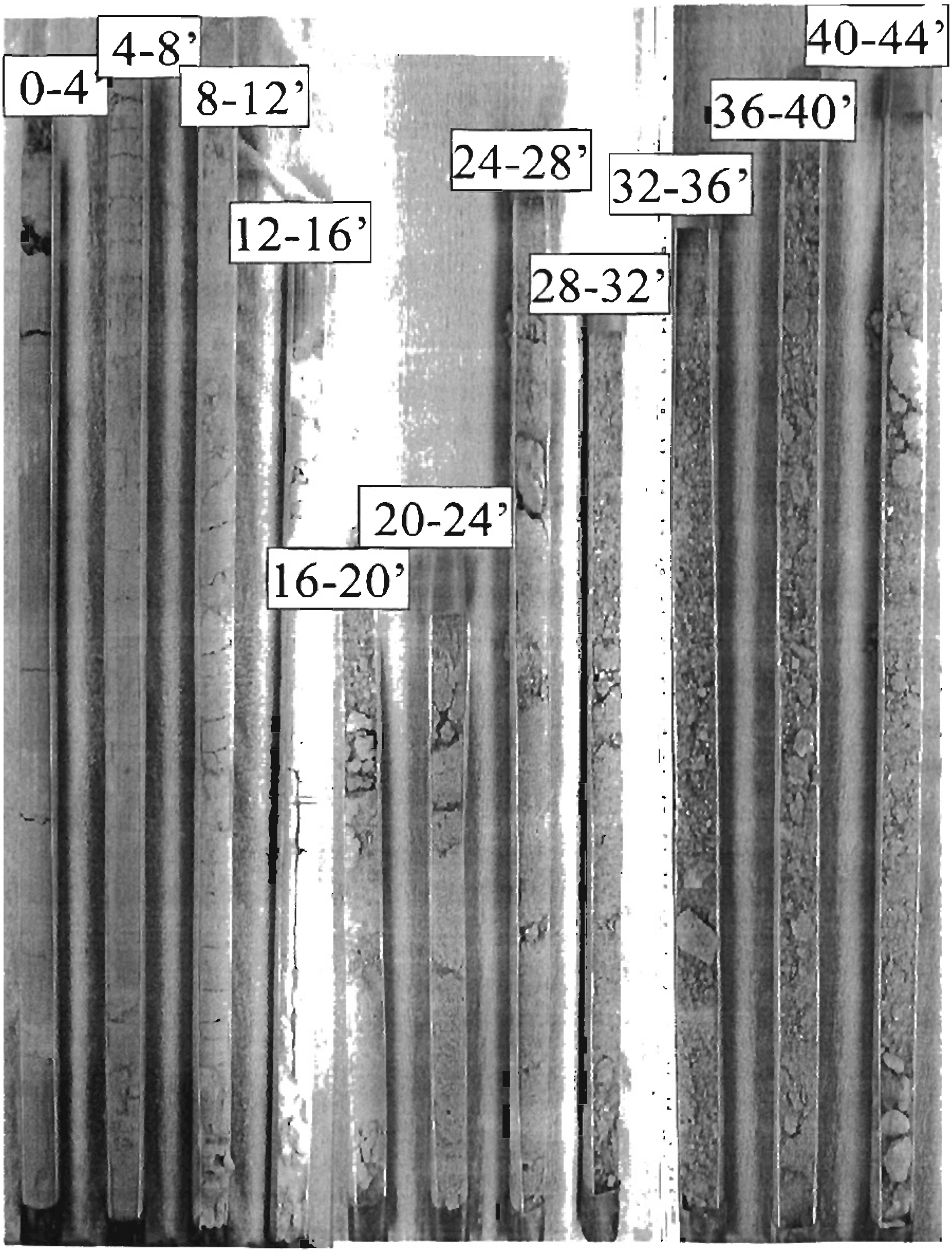
Test Hole 010A

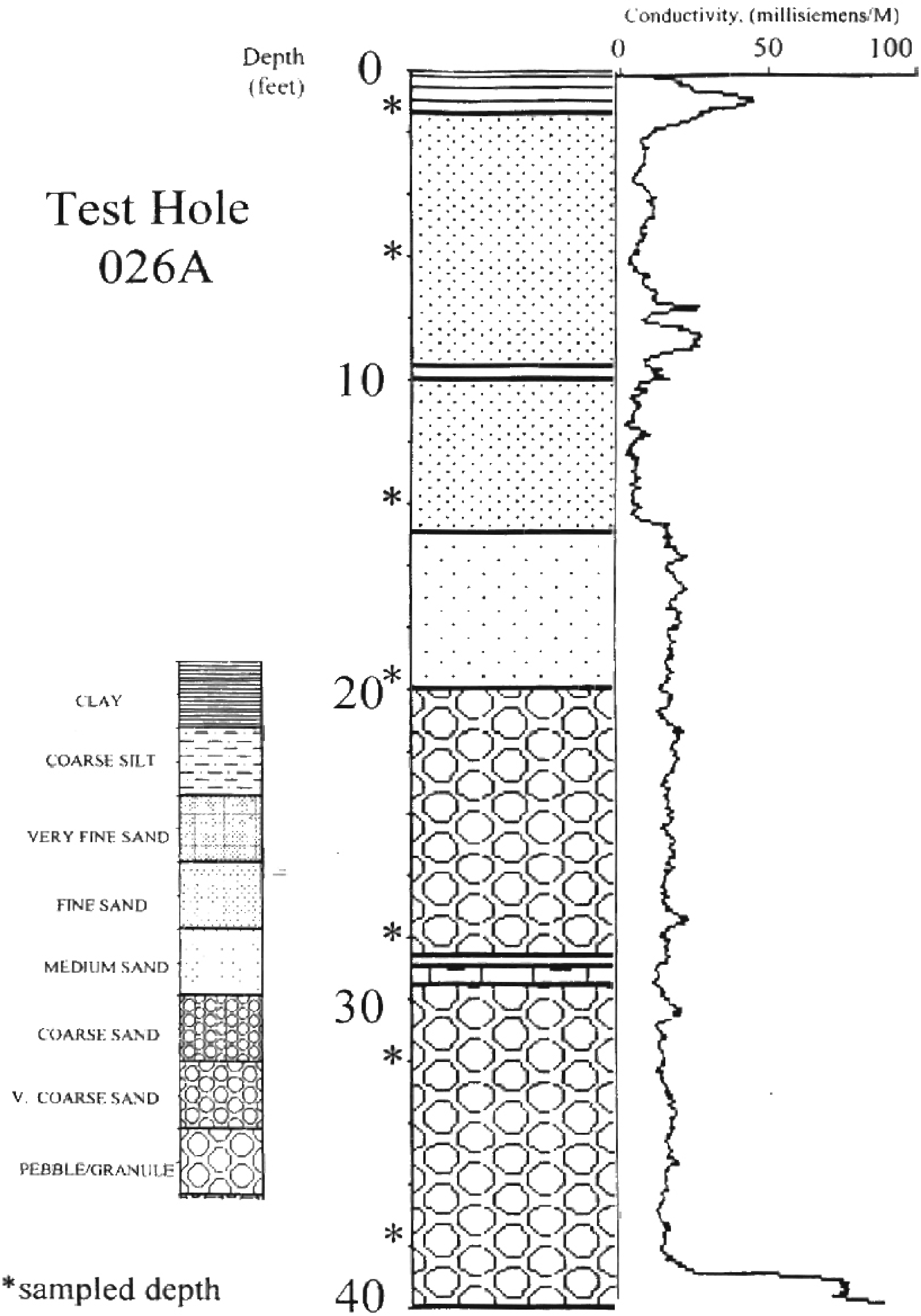


Test Hole 022A

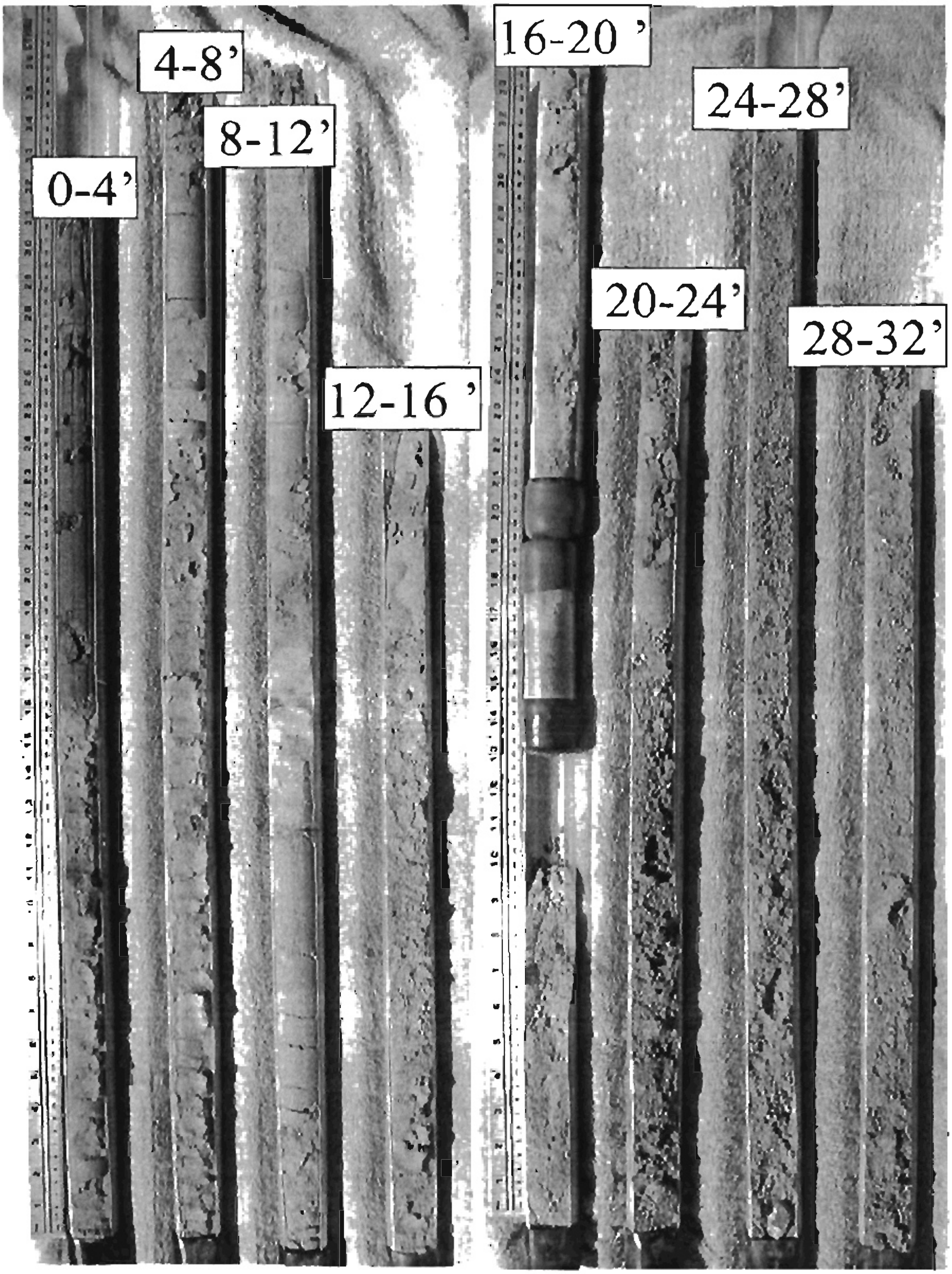


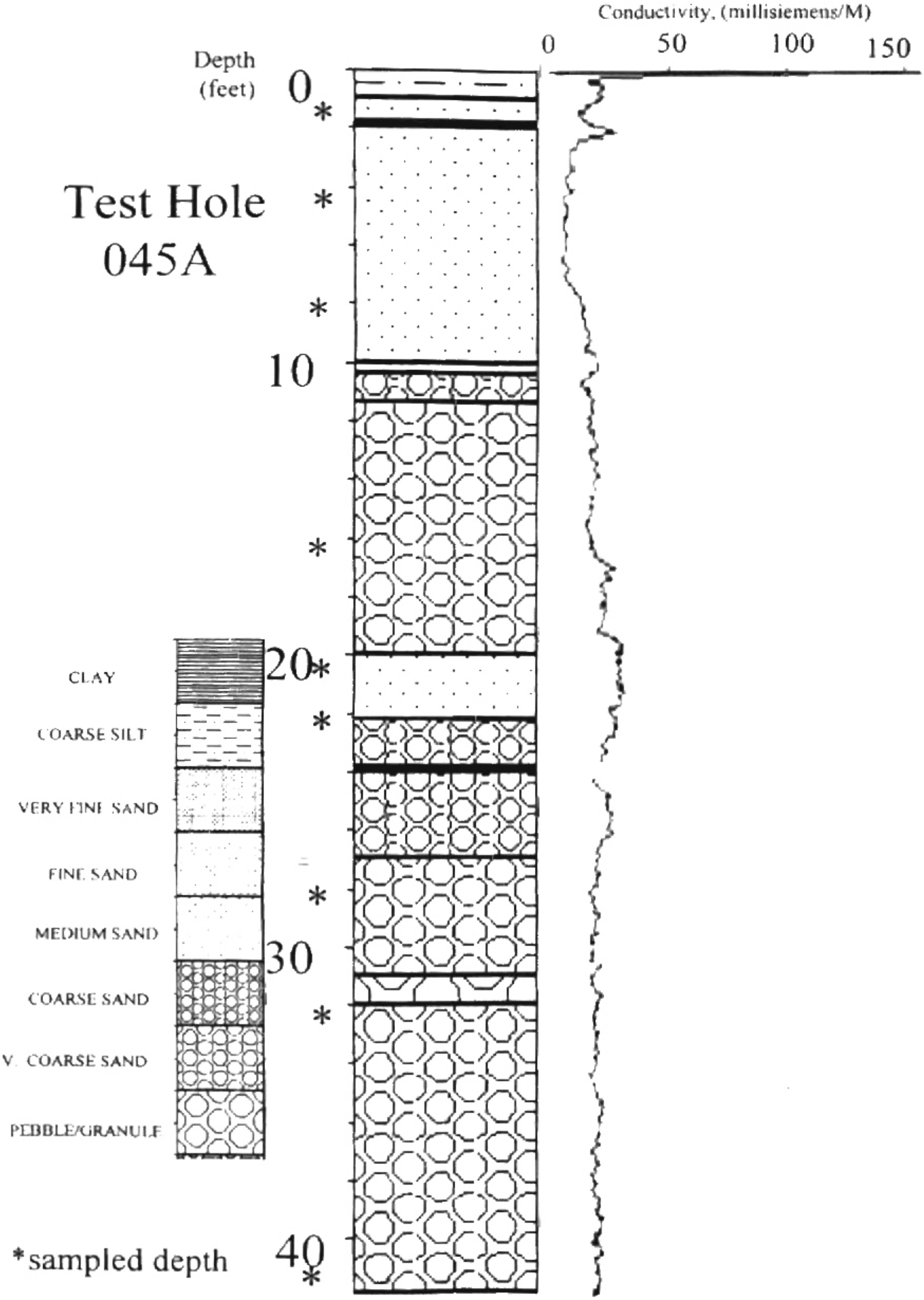
Test Hole 022A



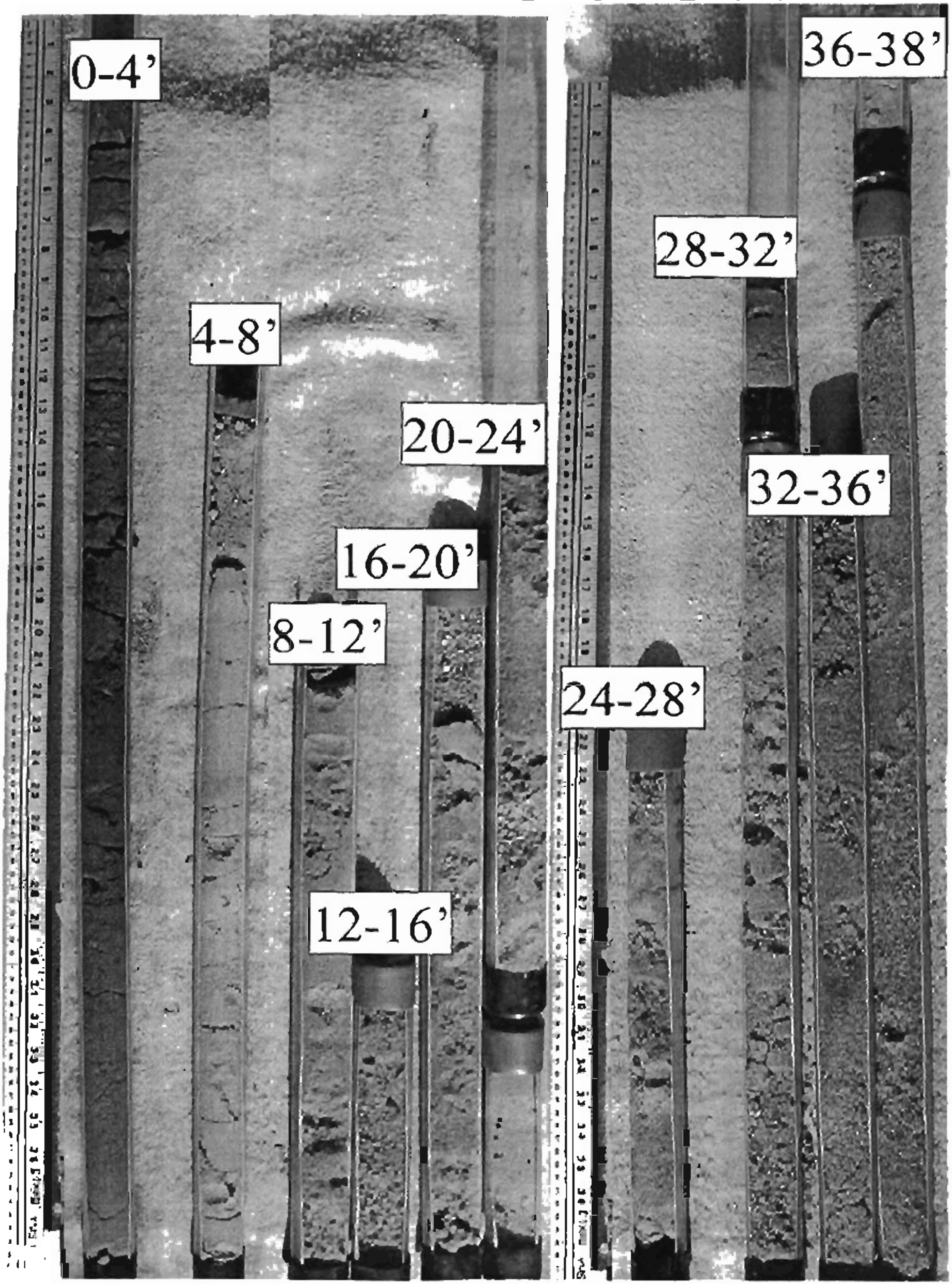

Test Hole
026A
Depth
(feet)
0
10
20
30
40
Conductivity, (millisiemens/M)
0
50
100
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 026A

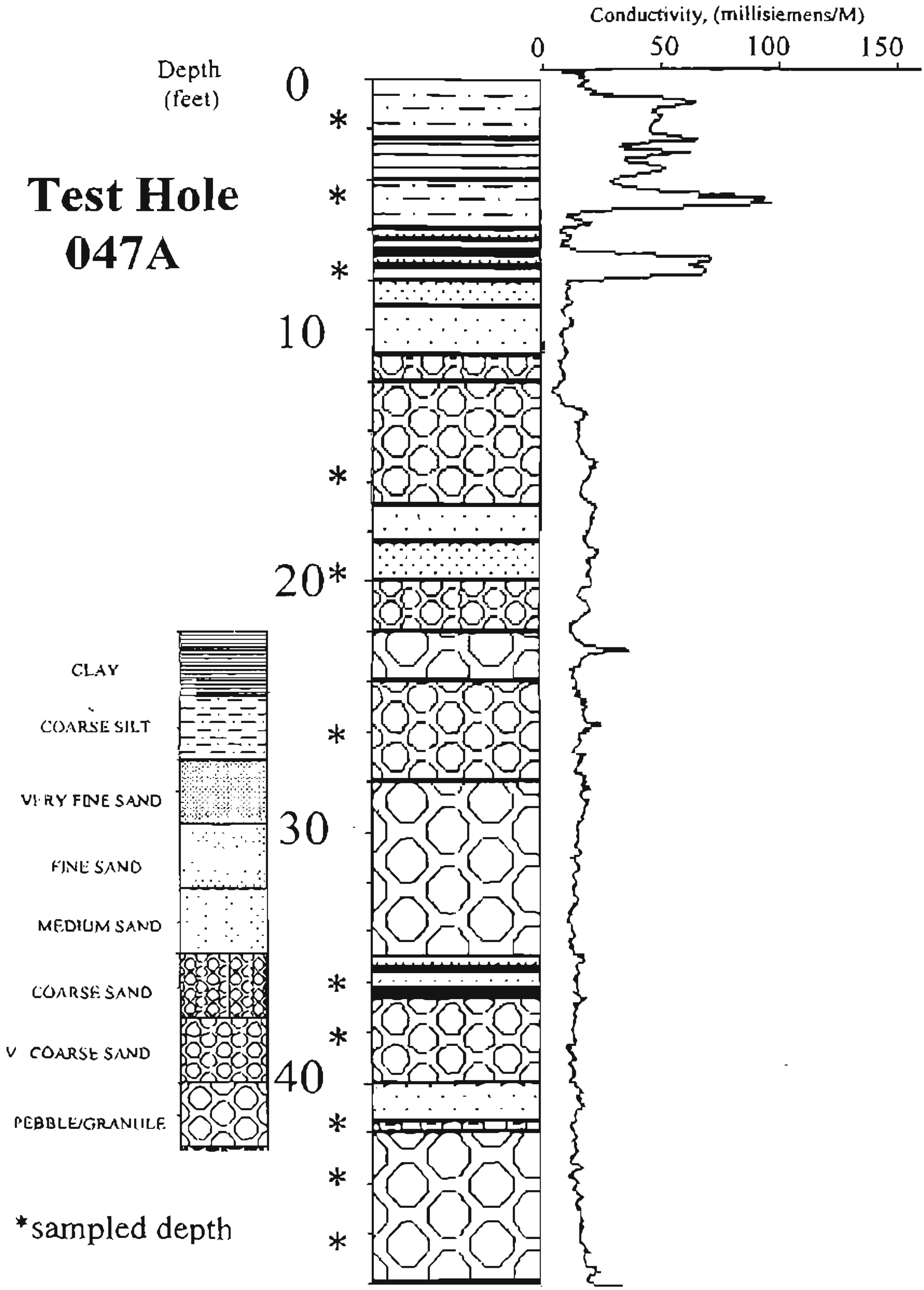



Conductivity, (millisiemens/M)
0
50
100
150
Depth (feet)
0
10
20
30
40
Test Hole 045A
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

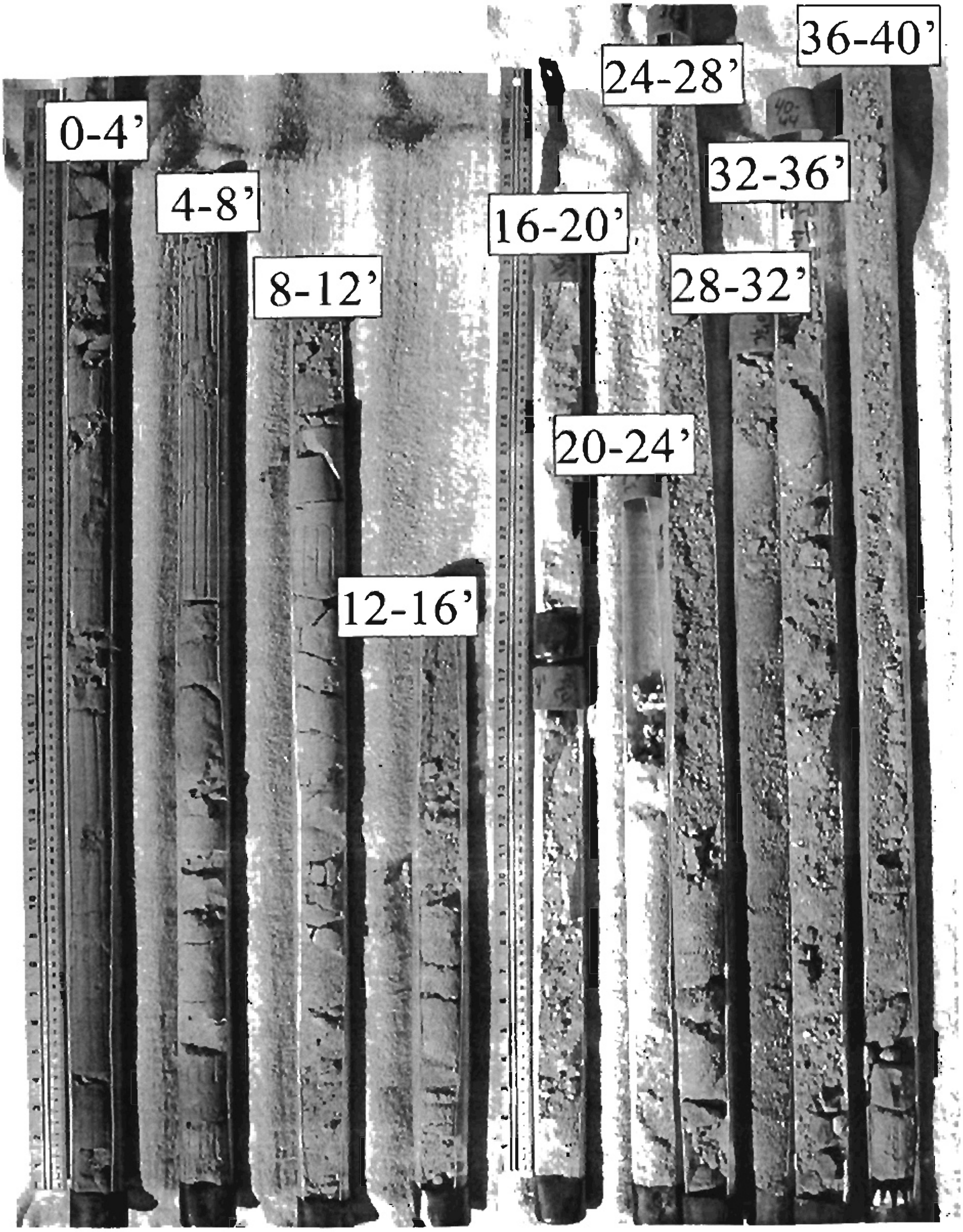
Test Hole 045A

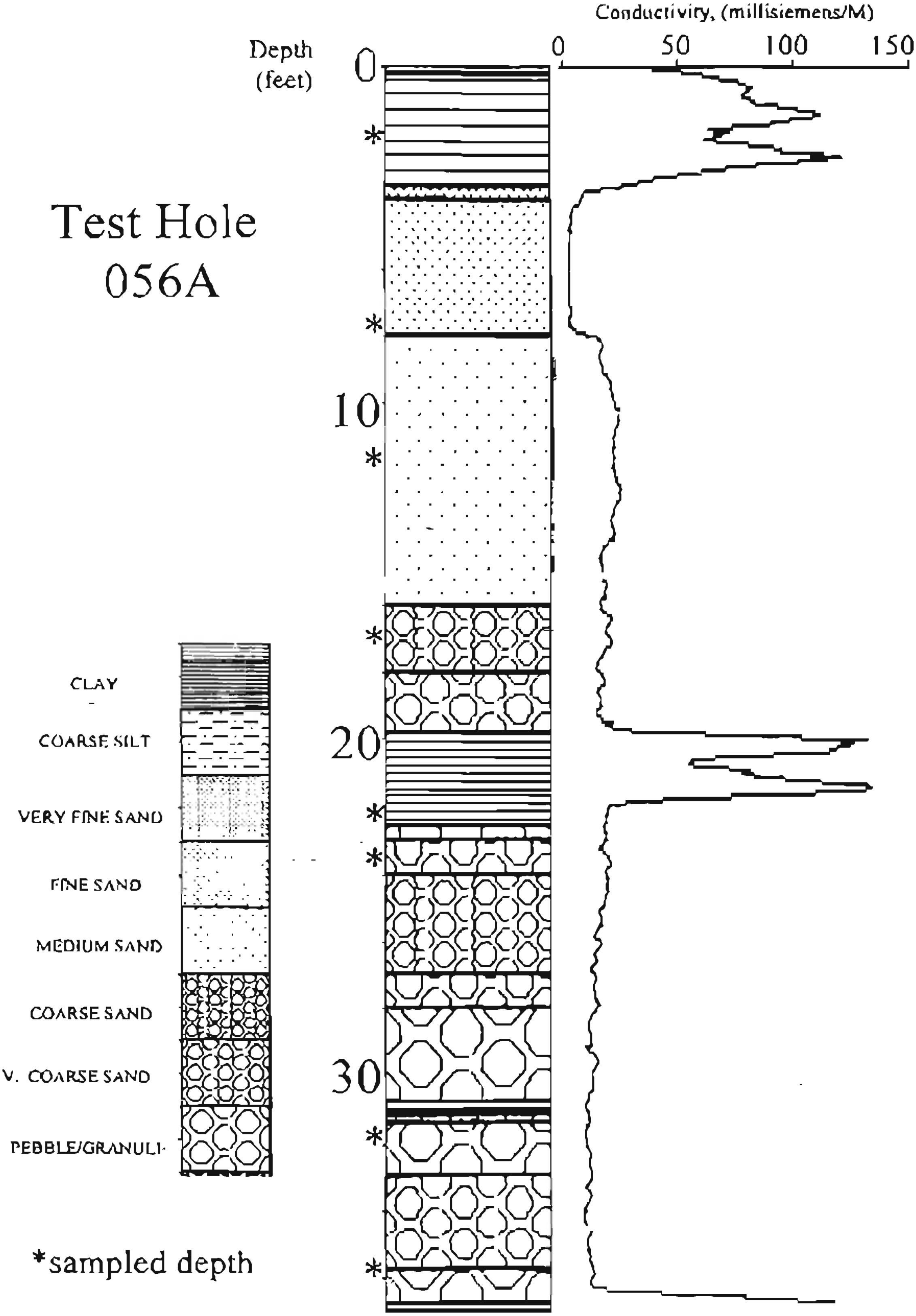


Test Hole 047A



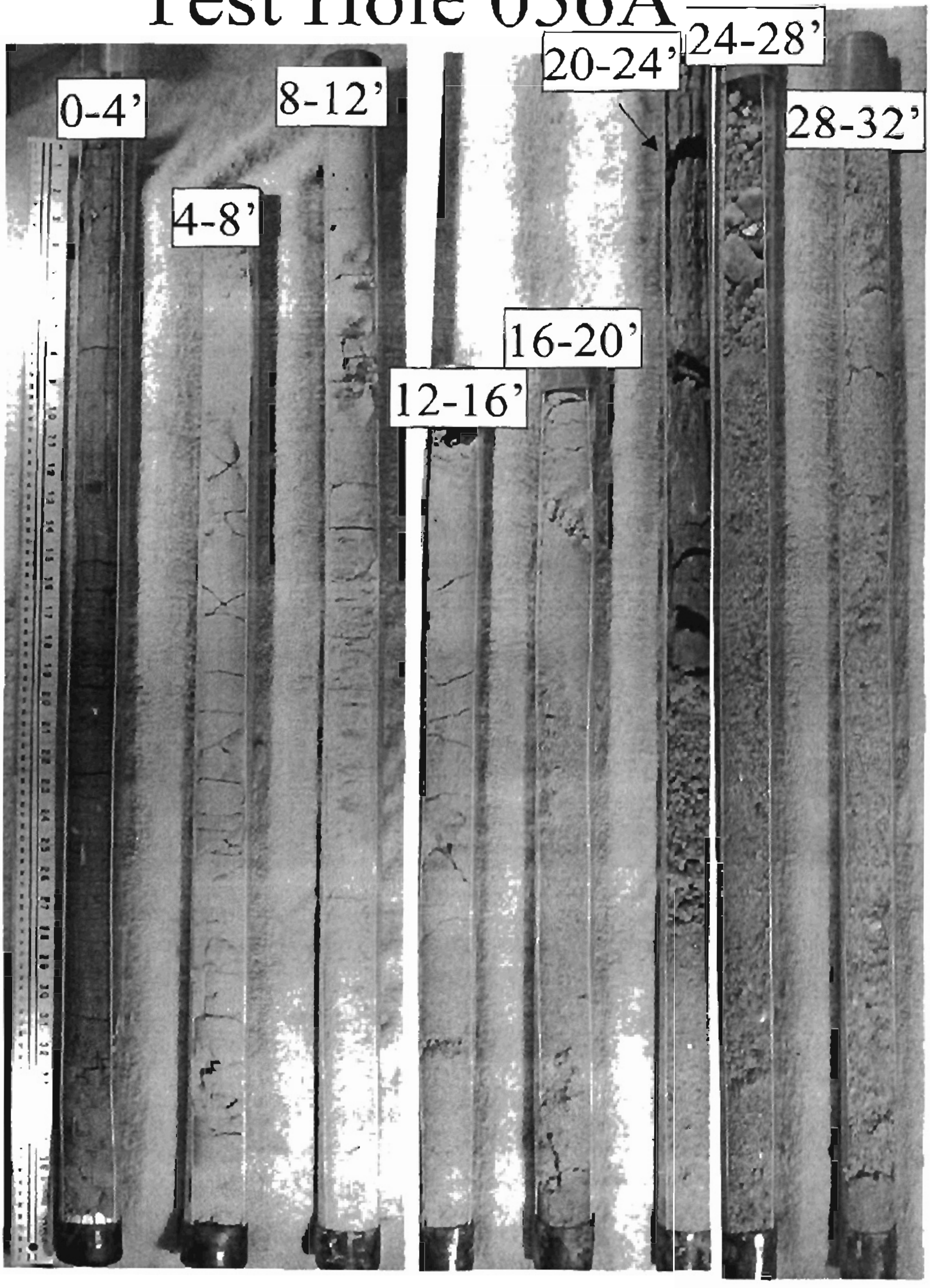
Test Hole 047A

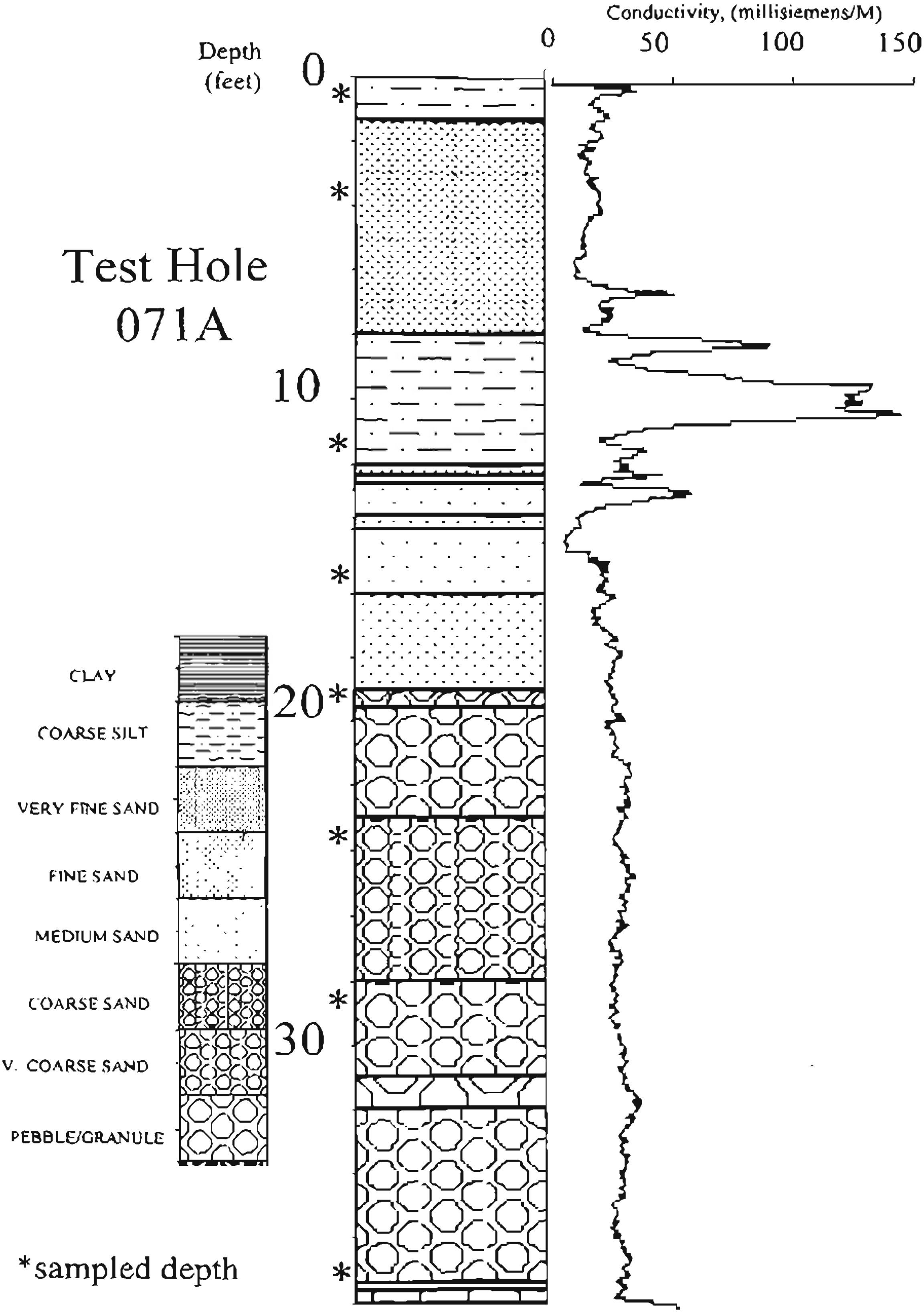




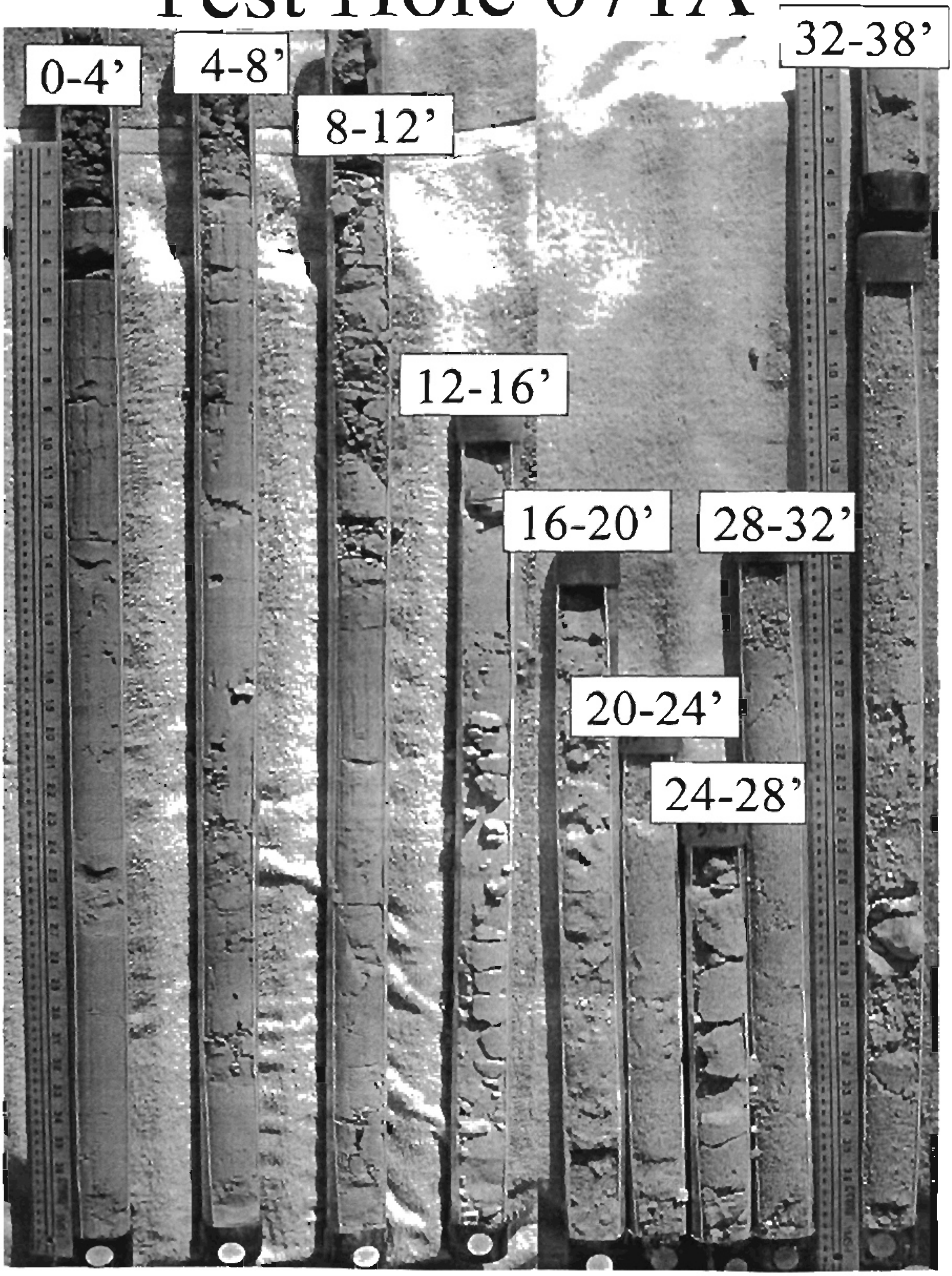
Test Hole
056A
Depth
(feet)
0
10
20
30
Conductivity, (millisiemens/M)
0
50
100
150
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 056A




Test Hole
071A
Conductivity, (millisiemens/M)
0
50
100
150
Depth
(feet)
0
10
20
30
CLAY
COARSE SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
V. COARSE SAND
PEBBLE/GRANULE
*sampled depth

Test Hole 071A



VITA

CALEB CASEY COPE

Candidate for the Degree of

Master of Science

Thesis: SEDIMENT CHARACTERIZATON: ALLUVIUM AND TERRACE DEPOSITS, ARKANSAS RIVER, SOUTHERN OSAGE COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in McAlester, Oklahoma on January 12, 1977, the son of Craig and Nancy Cope.

Education: Graduated from Hartshorne High School, Hartshorne, Oklahoma in May 1995; received Bachelor of Science in Geology from Oklahoma State University, Stillwater, Oklahoma in May 2000. Completed the requirements for the Master of Science degree with a major in Geology at Oklahoma State in May, 2003.

Experience: Worked as a teaching assistant for the Department of Geology at Oklahoma State University from May 2000 to May 2002; employed by the U.S. Geological Survey as a student Hydrologic Technician from October 2001 to present.