Environmental and Geotechnical Drilling

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Environmental and Geotechnical drilling projects provide subsurface data critical in the evaluation of a site. Whether the purpose of the investigation is to assess for the presence of soil and ground water contamination or for the design and construction of structures, proper subsurface investigations must be performed. Drilling provides one of the most fundamental ways in which subsurface information is obtained for evaluation by a geologist or engineer. In the text that follows, a brief overview of environmental and geotechnical drilling is provided. Also included are typical methods for describing soil and rock samples.

DRILLING METHODS

Prior to choosing a particular drilling method, consideration should be given to a number of variables including:

- Type of formation to be drilled (unconsolidated or consolidated material),
- Borehole depth,
- Borehole diameter,
- Quality of samples desired,
- Cross Contamination potential, and
- Whether a well will be installed in the borehole.

Once these variables have been considered one of the following four drilling methods are commonly used to make the boring.

Cable Tool Method

In the cable tool method, the borehole is advanced by lifting and dropping a heavy string of drilling tools (Figure 1). The tools are suspended on a steel cable and terminate in a chisel shaped bit. The impact of the bit breaks up the formation, which must then be removed from the borehole. Typically, the soil or rock cuttings are suspended in water in the borehole and are removed with a large bailer. In unconsolidated formations, temporary casing is advanced during drilling to keep the borehole from collapsing. The temporary casing also minimizes potential cross-contamination between materials in environmental investigations. Formation samples can either be collected from the bailer or with a variety of different soil samplers.

Fluid Rotary Method

Fluid rotary drilling involves rotation of a drill rod and bit. The most common type of bit is a tri-cone roller bit, designed to cut through soil and rock. A drilling fluid is circulated through the drill rod and bit and up the annular space between the rod and borehole (see Figure 2). The drilling fluid is used to lubricate the bit, carry cuttings to the surface and maintain hole stability. Additives, such as bentonite, are often mixed with water to increase the weight and viscosity of drilling fluid. Bentonite fluid drilling is often referred to as "mud rotary". Fluid rotary is a rapid way of advancing a large diameter borehole. However, soil samples recovered from the drilling fluid are marginal for accuracy due to loss of fine-grained materials. In addition, fluid remaining in the formation after drilling may lower borehole permeability and potentially alter ground-water chemistry.

Air Rotary Method

Air rotary drilling is similar to fluid rotary except that air compressed is used to cool the bit and carry cuttings to the surface. Air rotary drilling is generally limited to consolidated formations because air alone will not maintain an open hole in unconsolidated material. Air rotary is a very effective rock drilling methods. When combined with a downhole hammer drill bit, boreholes can be drilled very rapidly in bedrock. Another advantage of air rotary drilling is that water produced from the rock is carried to the surface allowing evaluation of the relative productivity of various strata. However, soil or rock sampling is limited to evaluating the drill cuttings as they are conveyed out of the borehole by the air.

Hollow Stem Auger Method

Hollow stem auger drilling is the most commonly used method in both environmental and geotechnical investigations. Figure 3 provides an illustration of the typical components in a hollow stem auger. This method is fast, relatively inexpensive and provides excellent sampling capabilities. With hollow stem augers, the hole is advance by rotating and pressing the auger into the soil. As the auger is advanced into the soil, cuttings are conveyed upwards on the auger flights. This methods is limited to unconsolidated materials and to depths generally less than 100 feet. The hollow stem auger method allows the collection of representative soil samples ahead of the lead auger. The hollow stem augers also permit the installation of monitoring wells.

MONITORING WELL INSTALLATION

Monitoring wells are installed for a variety of purposes but generally to allow discrete sampling of ground water. These purposes must be defined prior to installation so that a well can be properly designed and constructed from the right materials. The objectives for installing monitoring wells may include:

- Determining ground-water elevations, flow directions and velocities,
- Sampling and monitoring for the presence of contaminates, and
- Assessing aquifer characteristics (e.g., hydraulic conductivity).

Most monitoring wells are completed in the first permeable, water-bearing zone encountered. Care must be taken to assure that the well is completed at a depth sufficient to allow for seasonal water-table fluctuations. Monitoring well construction materials include: riser pipe and screen materials, annular materials and protective covers. The selection of well construction materials depends on the method of drilling, type of contamination expected, and the natural water quality.

Riser pipe and screen materials are specified by diameter, type of material and thickness of pipe. Well screens require an additional specification of slot size. Riser pipe and screen materials are commonly constructed from polyvinyl chloride (PVC); although Teflon, carbon steel, stainless steel, and galvanized steel are also available. The annular space between the borehole and the screen is usually backfilled with sand to an elevation 2 to 3 feet above the top of the screen. Bentonite is then placed on top of the sand pack and expands by absorbing water. This provides a seal between the screened interval and the rest of the annular space and formation. Cement grout is placed on top of the bentonite to ground the surface. The grout stabilizes the well and limits the potential of surface runoff reaching the screened interval. Gout, as applied to environmental or engineering projects, is typically a mixture of cement, bentonite and water.

A steel protective casing is often placed around the monitoring well. The protective casing has a locking cover and is set into a concrete pad. Small-diameter manholes are also available for situations requiring ground surface completions (i.e. wells located in roadways or parking lots). The purpose of the protective cover or manhole is to prevent vandalism that may result in groundwater contamination. An example of a monitoring well completion diagram is included as Figure 4. ASTM Standard Practice Design and Installation of Groundwater Monitoring Well in Aquifers (D5092-90) provides additional detailed information on the installation of monitoring wells.

SOIL AND ROCK SAMPLING METHODS

Although preliminary sample information can be obtained from soil or rock cuttings, far more accurate soil and rock samples can be obtained by collecting discrete soil samples or rock coring.

Soil Sampling

Discrete soil sampling consists of pressing or driving a sampler into the soil. The samplers can collect either disturbed or undisturbed soil samples. An example of a disturbed sample is one that is driven into place (i.e. split spoon sample, Geoprobe® sample, etc.). An undisturbed sample is one recovered in such a way that the physical structure and soil properties are relatively unchanged during sampling. These samples are typically obtained by <u>pressing</u> a thin-walled tube (such as a Shelby tube) through the desired interval. These galvanized steel tubes are typically 3 inches outside diameter with a sample length of about 30 inches. The retrieved tube is then sealed for shipment to a physical testing laboratory. Detailed information about undisturbed sampling may be found in the ASTM <u>Standard Practice for Thin-Walled Tube Sampling of Soils</u> (D1587-83).

A disturbed sample is collected by driving a sampler into the soil with either a free falling hammer or hydraulic hammer. These samples are usually either as split spoon sampler or a tube sampler. The split spoon sampler is driven through the desired interval by dropping a 140-pound hammer 30 inches. The number of blows required to drive the sampler for 6-inch increments are recorded and used to compare the penetration resistance between samples. The split spoon sampler normally measures 2 inches or 3 inches outside diameter with a minimum sample length of 18 inches. At the surface, the sampler is opened, allowing for soil classification and containerization for subsequent evaluation. Tube samplers, such as those made by Geoprobe, are lined with plastic sleeves and driven into the soil with a hydraulic percussion hammer. After removal from the borehole, the sleeve is removed and the sample classified and contained. Additional information about split spoon sampling may be found in the ASTM Method for <u>Penetration Test and Split Barrel Sampling of Soils</u> (D1586-84).

Rock Coring

Rock coring is used to collect discrete rock samples. The rock is cored with a tubular diamond-studded bit attached to a core barrel. As the diamond bit cuts a rock, a cylindrical-shaped rock sample is bushed into an inner barrel. Removal of the rock core from the subsurface is normally accomplished by lowering a wireline with a coupling into the drill rods, latching onto and pulling out the inner barrel. The recovered rock core is then removed from the inner barrel for examination or testing. The inner barrel is reinserted and the diamond bit advanced to the end of the next sampling interval. Water is constantly pumped down the rods during sampling to cool the core bit and flush cuttings to the ground surface. Diamond core barrels come in a variety of diameters and lengths. In environmental and geotechnical drilling, typically 2.0” or 2.5” diameter rock cores are collected (NX or HX size respectively) in 5.0-foot penetration runs.

Sample Description

Soil penetration tests and rock coring provide the geologist or engineer samples that can be used to make a variety of interpretations. The first step, however, is to describe and classify the recovered soil or rock sample.

Soil Description

Soils may be described and classified using a variety of methods. The most common method is the Unified Soil Classification System (USCS). This method identifies soil types on the basis of grain size and liquid limits. The soil is then categorized using a series of descriptive terms, followed by a two-letter symbol. In the USCS system, all soils are broken down into two broad categories – fine-grained soils (silt and clay) and coarse-grained soils (sand and gravel). The order of description for fine-grained soil is:

- Consistency (determined from blow counts)
- Moisture Content
- Color
- Modifying Soil
- Major Soil
- Other soil components
- Observations

An example of a fine-grained soil described according to the USCS classification system is "Moist red-brown silty CLAY, trace rounded quartz gravel (CL)". The order of description for coarse-grained soils is:

- Moisture
- Color
- Modifying soil
- Angularity
- Graduation
- Major Soil
- Other soil components

- Observations

An example of a coarse-grained soil is "Dry brown clayey fine to coarse SAND, little subangular fine gravel (SW-SC)". ASTM Practice for Description and Identification of Soils, (visual-manual procedure) (D2488) in an excellent reference for describing and classifying soils.

Rock Description

The components typically used to describe a rock core are color, thickness of bedding, rock type, weathering state, hardness, and joint or fracture spacing. Additional components, such as texture are used to further describe a rock as needed. An example of a rock description could be "Brown, thin bedded, fine-grained SANDSTONE, highly weathered, soft, close fractured". The definition of each of the components is given in Figure 5. Another important component worth noting in a core run is its structural integrity. This component can be approximated by calculating the rock quality designation (RQD). The RQD is determined by adding the total lengths of all pieces exceeding 4 inches and dividing by the total length of the coring run, to obtain a percentage (see Figure 6). The percentages between different core runs can be compared to quickly assess the rock quality between samples.

WELL LOG PREPARATION

Well logs provide documentation of drilling activities conducted during environmental and geotechnical investigations. The importance of properly completed well logs cannot be overemphasized. The information well logs contain is used by the geologist or engineer to make decisions which are critical to the successful completion of a project. It is the responsibility of the individual overseeing the drilling activities to prepare well logs that are accurate, consistent and legible. Most well logs include the following information:

- Project name and location,
- Boring/Well number,
- Date(s) drilling started and finished,
- Boring location and elevation,
- Page number and total number of pages for each boring,

- Depth of each sample taken,
- Depth at which obstacles were encountered while advancing the borehole (boulders, etc.).
- Length of drive for soil samples and length of sample recovered.
- Number of blows required to drive sampler when standard penetration test is used,
- Length of each run for rock core and footage of core recovered,
- RQD values for each run,
- Changes in drilling rate and fluid loss when coring rock,
- Full description of soil and/or rock samples, as discussed in Section 3.0,
- Reason for boring abandonment when specified depth is not reached,
- Unusual conditions encountered in advancing the boring and in sampling,
- Complete description of well materials used and depths (if applicable), and
- Depth to water while drilling, prior to removal of any casing and 24 hours after all down-hole tools have been removed.

An example of a boring log used by Parratt-Wolff, Inc. is shown in Figure 7.

CONCLUSION

The methods and procedures described provide a general overview of environmental and geotechnical drilling and sampling. These methods and procedures are used to provide critical subsurface data on many projects. The references that follow are just a partial list of the many publications currently available about Environmental and Geotechnical drilling.

REFERENCES

Aller, L. – et al, 1989. Handbook of suggested practices for the design and installation of groundwater monitoring wells; National Water Well Association, Dublin, Ohio, 398p.

American Society for Testing Materials (ASTM), 1993. Proceedings from Groundwater Monitoring and Sampling Technology Short Course: Design, Installation, Development and Sampling of Groundwater Monitoring Wells; American Society for Testing Materials, Philadelphia, Pennsylvania 244p.

American Society for Testing Materials (ASTM), 1995. Practices for design and installation of groundwater monitoring well in aquifers: D5092; 1997 Annual Book of American Society for Testing Materials Standards, Philadelphia, Pennsylvania, Vol. 04.09 pp.77-87.

American Society for Testing Materials (ASTM), 1994. Practice for thin-walled tube sampling of soils: D1587; 1997 Annual Book of American Society for Testing Materials standards, Philadelphia, Pennsylvania, Vol. 04.08 pp. 142-144

American Society for Testing Materials (ASTM), 1992. Practice for description and identification of soils (visual/manual procedure: D2488; 1997 Annual Book of American Society for Testing Materials standards, Philadelphia, Pennsylvania, Vol. 04.08 pp. 228-238.

Driscoll, F.G., 1986. Ground water and wells, 2nd edition; Johnson Division, St. Paul, Minnesota, 1089 pp.

Company Profile

Parratt-Wolff, Inc. (PWI) was founded in 1969 to provide soil and rock drilling to the Northeast. Since then, PWI has grown to a company of three offices, 50 employees and 29 major pieces of field equipment. Our service area includes all states from New Hampshire to Florida. Each year, PWI makes thousands of borings in both soil and rock. We keep a test boring log on nearly every hole drilled, giving us a comprehensive geologic data base. If you are in the Syracuse area and would like to tour our PWI's facility or would like to discuss subsurface conditions in your project area, give us a call.

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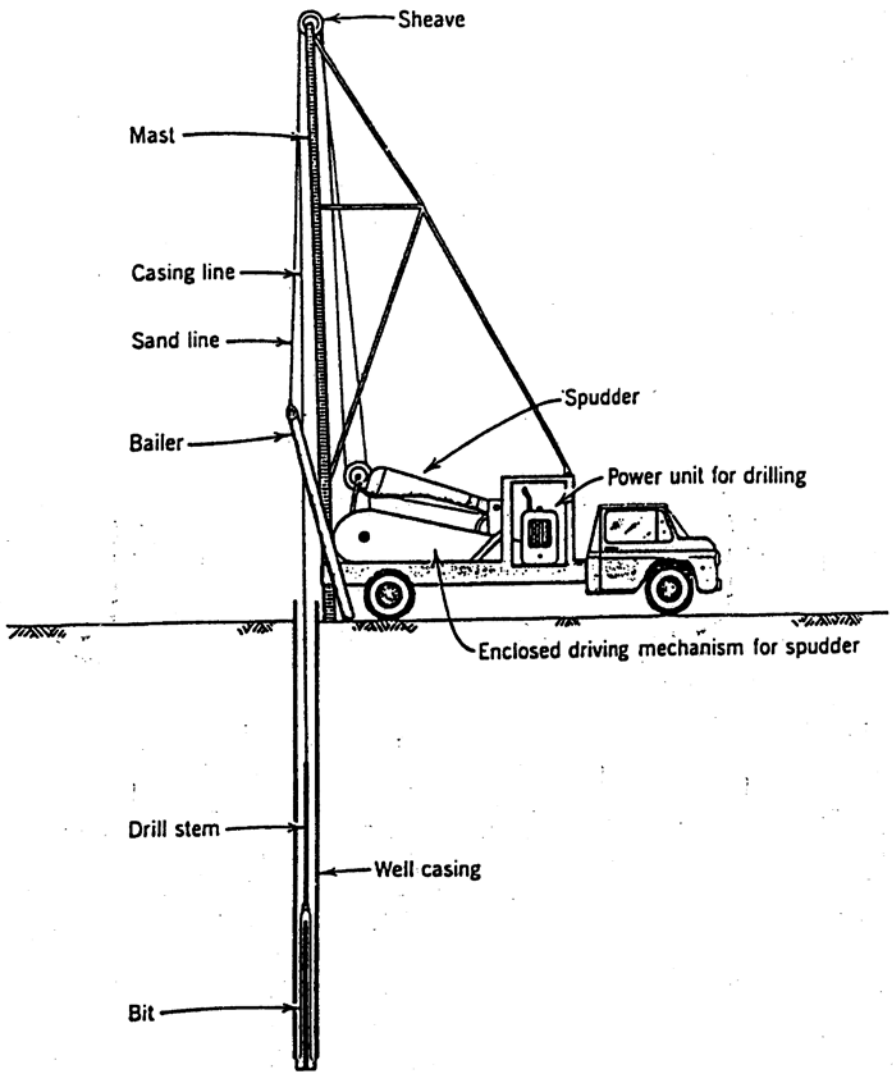

Figure 1. Cable tool method for making boreholes. The casing is advanced as the borehole is drilled in unconsolidated formations (Aller et al, 1989).

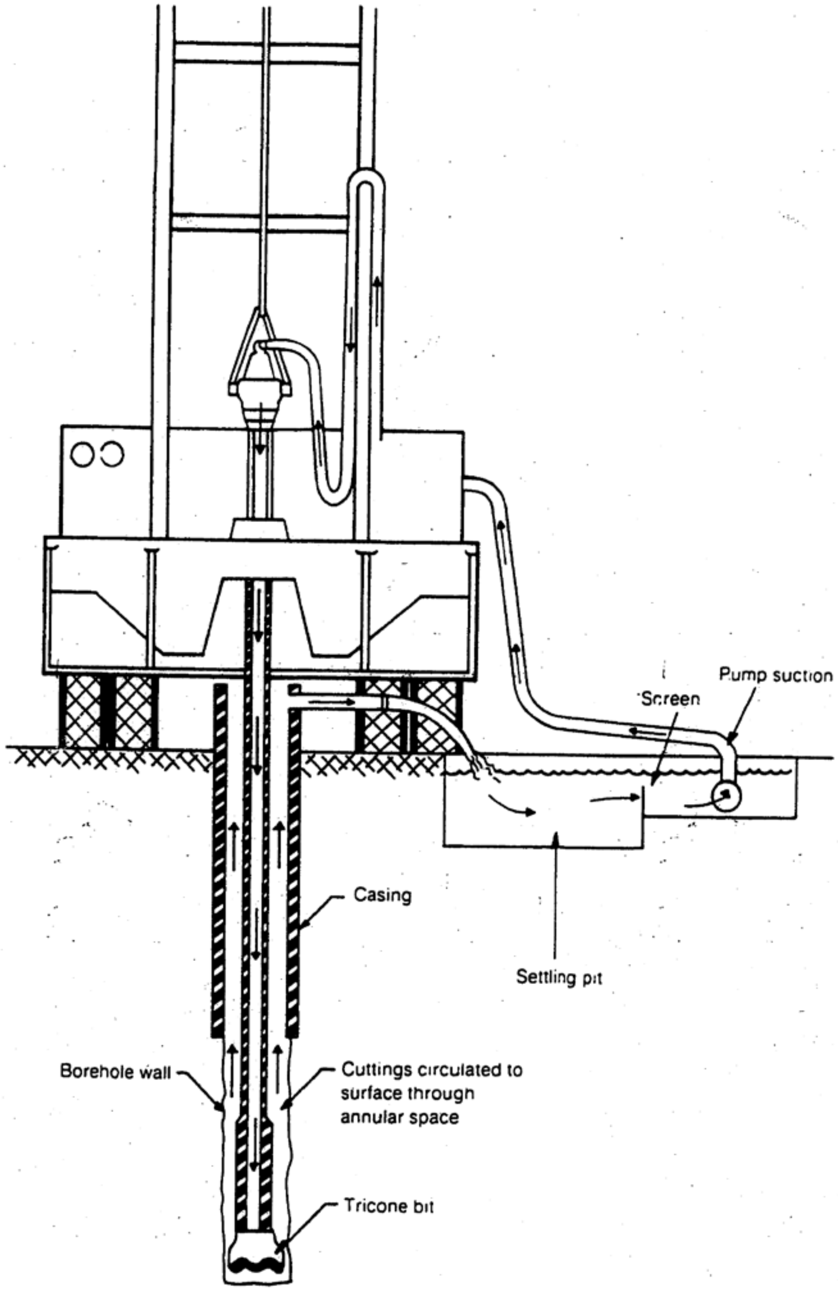

Figure 2. Diagram of direct fluid rotary circulation system (From Aller et al, 1989).

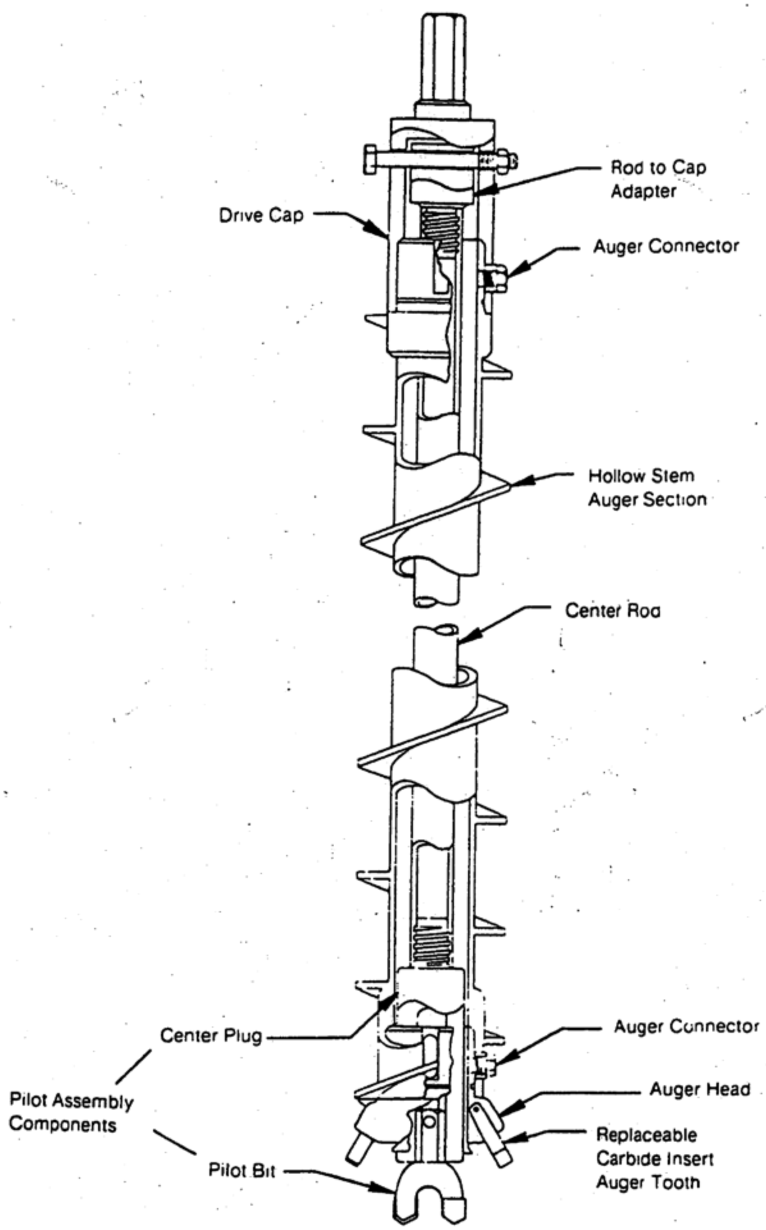

Figure 3. Typical components of the down-hole tools used with the hollow-stem auger drilling method (Aller et al, 1989).

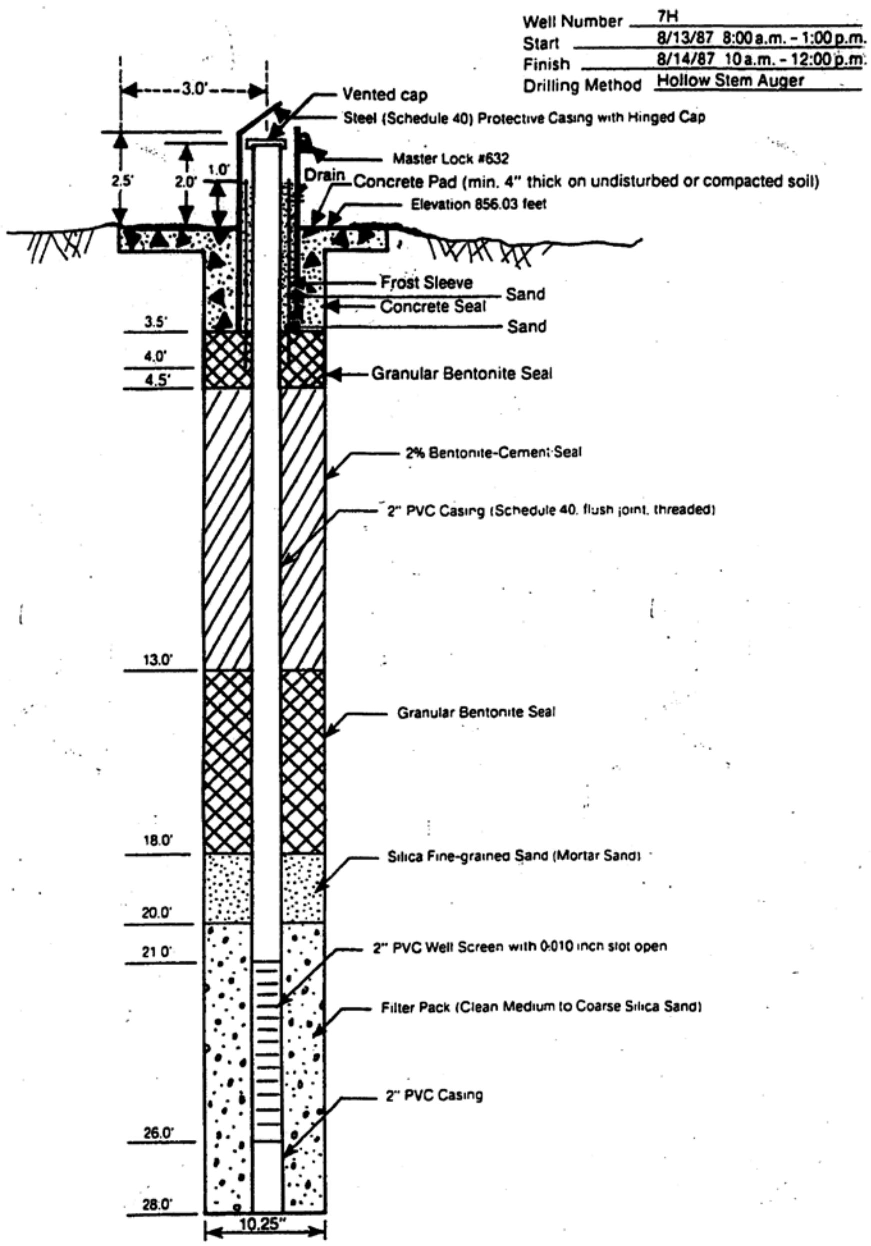

Figure 4. Typical monitoring well completion diagram showing the materials and dimensions of each component (Aller et al, 1989).

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ROCK CORE DESCRIPTION

The following components are commonly used by our drillers to describe collected rock cores:

- depth of core run;
- run number (R-1, R-2, etc.);
- recovery (in feet);
- rate of penetration - recorded as "minutes per foot" of penetration (ex: MPF = 6); and
- generalized rock description (i.e. Red/brown sandstone).

If the rock is logged by a Parratt-Wolff, Inc. geologist, the rock core descriptions will also commonly include:

- recovery (in percent);
- rock quality designation (RQD); and
- detailed rock description.

The RQD or "Rock Quality Designation" is the combined length of all core pieces whose individual lengths are greater than four inches, divided by the length of the core run. RQD is typically only used when describing NX cores or larger.

EXAMPLE OF DETAILED ROCK DESCRIPTION:

"Brown, thin bedded, fine-grained sandstone, highly weathered, soft, close fractured".

The components used to describe the rock core in detail are color, thickness of bedding, rock type, weathering state, hardness, and joint or fracture spacing. Additional components, such as texture, are used to further describe the rock as needed. The following tables include the definitions of these different rock descriptive terms.

Component	Term	Defining Characteristic
Bedding Thickness	Laminated	< 0.1 in.
	Very Thin Bedded	0.1 - 1.0 in.
	Thin Bedded	1.0 - 4.0 in.
	Medium Bedded	4.0 - 12.0 in.
	Thick Bedded	12.0 - 36.0 in.
	Massive	> 36 in.
Hardness	Soft	Scratched with fingernail
	Medium Hard	Scratched with a knife
	Hard	Difficult to scratch with a knife
	Very Hard	Can not be scratched with a knife
Joint or Fracture Spacing	Very Close	< 1.0 in.
	Close	1.0 - 2.0 in.
	Moderately Close	2.0 - 12.0 in.
	Wide	12.0 - 36.0 in.
	Very Wide	> 36.0 in.
Weathering State	Fresh	No visible sign of decomposition or discoloration
	Slightly Weathered	Slight discoloration inward from open fractures
	Moderately Weathered	Discoloration throughout fracture. Weaker minerals such as feldspar are decomposed.
	Highly Weathered	Most minerals are somewhat decomposed. Specimens can be crumbled by hand with effort and easily scraped by a knife.
	Extremely Weathered	Rock is decomposed to extent that it looks like soil, but original fabric or structure are preserved.

Figure 5 Components & Definitions Used to Describe Rock Core Samples

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Calculations:

Core recovery = total length of all recovered pieces.

RQD = the sum of all pieces greater than 4" in length, divided by the length of the run.

Example:

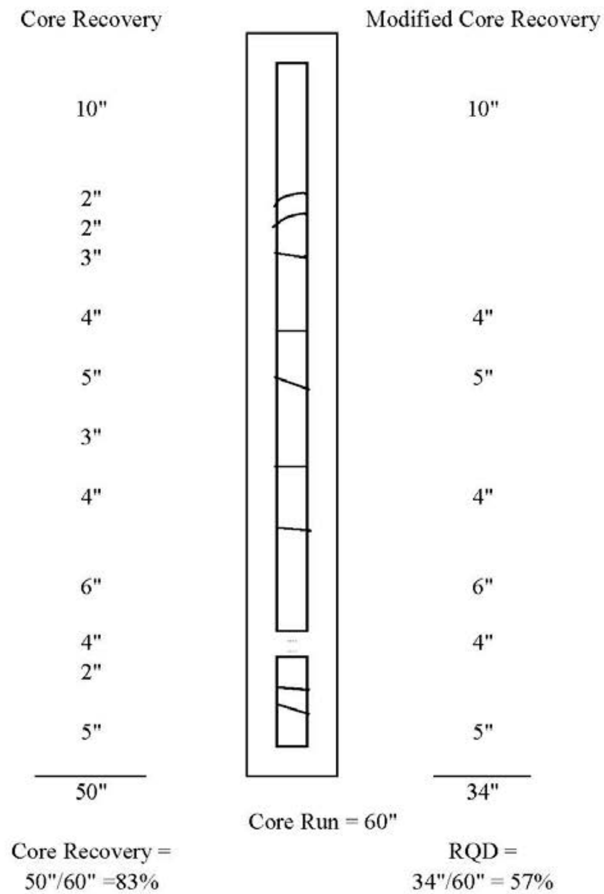

Figure 6 Method for calculating RQD - Rock Quality Designation.

TEST BORING LOG

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PROJECT **XYZ Facility**

LOCATION **Syracuse, New York**

GROUNDWATER DEPTH WHILE DRILLING	**12.0'**	HOLE NO.	**B-1**
BEFORE CASING REMOVED	**22.0'**	JOB NUMBER:	**9700**
AFTER CASING REMOVED	**19.0'**	DATE STARTED	**8/10/97**
CASING TYPE	**HOLLOW STEM AUGER, NQ WIRELINE**	DATE COMPLETED	**8/10/97**

N - NO. OF BLOWS TO DRIVE SAMPLER 12" W/140# HAMMER FALLING 30" - ASTM D-1586 STANDARD PENETRATION TEST

C - NO. OF BLOWS TO DRIVE CASING 12" W/ # HAMMER FALLING "/ OR PERCENT CORE RECOVERY

SHEET **1 OF 1**

Subsurface Elevation: 100.0'

DEPTH	SAMPLE DEPTH	SAMPLE NO.	C	SAMPLE DRIVE RECORD PER 6"		N	DESCRIPTION OF MATERIAL	STRATA CHANGE DEPTH
	0.0'-	1		11	15		Dry brown clayey fine to coarse SAND with	
	2.0'			17	5	32	little fine gravel (SW-SC)	
5.0								
								7.0'
	7.0'-	2		1	2		Firm moist red-brown silty CLAY with trace	
	9.0'			4	6	6	gravel (CL)	
10.0								
15.0								15.0'
	15.0'-	3		10	25		Hard moist brown silty SAND with some fine	
	17.0'			30	30	55	subrounded gravel (SM)	
20.0							Top of Weathered Rock	20.0'
	20.0'-	R-1	Rec	NX CORE			Brown thin bedded fine grained SANDSTONE,	
	25.0'		5.0'				highly weathered, soft, close fractured	
			100%					
			RQD=68%					
25.0								
	25.0'-	R-2	Rec				Gray thick bedded CRYSTALINE LIMESTONE,	
	30.0'		4.0'				slightly weathered, medium hard, wide	
			80%				fractured	
			RQD=90%					
30.0							Bottom of Boring	30.0'

Figure 7
Typical Test Boring Log

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