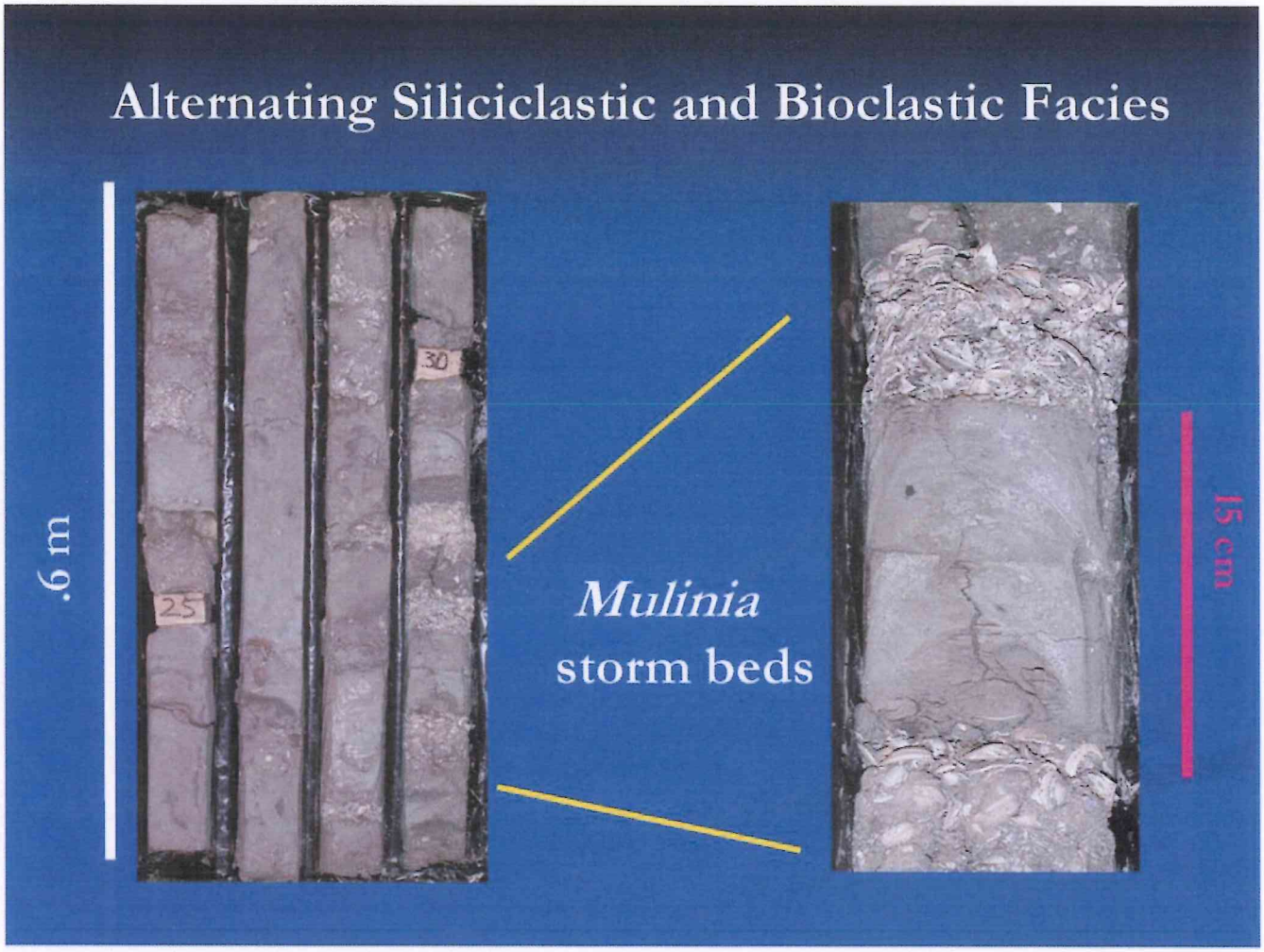
STANDARDIZED LOGGING TECHNIQUES FOR STUDENTS

A Laboratory Workshop

Southeastern Section - Geological Society of America - 2011

March 27, 2011 - University of North Carolina - Wilmington, NC

Co-sponsored by the SEPM - Society of Sedimentary Geology



Kathleen M. Farrell, PhD, PG - North Carolina Geological Survey

Jean M. Self-Trail, PhD - U.S. Geological Survey

T. Scott Bruce, BS, PG and Todd Beach, MS

Virginia Department of Environmental Quality

ATLANTIC COASTAL PLAIN
MUD ROTARY WELL CUTTINGS COLLECTION AND DESCRIPTION PROCEDURES

T. Scott Bruce

Proper collection, description, and interpretation of well cuttings from public supply, industrial, commercial, irrigation, agricultural, oil and gas, and aquifer storage and recovery wells are essential to characterize sub-surface geologic units, aquifers, and confining units in areas where core or split spoon samples are not available. Hydrologists and geologists utilize well cuttings information from mud rotary drilling operations to produce geologic maps, develop hydrogeologic frameworks, and provide information necessary to support ground water resources management activities by state regulatory agencies.

The Virginia Department of Environmental Quality (VA DEQ) is responsible for administering the Ground Water Management Act of 1992. The statute requires ground water users withdrawing 300,000 gallons per month from a well or well system to obtain a ground water withdrawal permit in specific ground water management areas. Well cuttings are used in conjunction with borehole geophysical logs to identify target aquifers and determine the maximum allowable production pump intake depth.

Mud Rotary Drilling

The mud rotary drilling technique is commonly used to advance boreholes in unconsolidated coastal plain sediments for water well construction. The drilling operation uses continuously circulating bentonite and polymer based fluids, called drilling mud, to cool the drill bit, stabilize the borehole wall, retard fluid loss, and transport sediment cuttings to the surface. Various methods are used to extract cuttings samples from the circulating mud prior to settlement in an excavated earthen mud pit, including above ground pans and trailer mounted mud treatment systems. A rig or trailer mounted mud pump circulates the clean mud back down the drill stem and out of the bit face. A typical drilling site layout is shown in Figure 22.



Figure 22. Photo of Windsor Shades Drill Site Layout.

Drag and roller bits are the most commonly used bit types in mud rotary drilling (Fig. 23). Each bit has advantages and disadvantages in the drilling process. Drag bits are less destructive to the original composition and structure of the sediments, have higher penetration rates in fine grain sediments, and are less expensive than roller bits. Disadvantages of drag bits include lower penetration rates in indurated or cemented sediments and large gravels, greater borehole deviation, and shorter bit life than roller bits.



Figure 23. Roller Bit (left) Drag Bit (right).

Roller bits are most commonly used in hard rock geologic settings but are favored by some coastal plain drillers. Roller bits disaggregate the sediment to a degree that makes it difficult to extract representative samples from the drilling mud, have slow penetration rates in fine grain sediments, and are more expensive than drag bits. Conversely, roller bits are better suited to cut through indurated or cemented sediments and large gravels, produce a straighter hole, and have longer bit life than drag bits.

Factors Influencing Cuttings Sample Collection

Many factors influence the collection of representative cuttings samples from a mud rotary borehole. These factors include hole depth, borehole diameter, drilling interval, circulation time, geologic material, communication between geologist and driller, penetration rate, mud characteristics (viscosity, weight, shear strength), up-hole fluid velocity vs. cuttings slip velocity , cutting shape and size, up-hole smearing, grain size sorting during the sample return, sample collection window, hole gage, and flow characteristics in the annular space between the drill rod and borehole wall (laminar, turbulent, preferential laminar, turbulent eddy). Sample quality is also highly dependent on the knowledge, skill, and experience of the onsite geologist and his or her familiarity with the local geology.

Hole Depth.--- Hole depth is the most important factor controlling sample integrity. The deeper the hole, the less representative the cuttings sample is of the actual geology. Personal experience of collecting, describing, and analyzing cuttings samples from more than 250,000 feet of borehole in the Virginia Coastal Plain has shown that sample degradation occurs at approximately 500 foot intervals. Specifically, cuttings are very representative in hole depths from 0 to 500 ft , less representative in hole depths from 500 to 1000 ft, and beyond 1000 ft, cuttings become broken down and difficult to distinguish in the sample return.

Borehole Diameter.--- The optimum borehole size for collecting cuttings and running geophysical logs is 6" for holes up to 300 feet and 8" for holes greater than 300 feet. Hole diameter is directly proportional to drilling speed and sample volume, (the larger the hole diameter = the larger the cuttings volume = the longer the time to drill).

Drilling Interval.--- Well drillers commonly use 20 foot drill rods to install water wells in the Atlantic Coastal Plain. In a few cases, 25 and 30 foot drill rods are used on large trailer mounted rigs. The VA DEQ requires that cuttings samples be collected every 10 feet; e.g., the length of rod or depth of hole that can be drilled before penetration is stopped to allow time for mud circulation to adequately clear the hole of cuttings. Drilling intervals of 20 feet may be authorized when drilling boreholes deeper than 1,000 feet in order to have enough sample volume returned at the surface.

Circulation Time.--- The borehole must be circulated after each 10 foot drilling interval to adequately clear the hole of cuttings. This is accomplished by continuing to run the mud pump and rotate the drill bit while holding the drill rod at a stationary position. Circulation times of 45 minutes to 1 hour per drilling interval are common in order to adequately clear cuttings in boreholes deeper than 1,000 feet.

Most drillers do not circulate the borehole long enough to adequately clean the hole of cuttings between drilling intervals. This leads to increased mixing of formations in the borehole resulting in sample contamination. Adequate circulation time is mostly dependent on depth, but other factors including mud viscosity, cutting size and shape, slip velocity, and hole gage also affect circulation time.

Geologic Material.--- Sediment texture and composition often influence the quality of the samples. For example, sediments comprised primarily of silt size material will often disaggregate to the single grain level and mix with the drilling mud. This situation can result in little or no noticeable return of materials at the surface. Predominately clayey material will often produce cuttings that are several inches in diameter which makes it difficult to remove them from the borehole. On the other extreme, the drilling fluid may not be capable of transporting large gravels out of the borehole.

Communication Between Driller and Geologist.--- An experienced driller can determine the general texture and composition of the sediments he or she is drilling by monitoring the instruments and gages on the rig. The driller is also aware of the sounds and vibrations of the rig which will give clues as to the type of geologic material being drilled.

Having a good avenue of communication with the driller will provide valuable information to the geologist describing the samples. Driller comments should always be incorporated in the geologist log.

Penetration Rate.--- Penetration rate of the bit and drill rod is primarily controlled by the driller but is heavily influenced by the drilling mud and mud cleaning system and to a lesser degree by the composition of the geologic formation. The optimum penetration rate with respect to sample quality occurs when the largest chip size (approximately ½ to ¾ inches in diameter in fine grain sediments) is obtained without producing a mud collar. Slow drilling speeds can adversely affect sample quality by smearing the sample throughout the borehole depth and washing fine grain sediments into the drilling mud resulting in diminished sample return volume at the surface.

Mud Characteristics (Viscosity, Weight, Shear Strength).--- Water well drilling mud viscosity is measured with a MARSH funnel viscometer (Fig. 24). Mud viscosity normally ranges from 32 to 35 seconds per quart but can reach up to 48 to 50 seconds per quart and still flow in the pump and drill string. Mud weight is measured in pounds per gallon (lb/gal) with a mud scale (Fig. 25). For comparison, water weighs 8.34 lb/gal and a clean water based bentonite and polymer drilling mud averages around 9 to 9.5 lb/gal. Cuttings laden mud traveling up the borehole ranges from 10 to 11.0 lb/gallon. Shear strength is another mud property that is linked to mud viscosity. Shear strength is the property of the drilling fluid to keep solids in suspension when the mud is at rest and it increases as viscosity increases and decreases as viscosity decreases. Mud viscosity and shear strength together determine if the mud is generally thick or thin.

Drilling fluids can adversely affect sample collection if the mud is too "thin" or too "thick". Thin mud will "dissolve" fine grain formation material into the drilling fluid preventing it from being sampled at the surface. Drilling mud that is too "thick" will entrain fine to medium grain quartz sand grains in the fluid which also hampers sample collection and can bias them to appear coarser than they actually are in place. Another complication of overly thick drilling mud is that the cuttings will not settle in the mud pit before being pumped back down the borehole resulting in increased sample contamination.



Figure 24. Baroid Marsh Funnel Viscometer and Quart Cup.



Figure 25. Baroid Mud Scale.

Up-hole Fluid Velocity Vs. Cutting Slip Velocity.--- The flow rate and output pressure of the mud pump coupled with the hole diameter primarily determine the rate at which the drilling fluid will travel from the bit to the surface. Mud properties, cutting size and shape, and slip velocity determine the up-hole velocity of the cuttings.

Cutting Shape and Size.--- Physical action of the bit face and jetting action of the drilling fluid on the sediments in conjunction with penetration rate and mud viscosity, determine the amount of disaggregation of the formation during drilling. For example, cuttings from the St. Marys Formation in Virginia are often ribbon shaped measuring 2 inches long by 1/2 inch wide by 1/8 inch thick when mud viscosity is greater than 38-42 seconds per quart (Fig. 26). Mud

viscosity of 28-32 seconds per quart will often disaggregate the sediments of the St. Marys Formation down to the individual silt grain and incorporate them into the drilling fluid. In this case, little to no sample can be collected at the surface. More commonly, sands and gravels disaggregate down to the individual grain size while fine grain sediments travel up the borehole in round or cubic shaped balls measuring ¼ inch to 1 inch in diameter. Preferred cutting size in fine grain sediments is ½ to ¾ inch which allows the geologist to break apart the chips to reveal the original composition and texture of the formation.



Figure 26. Example of St. Marys Formation Ribbon Cutting.

Up-Hole Smearing.--- Differing size, shape, and specific gravity of the cuttings cause them to "smear" or be strung out in the borehole while traveling from the bit to the surface. Sample volume per unit time observed at the sample collection point is directly proportional to the amount of smear.

Grain Size Sorting During Sample Return.--- The first mistake made by most rookie mud loggers is assuming that the first material cut by the bit during a drilling interval will be the first to arrive at the surface. In many cases, a poorly sorted quartz sand will sort itself in the

borehole so that the fine sand fraction arrives first at the ground surface (early arrival time), and the coarse sand arrives last (late arrival time).

Another example is if the first 4 feet of the drilling interval consists of well-sorted coarse quartz sand and the last 6 feet of the drilling interval consists of fine glauconitic sand, it is common for the finer sand to pass the coarse sand in the borehole while traveling up the borehole.

Sample Collection Window.--- A mud rotary borehole is never "clean", no matter how long it is circulated. There is always a percentage of cuttings from every geologic formation encountered in the hole that are never completely removed from the borehole during the drilling process. Cuttings left in the borehole after a drilled interval has been circulated are considered "contamination". Unfortunately, these "rogue" cuttings slowly discharge at the surface with the representative cuttings. The amount of contaminated samples can be minimized by carefully monitoring the cutting volume per unit time at the surface discharge point.

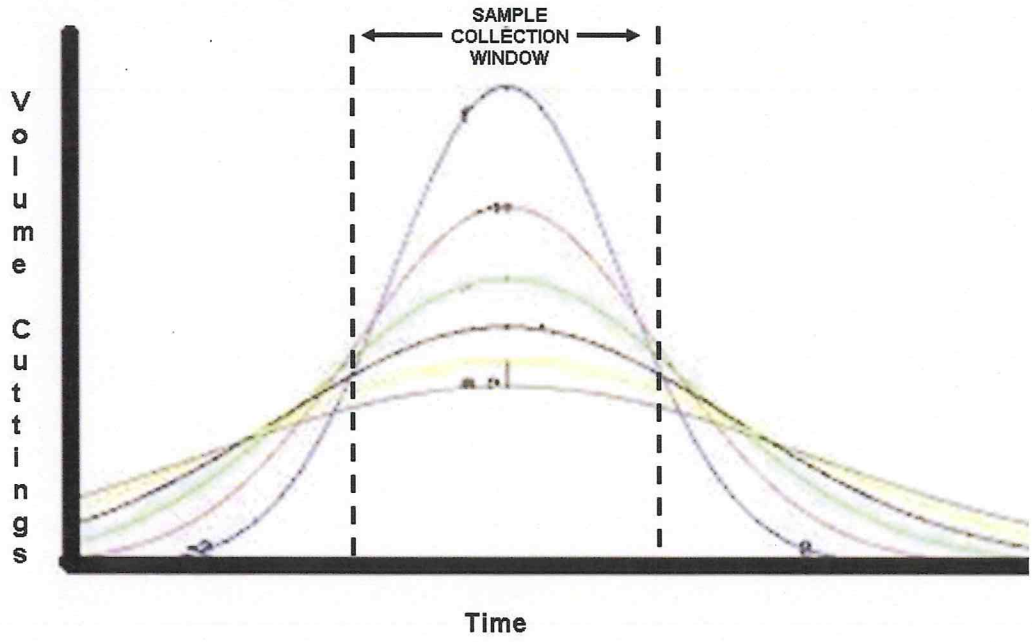


Figure 27. Generalized Graph of Cuttings Volume vs. Time.

A generalized graph of cutting volume versus time shows a series of curves Figure 27 reflecting various situations that can be encountered during drilling operations. The ideal situation for cuttings collection is represented by the bell shaped curve with the highest

amplitude and shortest wavelength. The lengths and amplitudes of the curves are controlled by bit type, penetration rate, mud properties, smearing, cutting shape and size, up-hole fluid velocity, circulation time and depth. Cuttings should only be collected during the middle portion of the curves. Cuttings in the surface discharge during the early time and late time portions of the curves contain a greater percentage of rouge cuttings and are therefore more highly contaminated and less representative than cuttings collected during the peak discharge period.

Hole Gage.--- Ideally, the borehole diameter is the same as the bit diameter. This is often not the case. "Wash-outs" or "possum bellies" can occur in the borehole which can adversely impact sample quality. Up-hole velocity drops adjacent to wash out zones causing the cuttings to eddy and not return to the surface. This can greatly reduce the amount of cuttings observed at the surface. When the next interval is cut by the bit, cuttings traveling up the hole can mix with and then replace cuttings already in the wash out zone from the previous interval thereby creating a delay in surface arrival time and greater sample contamination.

Flow Characteristics in the Annular Space Between the Drill Rod and Borehole Wall (Laminar, Turbulent, Preferential laminar, Turbulent Eddy)

Comparison of sediment texture, composition, and formation contact depths from 7 co-located wire line cores and mud rotary boreholes in the Virginia Coastal Plain has revealed a more complex fluid flow pattern than described in the literature. This manual presents a new theory to describe the process of how cuttings are transported from the drill bit to the surface.

Direct observation of deep mud rotary up-hole fluid flow is not possible. According to the N L Baroid/N L Industries, Inc. Manual of Drilling Fluids Technology, fluid flow in freshwater based bentonite/polymer drilling muds exhibit a quasi-Bingham flow behavior and is either turbulent or laminar. Fluid flow in the drill pipe is thought to be turbulent while the fluid flow in the annual space is thought to be laminar provided the critical velocity is not exceeded. Critical velocity is the velocity at which the flow pattern changes from laminar to turbulent and is expressed by the ratio of plastic velocity PV to yield point YP.

In addition to laminar and/or turbulent flow in the borehole annular space, the conceptual model includes two additional flow patterns. These are: preferential laminar flow, and turbulent

eddy flow. Both flow types can coexist and interact in the borehole annular space to affect cutting returns at the surface. Preferential laminar flow occurs when a continuous "snake-like" flow path, with a greater up-hole velocity, breaks up through adjacent zones of turbulent eddy flow of much lower velocity, in the borehole annular space Figure 28. Drill rod rotation may play a role in establishing the preferential laminar flow path. In some cases, turbulent eddy flow may have little to no effective up-hole velocity.

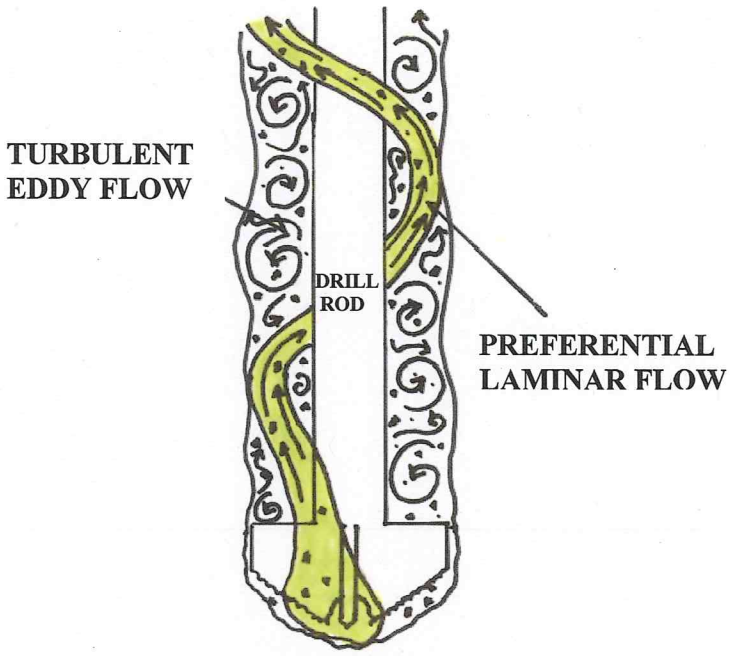


Figure 28. Diagram of Preferential Laminar and Turbulent Eddy Flow.

The shape and configuration of the preferential laminar flow path seems to be established based on the geologic material being drilled and the size and shape of the cuttings. Each time there is a significant change in the lithology being drilled, the preferential laminar flow path is disturbed resulting in a mixing of the cuttings caught in the turbulent eddies with the new lithology cuttings until a different preferential laminar flow path is established for the new lithology.

To illustrate this point, a continuous wire-line core was drilled through the Saint Marys and Calvert Formations and the contact between the units was documented. A mud rotary hole was drilled within 10 feet of the core hole using 20 foot drill rods with samples circulated every

10 feet. Fortunately, the St Marys/Calvert formation contact depth occurred at the same depth as a drill rod change in the mud rotary hole. Therefore, the next 10 foot drilling interval would be cutting the Calvert Formation exclusively.

Cuttings from the St. Marys Formation exhibited the elongated thin ribbon shape. The borehole was circulated extensively so that there was very little to no return of the ribbon shaped cuttings from the St. Marys Formation. Common theory would suggest that the cuttings samples from the next 10 foot drilling interval would be dominated by the Calvert Formation. This was not the case. The sample consisted of approximately 95-98 percent St. Marys ribbons and only 2-5 percent sandy clay silt balls from the Calvert. The next 10 foot interval was also heavily dominated by the St. Marys lithology. Calvert Formation cuttings did not dominate the cuttings return until the third 10 foot interval was drilled into the Calvert Formation and circulated.

Without prior knowledge of the formation contact depth from the core hole, the St. Marys/Calvert contact would have been placed 20 to 30 feet lower than it was observed in the core hole. The only possible explanation of this phenomenon is that the St. Marys ribbons were not being flushed from turbulent eddies in the borehole during circulation while the laminar preferential flow path was being flushed – giving the appearance that the hole was "clean".

Sample Collection Techniques

The geologist's objective is to collect and describe the cuttings being circulated from a borehole in order to accurately characterize the subsurface geology and/or hydrogeology. As shown previously, there are many factors that control how and when the cuttings travel from the bit face to the surface. Likewise, the procedures used to extract the cuttings from the drilling fluid are also extremely important. Major components of the cutting sample collection system include a side discharge pipe, several gradations of sediment sieves, sampling ditch with dams, washing bucket with garden hose, cyclone de-sander, and shale shaker on a trailer mounted mud cleaning system if available. Washed cuttings should be placed on the ground in 10 foot intervals for descriptions and photographs. Samples may also be containerized for future reference.

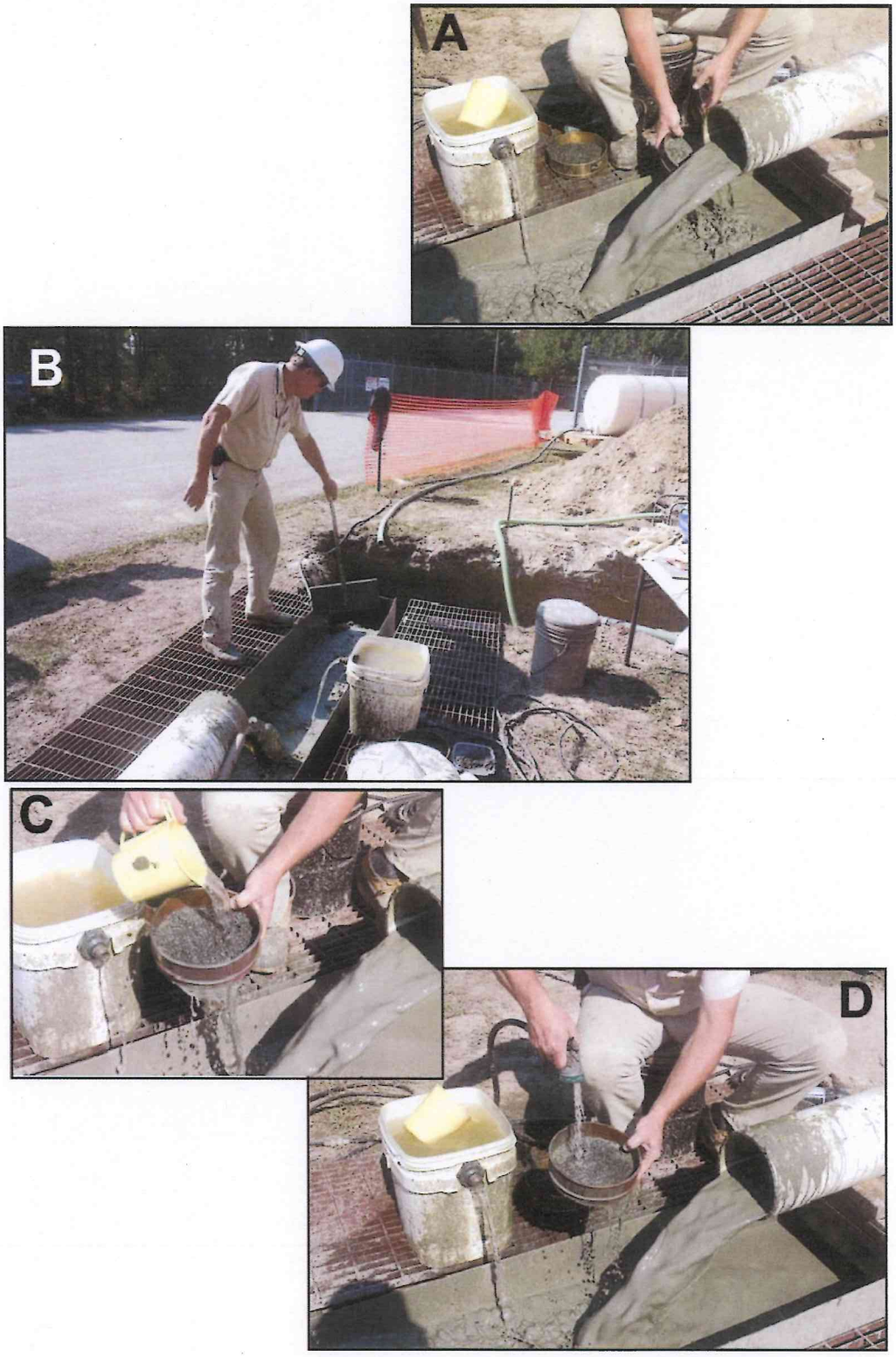


Figure 29. Photos that show collection process: A. Side Discharge Pipe. B. Sample Collection Ditch and Dam. C. Sample Washing With Cup. D. Sample Washing With Garden Hose.

Elevated Side Discharge Pipe.--- An elevated side discharge pipe is a mandatory part of the sampling protocol (Fig. 29A) if accurate sampling of representative samples is required. The side discharge pipe focuses the drilling fluid to a point where the cuttings can be screened from the drilling mud using different size sieves. Kitchen strainers should NOT be used because the bowl like shape of the strainer will not retain the smaller sand size material. The edge or lip of the sieve should be held beneath the bottom edge of the side discharge pipe. Sieve pans can be stacked to capture widely ranging cutting sizes. Cuttings should only be strained from the mud stream during the central portion of the maximum cuttings volume per unit time.

Sampling Ditch and Dams.--- An aluminum sample ditch and dam (Fig. 29B) is used to augment sample collection when fine grain glauconite and quartz sand can not be captured in the sieves. This situation occurs when the mud viscosity is high and the fine grain cuttings require a fluid velocity drop in order to fall out of the drilling fluid. It is important to note that the cuttings will gradationally drop out of the mud along the length of the ditch. A composite sampling of the entire length of the ditch is required to obtain a representative sample.

Washing Bucket with Garden Hose.--- Samples should be washed to remove the bentonite based drilling mud. Depending on the shape, size, geologic material comprising the sample interval, and the mud thickness, the cuttings should be washed by using a cup to dip water out of wash bucket and pour over the samples in the sieve pans (Fig. 29C). The sieves can be dipped directly into the wash bucket as well. Or, in some cases, a garden hose is required to quickly wash the samples (Fig. 29D). A garden hose is also effective to determine if glauconite from a shallower depth is sticking to the outside of non-glauconitic clays and silts deeper in the borehole. This technique involves spraying the cuttings in the sieve pan to see if the chips are coated with glauconite or if glauconite persists throughout the chip.

Cyclone De-Sander.--- A competent coastal plain driller will utilize a cyclone de-sander to remove fine grain material from the drilling mud that does not settle out in the mud pit or pan (Fig. 30A). Discharge from the de-sander should be sampled for each drilling interval and combined with the samples collected from the elevated side discharge pipe and/or ditch.

A



Sample Collection from De-Sander.

B



Trailer Mounted Mud Treatment System.

C



Typical Layout of Ground Samples.

Figure 30. Additional photos showing: A. Sample collection from de-sander; B. Trailer mounted mud treatment system; and C. Typical layout of ground samples.

Shale Shaker.--- Site conditions often preclude the use of an excavated mud pit to allow cuttings to settle before pumping the drilling fluid back down the borehole. A trailer mounted mud treatment system is used to clean the mud (Fig. 30B). Most mud treatment systems include a shale shaker with a battery of cyclone centrifugal de-sanders. The shale shaker screens the larger cuttings from the mud stream while the de-sanders remove the fine sand and silt fraction. If available, grab samples from the shale shaker should be included in the composite sample for each 10 foot drilling interval.

Ground Samples.--- Most geologists and/or drillers containerize or bag the cuttings samples as soon as they are collected. This practice is not preferred because the individual sample chips become molded into an indistinguishable muck. Placement of the cuttings samples directly on the ground allows a much better venue to study and describe the samples (Fig. 30C). Ground samples also allow a better visual comparison of adjacent sample intervals. Ground samples are easily photographed for future reference. Visual comparison of the samples to the geophysical logs is also much more efficient. Ground samples can be easily containerized if needed for sieve analysis or archived for future study.

Borehole Geophysical Logs

The Virginia Department of Environmental Quality requires borehole geophysical logging on all wells included in a ground water withdrawal permit. A typical geophysical log suite includes single point resistance, 16" normal, 64" normal, 6 foot lateral, spontaneous potential, and natural gamma. Log scale must be 1 in = 20 ft. The geophysical logs are used in conjunction with lithic logs prepared from analysis of cuttings samples to delineate geologic formations as well as hydrogeologic units (Fig. 31). In cases where formation contacts can not be determined accurately from cuttings samples, geophysical logs can often be used to pin-point major lithic breaks such as a phosphatic basal lag deposit which may coincide with a formation boundary.

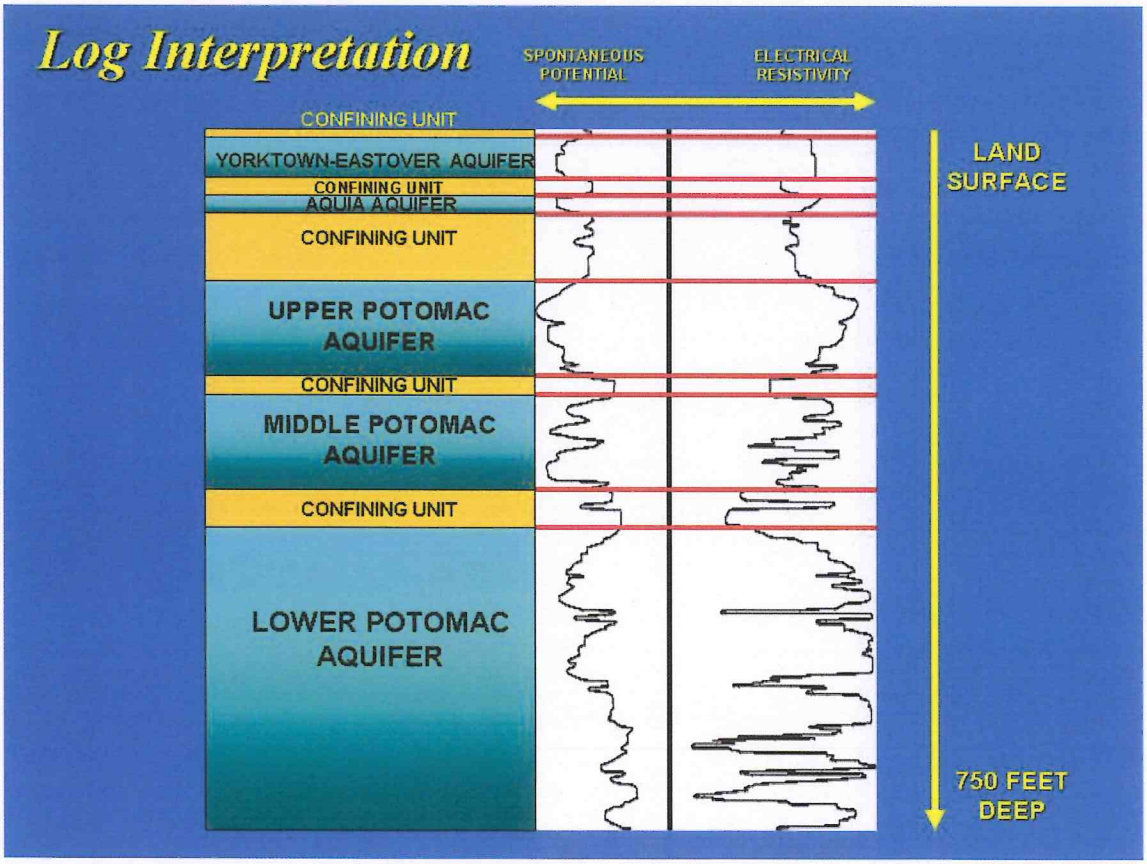


Figure 31. Geophysical Log Interpretation.

Workshop Exercise

A 7 7/8 inch pilot hole was completed to a depth of 798 feet encountering basement rock in eastern New Kent County located in the central Coastal Plain of Virginia (Fig. 32). Cuttings samples were collected at 10 foot intervals and analyzed using a 200 power binocular scope by DEQ staff. The borehole is located at latitude 37 25' 35.17752" N, 76 58' 12.56826" W. The horizontal datum is NAD 27. Coordinates were obtained using a Trimble GeoXH GPS unit with a post processed differential correction accuracy of 1 meter or less. A full suite of borehole geophysical logs was collected using Century logging equipment (Fig. 33).

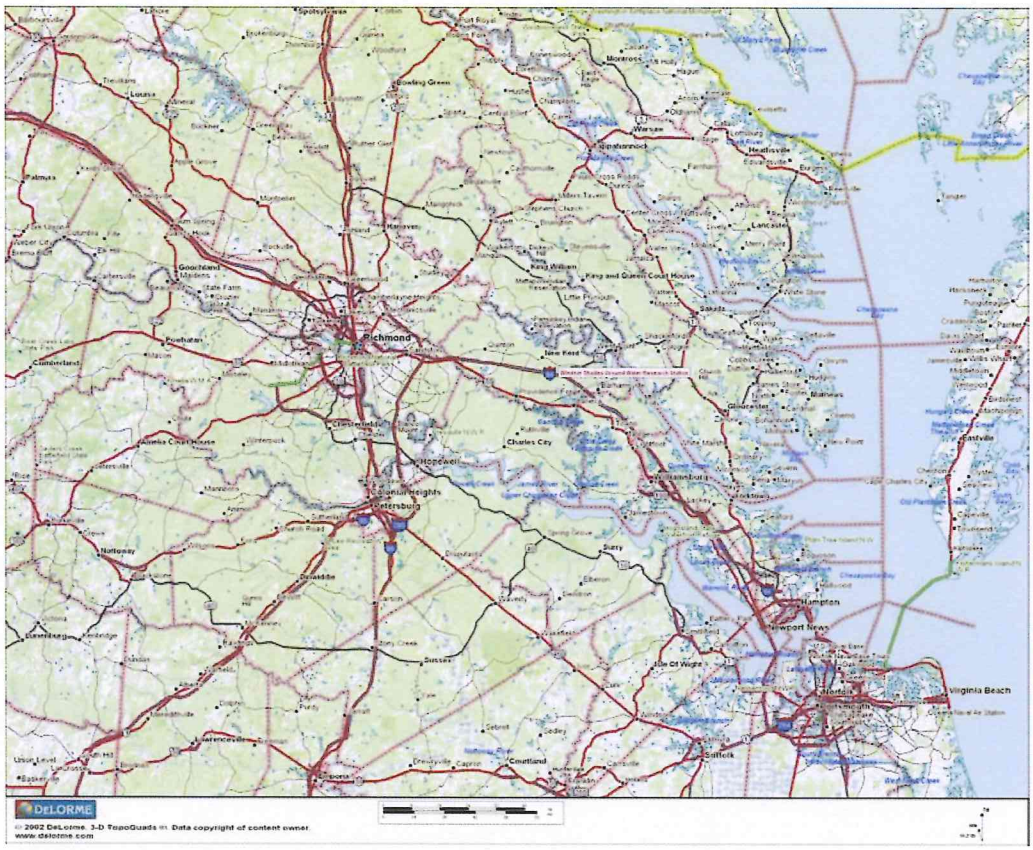


Figure 32. Location Map of Windsor Shades SOW Site.

Using the North Carolina Geologic Survey graphic log sheet (Fig. 13), complete a detailed description of the composition, texture, facies, and surfaces for the cuttings samples from the DEQ Windsor Shades pilot hole (120 feet to 260 feet). The samples represent marine as well as non-marine sediments from geologic formations ranging in age from Eocene to Cretaceous. Geologic Formations include the Piney Point, Nanjemoy, Marlboro Clay, Aquia,

and Potomac. 1" = 20' scale borehole geophysical logs will be distributed as a class handout. The Windsor Shades Cuttings Log is included in Appendix B.

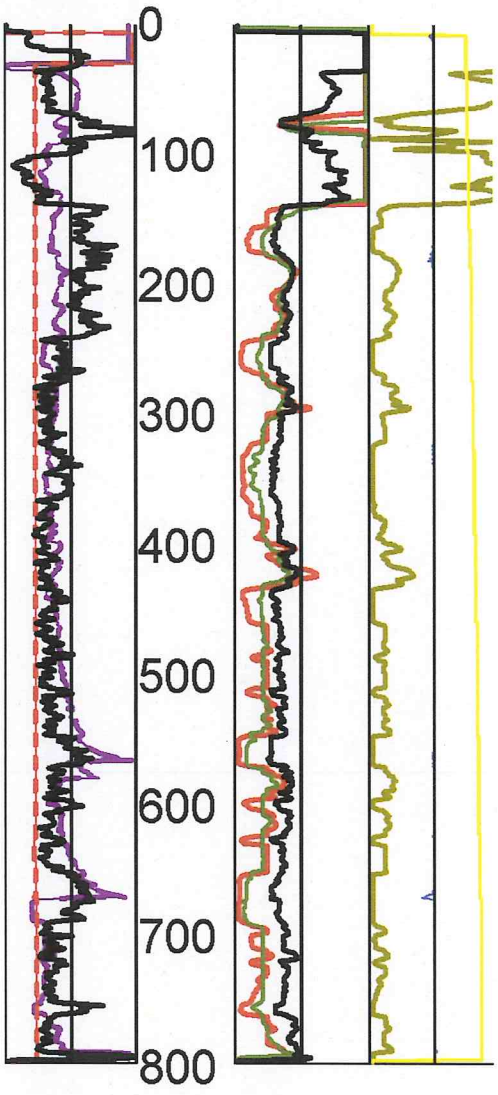


Figure 33. Windsor Shades Borehole Geophysical Log.

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APPENDIX A

Check List for Core Logging:

- **Camera**
- **Grain size card.**
  Available from Canadian Stratigraphic: http://www.canstrat.com/order.html
- **Blank logging sheets printed on "write in the rain" paper (11 X 8.5 sheets) USGS.**
- **Logging Template (Figure 13) NCGS**
- **Ruler.**
- **Waterproof pen or mechanical pencil; erasers.**
- **Clipboard.**
- **Measuring tape (in tenths of feet, not inches; or cm).**
- **Munsell Rock Color Chart.**
- **Binocular Microscope.**
- **Petri dishes.**
- **Needle probes with wooden handles.**
- **Hand Lens.**
- **Bottle of dilute HCl.**
- **Water bottle - squirting.**
- **Calculator.**
- **Flat scrapers: knife (USGS) or spatula with wooden handle (NCGS).**
- **White-out.**
- **Labels for photography.**
- **A variety of waterproof markers.**
- **Isopropyl alcohol.**
- **Paper towels.**
- **Wooden or composite blocks.**
- **Plastic sample markers.**

Additional Gear For Field Cuttings Method:

- **#12. #70, #100 Sieve Pans.**
- **USGS Photography Scale**
- **Index Cards for Labeling Ground Sample Photographs**
- **Wash Bucket**
- **Pressurized Water Hose with Spray Nozzle**
- **Viscometer, Quart Cup, Stop Watch**
- **Mud Scale**
- **8 Foot Aluminum Sampling Ditch and Dam**

Appendix B

Windsor Shades Cuttings Log

LOG

hole: Windsor Shades 233A
County/State: New Kent, VA
Date: October 11 to 14 2010
Geologist: TS Bruce and TA Beach
Land surface: 30 feet MSL
Latitude: 37 25 35.37709N WGS84
Longitude: 76 58 11.41810W PPDGPS

Depth Feet	Run/ Box	Lithology	Description
0			10YR6/6 brownish yellow and 10R7/3 very pale brown mottled to varigated, very fine sandy SILT.
			2.5Y7/2 light gray CLAY with trace of sand, orange areas of oxidation in trace sand zones.
			orange SAND & GRAVEL, fU to vcU subrounded sand, quartz and chert gravel up to 3cm diameter subrounded to rounded.
2 0		HM	2.5Y7/3 pale yellow vfL to fL SAND with some silt, "sugar sand" 10 to 15% dark grains (glauconite and heavy minerals). 10Y4/1 dk greenish gray with brown and black dark grains at 25'.
			vfL to fU angular to subrounded silty SAND with 10 to 15% dark grains.
4 0			5GY3/2 v dk grayish green vfL to fL silty SAND with 10 to 15% dark grains.
			vfL to fL, very micaceous with 15% dark grains.
6 0			Silt content increasing, sand size and content decreasing to SAND & SILT, vfL to fU sand with 5% dark grains.
			10GY6/1 greenish gray CLAY.
8 0		P	SAND & GRAVEL with Shell fragments, phosphate, gravel to 1.7cm.
			10Y4/2 dk grayish olive silty clayey vfU to mU SAND, sponge spicules, with 15% black grains - NOT glauconite.
		P	becomes shelly with vfU to cU sand below 95' depth.
10 0			dk brown micaceous SILT, trace shell frags, forams, pyrite, spicules.

Shirley Formation
Eastover Formation
Saint Marys FM?
Calvert Formation
old Ch1

LITHOLOGY : GRAIN SIZE : SORTING : INDURATION : MINERALOGY : FOSSILS : STRUCTURES : COLOR : CONTACTS

USGS

LOG

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Geologist: TS Bruce and TA Beach
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Latitude: 37 25 35.37709N WGS84
Longitude: 76 58 11.41810W PPDGPS

Depth Feet	Run/ Box	Lithology	Description
10	0		5GY6/1 greenish gray cemented glauconitic shell rock with vfL to mU sandy seams, 7 to 10% glauconite. Harder at 113 feet per driller. Contains abundant pyrite and blue/green clay inclusions.
12	0		5GY5/1 greenish gray with abundant pyrite.
			fU to vcU glauconite and quartz SAND, abundant brown stained rounded quartz grains, 30 to 40% glauconite primarily dk brown and brown, ostrea celeforma fragments.
14	0		Glauconite SAND in a 5Y3/2 v dk gray silt matrix , >50% glauconite, botryoidal jade green to black vfL up to cL, abundant mica flakes, 1 to 3% quartz grains. 5GY4/1 dk greenish gray SILT/CLAY with 15 to 20% botryoidal glauconite, vfU to cL, highly micaceous, trace shell fragements.
16	0		Glauconite content increases below 165',mainly black to dk green vfL to mU glauconite with trace of brown, 1 to 3% quartz, many angular black grains - phosphate? Phosphate pebbles at 176' on contact.
18	0		N5/1 gray and 5YR5/4 reddish brown Marlboro Clay, micaceous, appears contact is burrowed.
			10Y4/4 olive fL to mL glauconite/quartz SAND in a clay/silt matrix, with some shell fragments, glauconite is 50% brown 50% black/green, approximately 50% quartz sand and 50% glauconite. Size increases to fL to cU with trace of gravel up to 7mm
20	0		

Piney Point Formation

Nanjemoy FM Woodstock Mbr

Nanjemoy Formation Potapaco Member

Marlboro Clay

Aquia Formation

LITHOLOGY : GRAIN SIZE : SORTING : INDURATION : MINERALOGY : FOSSILS : STRUCTURES : COLOR : CONTACTS

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Depth Feet	Run/ Box	Lithology	Description
20	0		10Y4/1 dk greenish gray glauconite and quartz SAND in a silt binder, fL to mU, approx 50% glauc 50% quartz, 1 to 3% shell fragments, 30% brown glauconite.
			10Y2.5/1 greenish black glauconite/quartz SAND in silt binder, vfU to mL, much of the quartz is subangular, 30% brown glauconite, 3% sand sized shell fragments.
22	0		Glauconite content exceeds silt and sand content, 3% quartz mostly subangular, 1% brown glauconite most is dk green to black fU to vcL subrounded to rounded.
			clay/silt binder content increases, green and black botryoidal glauconite subrounded to rounded, some 5GY4/4 olive green layers, 5% quartz.
24	0		Gravel to 1.1cm at contact.
			5G6/2 pale green fine sandy SILT.
			10Y3/1 v dk greenish gray micaceous SILT.
			2.5Y5/4 lt olive brown mixed with 5G6/2 pale green mottled CLAY.
			5G6/1 greenish gray micaceous SILT mottled with 10YR4/4 dk yellow brown SILT, paleosoils, trace vfL to fL sand.
26	0		
			lt gray sandy SILT/CLAY, very micaceous, vfL to fL sand.
			SAND with SILT, vfU to vcU subangular to subrounded.
28	0		SAND with silt/clay binder, micaceous, garnetiferous, fL to vcL, some gravel to 6mm.
			dk gray SAND & GRAVEL, some silt, gravel to 1cm, garnet rich, very micaceous, 3% kaolinized feldspar grains, fL to vcU.
30	0		

Aquia Formation

Potomac Formation

LITHOLOGY : GRAIN SIZE : SORTING : INDURATION : MINERALOGY : FOSSILS : STRUCTURES : COLOR : CONTACTS

USGS

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Depth Feet	Run/ Box	Lithology	Description
30	0		As above.
			5G6/2 pale green clayey/silty fine SAND, micaceous, chlorite stained quartz, fU to mL sand, becoming more sandy near 318.5 per driller.
32	0		Chatter at 320', vfU to vcU angular to subangular SAND with GRAVEL to 1cm, coarser zone 320 to 325.
			Clay content increases below 325' to sandy CLAY.
			Red and blue/green to gray CLAY PALEOSOLS, very stiff.
34	0		
36	0		Gray sandy CLAY, abundant mica.
			Blue gray clayey SAND to sandy CLAY, abundant feldspar, trace of gravel to 6mm, vfU to vcU sand
38	0		clayey SAND, vfL to vcU, subangular to subrounded.
			Gravel to 1cm at 390'
			Blue gray to yellow brown clayey SAND, abundant garnets, vfL to vcU sand, many chloritized quartz grains.
40	0		

Potomac Formation Continued

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Potomac Formation Continued

Depth Feet	Run/ Box	Lithology	Description
40	0		Light gray to yellow brown clayey SAND, abundant 3% feldspars, garnets, fU to vcU, trace of gravel to 6mm.
			White to pale green fU to vcU clayey SAND, sugangular to subrounded.
42	0		mL to vcU SAND, subangular to subrounded, chloritized granite fragment, garnetiferous, abundant feldspar grains some highly kaolinized.
			Gravel to 7mm at contact.
			Pale green and yellow brown CLAY, some kaolinized feldspar grains.
44	0		Pale blue to pale green sandy CLAY, micaceous, vfL to vcL sand.
			Pale blue to pale green sandy CLAY to clayey SAND, vfL to vcU subangular to subrounded sand, micaceous, garnetiferous, no feldspar
46	0		Pale blue fL to vcU SAND, micaceous, some clay binder, no feldspar.
			Abundant honey brown quartz gravel to 5mm, vfu to vcU sand, few feldspar.
			Grayish white sandy CLAY to clayey SAND, vfL to vcu, micaceous, no feldspar
48	0		Light gray SAND & GRAVEL, some binder, vfL to vcU, gravel to 1cm.
			Blue green sandy CLAY, some clay stringers and layers, vfL to mU sand, subangular to subrounded, micaceous, garnetiferous.
			Coarsening downward but still clay rich.
50	0		

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Potomac Formation Continued

Depth Feet	Run/ Box	Lithology	Description
50	0		Blue green SAND & GRAVEL in a CLAY binder, gravel to 7mm.
			White to blue gray SAND & GRAVEL in a CLAY binder, vfL to vcU, garnetiferous, chloritized quartz, few feldspar grains.
52	0		SAND & GRAVEL, some clay binder, micaceous, garnetiferous.
			White clayey SAND to sandy CLAY, fL to mL sand.
		B&G	Dark brown to black SAND & GRAVEL with with black and greasy SILT interlayer, carbonized plant fragments, micaceous.
			Green clayey SAND to sandy CLAY, vf mica flakes, vfU to vcU.
54	0		Brown and white SAND & GRAVEL, gravel to 7mm, fL to vcU, micaceous, few garnets.
			Green CLAY PALEOSOLS.
			Green, red, gray with a trace of white CLAY PALEOSOLS.
56	0		Gray and red CLAY PALEOSOLS.
			Chocolate brown CLAY PALEOSOLS.
			Gray to white sandy SILT/CLAY to silty clayey SAND, vfL to vcU, some gravel to 6mm, some kaolinized feldspar.
58	0		Pale green SAND & GRAVEL, gravel to 6mm, subangular to rounded gravel, chloritized quartz, abundant kaolinized feldspar.
			White sandy CLAY
			Gray brown SAND & GRAVEL, gravel to 8mm, kaolinized feldspar.
60	0	B&G	Black and greasy highly micaceous SILT in a dark gray clayey SAND.

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Potomac Formation Continued

Depth Feet	Run/ Box	Lithology	Description
60	0		Dark gray clayey SAND coarsens downward to a pale green chloritized SAND.
			SAND & GRAVEL, gravel to 8mm, chloritized quartz, subangular to subrounded, abundant feldspar some are kaolinized.
62	0		
			5G4/1 dk green gray CLAY.
			Pale green quartz SAND & GRAVEL, chloritized grains, fL to vcU, subangular to subrounded, abundant feldspar grains.
64	0		
			5YR4/3 red brown with green mottles CLAY PALEOSOLS.
66	0		
68	0		Gray CLAY PALEOSOLS, sandy, micaceous.
			Lt gray to white sandy SILT/CLAY to clayey/silty SAND, very micaceous, vfL to cU sand with silt/clay binder.
70	0		

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Depth Feet	Run/ Box	Lithology	Description
70	0		Lt gray to white sandy CLAY to clayey SAND, vfU to cL, with chloritized quartz.
			Lt gray SAND, little to no binder, fL to vcU some vcU feldspar grains, trace of orange quartz grains.
72	0		
			Lt gray to bluish white sandy CLAY to clayey SAND, vfL to vcU, subangular to subrounded.
			Pale greenish white silty SAND, vfL to vcU, subangular to subrounded, abundant garnet.
74	0		
			Pale greenish white silty/clayey SAND, vfL to cU, subrounded to rounded, some chloritized quartz grains.
			2.5YR2.5/1 reddish black CLAY with vf mica flakes, some vf sand.
76	0		
			White to lt gray CLAY grading downward to sand at 768'.
			White SAND with some rounded rock fragments, vf gravel, vfL to vcU sand, vf mica flakes, trace of feldspar, most kaolinized to clay, abundant vcU to small gravel size quartz grains.
78	0		
			Quartz SAND, vfU to vcU, angular to subrounded, some garnets, many grains are chloritized, trace of feldspar.
		BOH	Bedrock Boring terminated at 797.83 feet on 10-14-2010 in Bedrock.
80	0		

Potomac Formation

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