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Instructions for Borehole Sampling				ECN No.	
Name	MSIN	Text With ALL Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only

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1. EDT 609156

2. To: (Receiving Organization) Distribution			3. From: (Originating Organization) Earth & Environmental Technical Services			4. Related EDT No.: N/A		
5. Proj./Prog./Dept./Div.: RW/ID2			6. Cog. Engr.: K. D. Reynolds/K. A. Lindsey			7. Purchase Order No.: N/A		
8. Originator Remarks: APPROVAL/RELEASE						9. Equip./Component No.: N/A		
						10. System/Bldg./Facility: N/A		
11. Receiver Remarks:						12. Major Assm. Dwg. No.: N/A		
						13. Permit/Permit Application No.: N/A		
						14. Required Response Date: ASAP		

15. DATA TRANSMITTED					(F)	(G)	(H)	(I)
(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	Approval Designator	Reason for Transmittal	Originator Disposition	Receiver Disposition
1	WHC-SD-EN-AP-181		0	Instructions for Borehole Sampling	N/A	2	1	

16. KEY					
Approval Designator (F)		Reason for Transmittal (G)		Disposition (H) & (I)	
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)		1. Approval 2. Release 3. Information	4. Review 5. Post-Review 6. Dist. (Receipt Acknow. Required)	1. Approved 2. Approved w/comment 3. Disapproved w/comment	4. Reviewed no/comment 5. Reviewed w/comment 6. Receipt acknowledged

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2	1	Cog. Mgr. J.W.Cammann/M.G.Gardner	<i>JWC</i>	11/11/94	H6-084						
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Document Number: WHC-SD-EN-AP-181, REV. 0

Document Title: Instructions for Borehole Sampling

Release Date: 11/14/94

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SUPPORTING DOCUMENT		1. Total Pages 9
2. Title Instructions for Borehole Sampling	3. Number WHC-SD-EN-AP-181	4. Rev No. 0
5. Key Words Geologic Sampling Soil Sampling Analytical Sampling	6. Author Name: K.D.Reynolds/K.A.Lindsey Signature Organization/Charge Code 8H250/RW1D2	
7. Abstract		
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8. RELEASE STAMP		
<div style="border: 1px solid black; padding: 10px; text-align: center;"> OFFICIAL RELEASE BY WHC DATE NOV 14 1994 35 Station 21 </div>		

INTRODUCTION

Geologic systems generally are complex with physical properties and trends that can be difficult to predict. Subsurface geology (including stratigraphy, mineralogy, geochemistry) exerts a fundamental control on groundwater flow and contaminant transport. Federal and state regulations (Title 40, Code of Federal Regulations (CFR) Part 265.90(a), 40 CFR 265.90(c)(1)(ii), 40 CFR 265.90(2)(i), 40 CFR 265.91(a), Washington Administrative Code (WAC) 173-303-282, WAC 173-303806, WAC 173-200-080, WAC 173-160-050) require characterization of subsurface hydrogeologic conditions to allow for defensible calculations of flow and transport conditions, and to assess the impacts of the geology on groundwater and vadose zone conditions.

The primary source for direct observation of subsurface geologic information is a borehole. However, direct observations from a borehole essentially are limited to the diameter and spacing of boreholes and the quality of the information derived from the drilling. Because it is impractical to drill a borehole every few feet to obtain data, it is necessary to maximize the data gathered during limited drilling operations. A technically defensible balance between the customer's data quality objectives and control of drilling costs through limited drilling can be achieved with proper conduct of operations.

This report presents the minimum criteria for geologic and hydrologic characterization and sampling that must be met during drilling. It outlines the sampling goals that need to be addressed when drilling boreholes, and the types of drilling techniques that work best to achieve these goals under the geologic conditions found at Hanford. This report provides general guidelines for: (1) how sampling methods are controlled by data needs, (2) how minimum sampling requirements change as knowledge and needs change, and (3) when drilling and sampling parameters need to be closely controlled with respect to the specific data needs. Consequently, the report is divided into two sections that center on: (1) a discussion of basic categories of subsurface characterization, sampling, and sampling techniques, and (2) guidelines for determining which drilling and sampling techniques meet required characterization and sampling objectives.

Data quality objectives for subsurface characterization in any given project are established in characterization plans, work plans, data sheets, and similar documentation. The guidelines outlined in this report are used to determine the appropriate drilling and sampling techniques necessary to achieve the stated objectives. This document is not intended to be used to establish the data quality objectives for a specific project, only to aid in achieving them.

SUBSURFACE SAMPLING

Subsurface sampling is the main driving force of any characterization/drilling program. Sampling during drilling can be grouped under general categories which relate to the data needs for a given project. These categories range from no sampling, to basic or gross scale sampling, to intermediate sampling, to detailed analysis. Depending on data needs and project objectives, different scales of sampling effort are necessary. Successful implementation of sampling, regardless of the type, is highly dependant on input from an experienced drilling engineer and the project geologist.

Sampling Categories

The basic rational, typical techniques, and situations for the different categories of sampling are outlined below:

1. No Sampling - In some situations a projects data quality objectives may not involve geologic/physical sampling. Under these circumstances it would be appropriate to not do any geologic sampling.
2. Basic Sampling - Basic sampling (also referred to as gross or grab sampling) is used to provide enough information to identify basic geologic features such as formation, member, and unit and to differentiate between major sediment types or facies. Under some circumstances, these samples also may be adequate for chemical and radiological screening. Basic samples typically consist of cuttings bailed from the borehole and/or removed from an air/fluid circulation stream. The geologist's ability to accurately interpret the geologic features represented by particular cuttings is directly dependant upon drilling factors such as lagtime, hole cleaning, over drilling, and excessive milling. Generally, basic sampling is done in areas were sufficient data already exists to meet project data needs, in areas were only confirmation of the most basic geologic information is needed, and as a scoping tool in areas where reconnaissance or exploratory drilling is being conducted.
3. Intermediate Scale - Intermediate sampling is done in areas where a moderate amount of data already exists and where project goals call for specific, limited technically defendable sampling. Such objectives include, but are not limited to, verification of stratigraphic picks and facies types previously interpreted from cuttings and the collection of certain types of samples for specific analysis. Commonly, this type of characterization may require that samples be called for anytime there is a need to establish a level of control or defensibility not attainable with drill cuttings alone. Appropriate techniques for this sampling would include split spoons, sonic core barrel methods, and rotary coring.
4. Detailed - Detailed sampling, generally in the form of coring (e.g., rotary or sonic), usually is undertaken in areas where there is little

or no accurate data to meet project data quality objectives. These needs range from physical data about formation geologic properties that is only obtainable from intact samples to specific sample requirements for analytical evaluation. Specific sample techniques are controlled by the types of samples needed and the geologic conditions (e.g., cemented vs. uncemented, or gravelly vs. silty).

Establishing Sampling Categories

Determining which sampling category is used during any given project is dependant on a clear definition of the data quality objectives. In order to determine the objectives, one must first evaluate the nature and quality of existing data applicable to a given project. Based on this evaluation specific project data needs (e.g., the data quality objectives) are identified and the requirements for borehole sampling established.

The existing data and data needs are usually identified in characterization and work plans written prior to the beginning of a drilling project. Data sheets for individual wells take the information from the work and characterization plans to identify drilling and sampling goals (e.g. sample categories) for a well, establish the type of sample required, and indicate the approximate sample intervals. The project geologist, in consultation with the client, is responsible for determining overall sampling needs, and the effectiveness and reliability of the samples retrieved during the project.

The following discussion lists two examples of how sampling categories are used in combination to achieve specific data quality objectives:

1. For many projects adequate well coverage and data to address most, if not all, data quality objectives already exists. In these situations new drilling and sampling will center on correlating the geology encountered in the new wells to preexisting wells, and sampling will consist dominantly of category 2 methods. Some category 3 sampling to verify stratigraphic/facies picks will be undertaken if it is determined to be necessary. Occasionally, category 4 sampling will be undertaken if site specific data quality objectives must be met. In some cases if no additional information is required no sampling would be needed (i.e., sampling category 1).
2. For some projects little or no data applicable to the project objectives may exist. Consequently, drilling for this project relies heavily on sampling categories 3 and 4 in order to establish site specific data and tie the new site to other, previously characterized locations.

During any given project, the scale of the sampling effort is likely to change. For example, as data from drilling is assimilated, the level of the sampling effort may decrease (e.g., from categories 4 to 3) as data quality objectives are met. Another example of conditions under which a

scale-down in sampling may occur is in situations where drilling conditions are such that intact cores (category 4) simply can not be obtained. Under many circumstances a scale up in sampling effort is necessary. This typically happens when previously unforeseen geologic conditions are encountered during drilling and it is determined that more detailed sampling is necessary to meet the project data quality objectives.

SAMPLING TECHNIQUES

Sampling techniques and sampling categories are closely related and, in practice, essentially inseparable. Inappropriate sampling techniques for the geologic conditions encountered limits the ability to recover a representative sample, and consequently leads to decreased accuracy and reliability in the analysis performed. During subsurface geologic sampling, data needs and formation conditions must be considered when determining the appropriate drilling/sampling techniques to collect the required data.

Tables 1 and 2 compare various field and analytical samples to different drilling techniques to show which techniques are more appropriate for the kind of analysis planned. These comparisons take the form of a yes (Y) or no (N) to show whether a particular drilling method has a reasonable chance of acquiring a sample adequate for a given analysis or data need. In many cases the yes/no response is marked by a number that corresponds to a footnote following the tables. These footnotes list basic considerations that need to be taken into account for the specific drilling techniques and sampling requirements. These considerations center on two fundamental areas of critical importance to the acquisition of representative subsurface samples: (1) geologic or formation conditions, and (2) drilling technique and rig operation.

Table 1 lists the descriptive parameters that well site geologists commonly consider when providing general subsurface geologic descriptions. In addition, the parameters listed in Table 1 generally represent the minimum data requirements necessary for the field geologist to identify subsurface samples that meet sampling criteria established in the characterization plans and data sheets.

Table 2 lists analyses typically done on borehole samples and compares them to the various drilling techniques. This table shows that a number of drilling techniques are not appropriate for the types of analysis requested for many of the samples collected on the Hanford Site. The table can be used to establish the drilling technique needed to acquire samples for the analyses required to meet the project data quality objectives. If the drilling criteria for the specific analyses outlined in Table 2 cannot be met, the data quality objectives for the project will not be met. In such cases the selected drilling/sampling techniques need to be reassessed.

Table 1. Field Criteria

	Auger, solid stem	Cable Tool, HT	Cable Tool and Auger, spl. spoon, core barrel	Sonic core barrel and split spoon	Air Rotary, cuttings	Air Rotary, split spoon	Mud Rotary	Rotary Coring
Relative Moisture (see EII 9.1)	N ²	N	Y ¹	N ⁹	N	Y ⁶	N	Y ¹
Cements (Ca, Si, Fe)	Y ¹⁰ /N ²	Y ¹¹	Y ⁴	Y	Y ^{3,10}	Y ⁴	Y ¹⁰	Y
Colors (<1 ft)	N ²	N	Y	Y/N ⁵	Y ^{3,12}	Y	Y ¹²	Y
Lith., textures (1 phi)	N	N	Y ⁴	Y/N ⁵	Y ^{3,12}	Y ⁴	Y ¹²	Y
Lith., bedding (2 ft) ¹⁴	N ¹³	N ¹³	Y	Y/N ⁵	Y ³	Y	N-uncon. ¹² , Yconsol.	Y
Mineralogy (+5%)	N ²	N ^{6,12}	Y ⁴	Y	Y ³	Y ⁴	N	Y

Explanations of parameters used in Table 1.

Cements - The basic nature and characteristics of cementing agents need to be identified because of their fundamental control on hydrologic properties such as high and low flow zones. Cementing agents typically present include calcium carbonate, silica, ferro-magnesium oxides, and muds.

Colors - Color changes are often an important indicator of unit and facies changes. As such they need to be readily identified. Changes in color need to be identified within 1 foot of actual occurrence.

Lith., textures - Lithologic texture essentially refers to grain size. Grain size variations down to 1 phi have to be identifiable in the sand to small pebble range.

Lith., bedding - Resolution of stratigraphic features within 2 ft of their actual occurrence is necessary to identify facies changes important to hydrologic flow systems and to pick major formational and stratigraphic unit contacts.

Mineralogy - In fine-grained sand and larger sizes the field geologist should be able to identify major mineral types (e.g. basalt, quartz, feldspar, micas, etc.) and estimate abundance by volume to $\pm 10\%$. Below the fine-grained sand size geologist cannot identify mineralogy by hand lens.

Table 2. Analytical Criteria

	Auger, solid stem	Cable Tool, HT	Cable Tool and Auger, spl.spoon, core barrel	Sonic core barrel and split spoon	Air Rotary, Cuttings	Air Rotary, split spoon	Mud Rotary cuttings	Rotary Coring
Moisture	N	N	Y ¹	N ⁹	N	Y	N	Y ^{1,7}
CaCO ₃ , Cements	N ²	N	Y	Y	Y ³	Y	Y	Y
Sieve	N ²	N	Y ⁴	Y	N	Y ⁴	N	Y
Specific Gravity	N	N	Y ⁴	Y/N ⁵	N	Y ⁴	N	Y
Density, Porosity (>3.5")	N	N	Y ⁴	Y/N ⁵	N	Y ⁴	N	Y
Unsat & Sat K (>3.5")	N	N	Y ⁴	Y/N ⁵	N	Y ⁴	N	Y
Moisture Retention	N	N	Y ⁴	Y/N ⁵	N	Y ⁴	N	Y
XRD Min.	N ²	N	Y ^{4,8}	Y	Y ³	Y ^{4,8}	Y ³	Y
XRF Geochem.	N ²	N	Y ^{4,8}	Y	Y ³	Y ^{4,8}	Y ³	Y
Thin Sec.	N ²	N	Y ^{4,8}	Y	Y ³	Y ^{4,8}	Y ³	Y
Chemical	N ²	N	Y	Y - nonvol. N - volatile	N	Y	N	Y ⁷

Density, Porosity and Unsat. and Sat. K - A minimum 3.5 inch diameter sample needs to be acquired on sample runs less than 10 feet long. If sampling runs longer than 10 ft are being done sample minimum diameter will be 2.5 inch.

Footnotes to Tables 1 and 2.

1. If fluid not added.
2. Mixing of cuttings with borehole wall during transport of cuttings up auger flights limits use.

3. Assumes a reasonable lag time of no more than 20% over calculated lag time based on an uphole velocity of 6000 ft/min, less than 1 ft of slough in the borehole, absence of significant overmilled material, and position of drill bit is as per manufacturers spec for the system in use.
4. Best applied in unconsolidated to consolidated muds and sands. Will not work well in gravelly or cemented deposits because driving the sampler into these sediment types will break and fracture formation materials. Anything recovered from the sampler under these circumstances will not be intact.
5. Sonic core barrel samples in many cases show evidence of having expanded at some point during drilling (e.g. rig will drill 5 ft but sample will fill a 10 ft of core barrel). Expansion commonly results in the destruction of bedding features. As yet, the cause and extent of expansion is not clearly understood, making it difficult to determine if many samples are representative of true formation conditions. Whether or not expansion has occurred needs to be determined in order to decide if a yes or no applies.
6. Fines are generated while driving the sampler because of abrasion and breaking of formation materials. Also have to have clean boreholes to insure recovery of representative sample.
7. Mud rotary core may alter.
8. In crystalline and homogeneous sedimentary rocks should work well. In heterogeneous deposits have to assume an ability to separate grains broken during drilling from those that are unbroken. As a consequence, this may only be usable in gravel-poor formations and uncemented strata.
9. Temperatures measured during drilling are too high for reliable estimates of moisture content and sampling of volatile materials.
10. Can use observed differences in drilling responses, e.g. chattering, torque, changing advance rate, bucking, etc; to determine at least the presence or absence of cement.
11. Gross scale observations (changes over several feet), based on advance rate. Small scale features such as individual beds and changes over just a few feet are difficult to identify.
12. Gross scale resolution of such things as beds over several feet thick and formation and member contacts is based on first arrivals of a particular parameter. Small scale features such as individual beds and changes over just a few feet are difficult to identify.
13. The exception is formation and high contrast member/unit contacts that are based on major, large scale parameters such as very different colors, textures, etc.

14. Resolution of bedding is incumbent upon whether or not features are actually present. Knowing this is dependant upon good regional and facies knowledge typically acquired from outcrop analogues and intact cores.

CONCLUSIONS

Accurate subsurface characterization is dependant on the acquisition of representative geologic samples. To acquire such samples, the appropriate drilling technology must be matched to a projects stated data needs. These data needs, presented as part of the data quality objectives, should be found in planning documents (such as the characterization plan, drilling plan, and data sheets) for any given project. The guidelines outlined in this report can then be used by the project staff, in consultation with the client, to determine the specific drilling techniques necessary to obtain the stated data quality objectives for subsurface characterization.