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6th Semester, Mining Engineering

MNT – 603
Sub: - Mining Geology
Chapter – Sampling

GEOLOGIC SAMPLING METHODOLOGY

A. SAMPLE COLLECTION TECHNIQUES

The importance of representative (unbiased) sampling cannot be overemphasized. Of primary concern is the assurance that the geologic sampling scheme is representative of the permit area and adequately characterizes, both vertically and horizontally, the overburden strata that will be disturbed during mining.

Geologic logs should be prepared in a manner, which identifies the position and thickness of all geologic strata and geologic-related features (e.g., faults, fractures, water-bearing units). ASTM affords some additional guidance, which is published as standards D 5782, dealing with air rotary drilling, and D 2113, dealing with rock core drilling. Various other ASTM standards are available which describe logging techniques (D5434), terminology (D 653), and decontamination practices (D 5088). Likewise, other acceptable drilling and sampling methods and standards are available but should be documented as to the sources used. Section D of this chapter will address quality control and assurance issues as it relates to overburden sampling techniques. This section provides for a brief overview, which describes geologic sampling techniques commonly used in West Virginia.

1. Air Rotary Drilling

Standard-circulation air rotary drilling is the most common method of collecting drill hole data in the oil and gas industry in West Virginia. Because it is hard to get a representative sample of a specific overburden using this technique, the use of air rotary drilling is usually discouraged for most coal related geologic sampling. Although rotary drilling can provide reasonably representative geologic samples for thicker geologic strata, a cooperative driller and a good sampling technique are needed. Therefore, the use of air rotary drilling should always be to supplement previously drilled continuous core samples, which provide undisturbed rock material. Such could then be used in determining the need and placement for any supplemental air rotary drilling information.

In air rotary drilling environments, without the cooperation of a good driller, cross contamination or loss of cuttings could result from washing and/or sloughing of cutting materials back into the borehole. Likewise, without increasing the air pressure and allowing for adequate purging of the hole at defined intervals, cuttings recovery and mixing of cuttings will become more of a problem as the hole gets deeper. The size of the cuttings that are delivered to the surface is normally ½ inch or less in diameter; and the cuttings are delivered at a rate relative to the pressure of the compressed air, the moisture and competency of the material being drilled, and the degree of fracturing of the rock. The air compressor on the drill should be able to deliver an air velocity of between 3000 and 4000 ft/minute, although lower velocities can still deliver cuttings (ASTM D-2113-99). Standard-circulation methods should be confined to consolidated materials, especially if the unconsolidated materials are wet or moist. If the drilling will intercept areas of extensive geologic fracturing (e.g., longwall subsidence areas) or a mine void, reverse circulation techniques will probably be needed. Otherwise, cuttings will be lost to the fractures and voids resulting in little, if any, return occurring. Reverse circulation will also allow the collection of representative samples from unconsolidated materials (e.g., spoil, coal refuse, and alluvial materials) even when the hole is wet.

Cuttings

Size: Cuttings should normally be of a size that allows for identification of certain rock characteristics (e.g., rock type, grain size, mineralogy). If cuttings are too small (rock flour), it is often because the driller is applying too much pulldown, not enough pulldown, or the bit is dull. A knowledgeable driller can normally control the size of the cuttings exiting the borehole.

Return: A lack of cuttings return will normally mean insufficient air flow or dampness in the borehole. When it is first noticed that the cutting return has stopped or significantly declined, the driller should immediately stop drilling, raise the bit off the bottom of the hole, and blow the hole clean. If the hole is extremely deep, an increase in air flow may be required. If the hole is damp, cuttings may be adhering to the wall of the borehole and the drill rods, which will have to be physically washed out by adding water. If these cuttings are not recovered, acid- or toxic-forming zones can easily go unrecognized. Therefore, the cuttings must be recovered to provide information on the lost interval and to prevent the contamination of an underlying sample. Cuttings recovery will usually return to normal once water is injected into the borehole or ground-water influx occurs. If water or foaming agents are added, the depth at which cuttings loss were identified should be recorded.

Procedures

1) Prior to sampling, the underside and aprons of the drill table must be cleaned to remove any previously drilled soil or rock material that might result in contamination of the samples. A periodic inspection and cleaning during drilling should also occur.

2) Determine how the depth of drilling can be easily monitored. This can be done through physically marking the drill stem or by counting links in the drive chain (once the number of links/feet has been determined). Some drill rigs have the mast marked into feet and tenths of feet, making depth determination possible by noting the downward progression of the drill head or upper kelley.

3) For the most accurate cuttings recovery, a diverter (often incorrectly referred to as a blowout preventer) or equivalent technology should be used. The diverter is installed by first drilling through the soil and unconsolidated materials using a larger diameter bit (e.g., 8 3/4 inch) than the remainder of the hole. Once bedrock is encountered, the drill stem is removed and a PVC or metal casing (e.g., 7 inch) installed. The diverter can then be placed on top of the casing and the drilling can continue, using a smaller diameter bit (e.g., 4 inch). All cuttings will then be passed through the diverter and exit at one point. This will result in much better cutting recovery and prevent contamination of samples by material sloughing back into the annulus. Figure III-1 illustrates the use of a cuttings diverter to obtain samples. Should a diverter not be available, the installation of the casing alone will help minimize contamination, although cuttings recovery will be less accurate. There is now technology using a floating head control that provides similar cuttings control.

If no form of casing is installed in the borehole, the cutting pile must be constantly removed to prevent sloughing into the borehole, which would result in an unacceptable mixing of cuttings. Likewise, should ground water be encountered, cuttings will most likely be washed back into the borehole and mix with other intervals. In any instance, cuttings should be removed only when the borehole is being blown out and not during actual drilling advance. Sampling should not typically be performed from the dust collector (cyclone separator) bins because of the contamination and mixing of sample intervals.

4) Once drilling begins, sampling should be continuous and in 1-foot intervals, unless a lithology change warrants a smaller increment. Samples can later be combined for analytical purposes according to the guidance given under Section B.2 of this chapter.

5) Cuttings can be collected in a bucket or on a shovel placed under the dust apron or at the exit to the cuttings diverter (see figure III-1).

6) The drill should advance in 1-foot intervals with the borehole being blown out after each increment. This will purge the annulus of any potential sources of contamination before the next interval is drilled.

7) Cuttings should be promptly placed in sample bags (plastic or cloth), or other suitable container, and labelled with a permanent marker or indelible ink. Labels should include at a minimum:

- Site name or project
- Drill hole number
- Drilling date(s)
- Sampling interval (e.g., 12-13 feet) or identification number keyed to a log book kept by the geologist

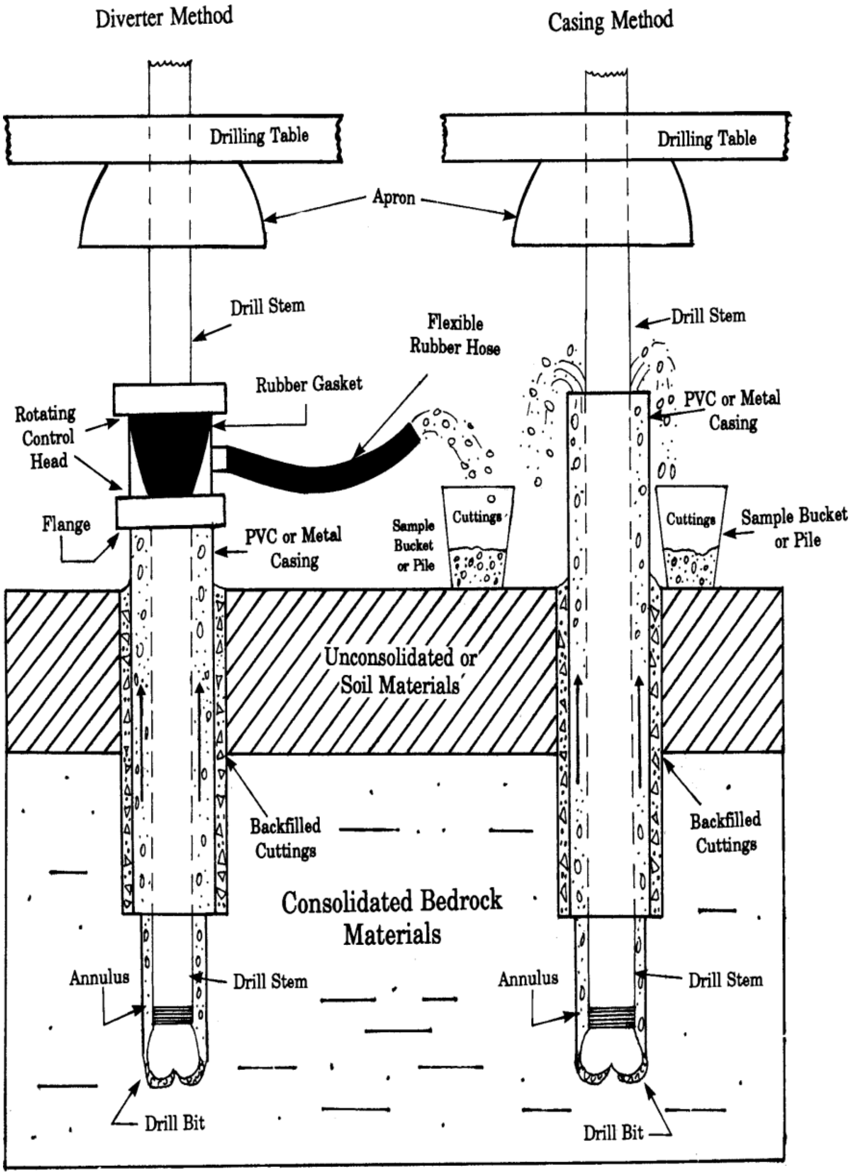


Figure III-1. --Diagram of Diverter and Casing for Collection of Rotary Cuttings

8) Samples are then ready to be composited for laboratory analysis. See section C.2 of this Chapter for discussion of compositing methods.

9) The more common advantages and disadvantages of air rotary drilling are as follows:

Advantages:

a. Relatively inexpensive
b. Equipment readily available
c. Provides relatively representative samples when correctly collected
d. High penetration rates compared to continuous core drilling
e. Estimates of water yield from various formations can be made

Disadvantages:

a. Mixing of cuttings in borehole results in a lack of accurate definition of critical lithologic intervals (e.g., splits, partings)
b. Lag time between the actual drill penetration and cuttings reaching the surface may result in misidentifying the actual strata depth
c. Provides disturbed samples
d. Should be supplemented with geophysical log to allow for correlations with core holes, to identify discrete zones in the stratigraphy, and to provide accurate depths to strata
e. Provides no intact solid material large enough for engineering tests
f. Standard circulation methods do not deliver a representative sample in unconsolidated materials (e.g., spoil, refuse, alluvial materials).

2. Continuous Core Drilling

Core drilling is the preferred method of collecting overburden samples because the lithologic units can be directly related to their original stratigraphic position. It is also the required drilling method when performing various engineering tests, such as rock durability studies. The sample is collected as a continuous cylinder, which normally ranges between 5 and 15 feet long, and 2 to 4 inches in diameter, depending upon the dimensions of the core barrel. The resultant core produces a sample that will facilitate detailed petrologic or petrographic analysis of lithology and mineralogy. Structural features such as faults, fractures, and brecciated zones can often be identified in cores that would be lost using conventional air rotary techniques. Cores can also be used to determine bedding characteristics and identify fossil zones that may be useful in correlation between drill holes. Because most continuous core drilling in West Virginia is done by contract drillers experienced in core recovery, the primary concern of the field geologist at the site is to ensure that the core is properly logged.

Procedures

1) Determine how the depth of drilling can be easily monitored. This can be done through physically marking the drill stem or by counting links in the drive chain (once the number of links/foot has been determined). Some drill rigs have the mast marked into feet and tenths of feet, which make depth determination possible by watching the downward progression of the drill head or upper kelley. More sophisticated equipment now monitors depth of penetration through real-time devices on the drill itself.

2) Once drilling begins, the unconsolidated soil and subsoil material will normally require hand sampling because they will not be recovered in the core drilling process. Therefore, the depth from the land surface to the top of the actual core should be promptly recorded on the geologic log and in the drilling record to prevent any confusion.

3) After each core is retrieved from the borehole it should be immediately examined for any core loss. Irregularly shaped core and ground or brecciated zones are indicators of rock strata subject to being "washed out" during the core drilling operations. The stratigraphic position of these zones should be recorded.

4) After core loss zones have been identified, the actual amount of recovery made during each drilling segment should be made. Recovery is expressed as the percentage of actual core return, as compared to the actual depth drilled. To get a valid figure for recovery, both the distance cored and the core length must be carefully measured and not be left to casual driller observations. The percentage recovery can be calculated using the following equation:

$$\text{percent recovery} = \frac{\text{length of core recovery}}{\text{distance drilled}} \times 100$$

A core recovery calculation should also be performed for the entire drill hole using the cumulative length of recovered core compared to the total hole depth. If the recovery is less than 95 percent, the hole should probably be re-drilled to obtain better recovery.

5) Next, a generalized geologic log should be constructed, which identifies any core loss and general stratigraphic and lithologic information. A more detailed geologic log of the core can be more easily accomplished at a protected location like the mine office or laboratory.

6) When core materials will be subjected to subsidence-related engineering tests, the immediate roof, floor, and coal should be preserved to maintain the original moisture content. This is accomplished by tightly wrapping these materials in plastic or inserting them into a core tube. In both cases, the samples are then sealed with wax to prevent any desiccating effects until a moisture content can be determined by a qualified laboratory.

7) The core should then be placed in properly designed core boxes for transport to a protected location. Core boxes, with dividers spaced according to the core diameter, made of wood, plastic, or corrugated cardboard, offer excellent protection during transport and storage of these samples. The top and bottom of the core in each box segment should be plainly marked to avoid any confusion over the original stratigraphic position. The thickness and position of all core loss should also be identified. The outside of each core box should be marked to include a minimum of the following information:

- Site name or project
- Drill hole number
- Drilling date(s)
- Core depth interval represented in each box (e.g., 50-60 feet)
- Box number and total number of boxes in the entire core sample (e.g., box 2 of 5)

8) Field splitting of cores for chemical analysis is discouraged unless the entire core is split and each half is retained intact until logging is completed. A more accurate determination of the core characteristics can best be made under the controlled conditions of a field office or laboratory. Once a thorough geologic log has been prepared and the physical properties documented, a better assessment of how the core should be split and composited can be made. This is especially true when engineering tests are to be performed which require a minimum size sample for analysis. This will also prevent the loss of valuable core, which may be needed in the future.

9) Samples are then ready to be composited for laboratory analysis. See section C.2 of this Chapter for discussion of compositing methods.

10) The upper 20 feet may require a spilt spoon or shovel to obtain.

11) Running coal or other parts of the section in a separate lab can lead to a large source of error.

12) The more common advantages and disadvantages of continuous core drilling are as follows:

Advantages:
a. Provides a continuous stratigraphic record
b. Provides a sample suitable for engineering testing of the rock
c. Provides a relatively undisturbed sample

Disadvantages:
a. Equipment not readily available, unless drilling is contracted
b. Slower and more expensive to operate
c. Requires good techniques to ensure proper core recovery
d. Occurrence of discrete water-bearing zones will be somewhat obscured because of the use of water during the drilling process
e. Requires a water source for drilling

3. High wall Outcrop Sampling

Highwalls and outcrops are not specifically recognized in the geologic regulations as an acceptable source of geologic information. However, this type of sampling may be acceptable if it can be demonstrated to be representative of the permit and adjacent area. Samples must be collected from un-weathered material in high walls and outcrops, which may be difficult to obtain in older exposures. Therefore, a “fresh” section of the high wall should be exposed to obtain a representative sample. This would require a trench to be cut through the exposed weathering zone using a backhoe or hand equipment. An analysis of the paste pH should be performed to determine if the collected samples are actually fresh.

Sampling should be continuous and must evenly represent the entire interval being sampled. High wall sampling may be used to augment samples obtained from air-rotary or core drilling but generally should not be used as the primary source of geologic information. However, high-walls can be of considerable value for determining general stratigraphic relationships needed to describe the permit and adjacent area.

Procedures

1) The face of the high-wall in the area to be sampled must be cleaned of all debris down to the lowest strata to be sampled. Talus piles must be removed in the sampling area to insure that sloughing of this material will not contaminate the samples being extracted near the bottom of the column.

2) Once the area has been cleaned, a channel must be excavated through the existing outcrop or high-wall to expose fresh, un-weathered material. This channel must extend down to the lowest strata to be sampled.

3) Samples can then be taken using a rock hammer, a pick, or a chisel. Where harder, more resistant material is exposed, a gasoline-powered jackhammer or other percussion equipment may be required. A backhoe or bucket loader may also prove to be useful in some instances.

4) Sampling should be continuous and in 1 foot intervals unless a lithology change warrants a smaller increment. Samples can later be combined for analytical purposes, according to the guidance given under Section B.2 of this chapter.

5) Sampling should always start at the bottom of the high-wall or at the lowest interval to be sampled and work up. This will allow the debris and rock material from each successive sampling interval to fall on a previously sampled zone. Thus, the potential for contamination is minimized.

6) Samples can be collected on a shovel, in a sample bag, or in a bucket located at or immediately below the interval being sampled. The use of a catch cloth at the base of the high-wall is discouraged because falling rocks from the sampling zone will normally dislodge other materials, which have the potential for contamination of the sample.

7) Once collected, samples should be promptly placed in sample bags (plastic or cloth), or other suitable container, and labelled with a permanent marker or indelible ink. Labels should include at a minimum:

- Site name or project
- Sampling site location and/or number keyed to a geologist's log book
- Sampling date
- Sampling interval (e.g., 2-3 feet above coal seam to be mined) or identification number keyed to a log book kept by the geologist

8) A stratigraphic log or column should be constructed for the sampling site to show the thickness and relative position of all geologic strata. Photographs of the high wall or outcrop exposure should be taken to document the area stratigraphy at the sampling site.

9) If the entire vertical column of overburden material is inaccessible or incomplete, the total column may be collected by combining lateral movement with vertical sampling, thus establishing a step-like sampling pattern across the high wall. If this technique is used, the location of each lateral sampling point should be documented along with the interval represented at each point.

10) Samples are then ready to be composited for laboratory analysis. See section C.2 of this Chapter for discussion of compositing methods.

11) The more common advantages and disadvantages of high-wall sampling are as follows:

Advantages:

a. Normally the least expensive sampling technique

b. No special equipment normally needed, although percussion equipment or mining machinery might be required

c. Allows identification of lithologic and stratigraphic features lost in rotary methods.

d. Allows a determination of both horizontal and vertical variations in stratigraphy.

Disadvantages:

a. Potential for weathered samples

b. Exposed strata do not extend through the entire geologic column proposed for disturbance (e.g., second-cut contour mines)

c. Normally no access to the strata below the lowest coal seam proposed to be mined

d. Potential for biased samples caused by rock hardness (hard, resistant sandstones may be nearly impossible to get a continuous sample from hand-held equipment).

e. Potential for injury resulting from falling rock materials sloughing off the high wall.

f. Difficult access

B. WELL AND SAMPLE LOGGING TECHNIQUES

This section briefly describes the methods to properly locate a drilling or sampling site and how to properly log the resultant stratigraphy. The section describes both geologic and geophysical logging techniques and the types of information, which might be recorded under each method.

1. **Site Location**

An accurate location of all drilling or sampling sites is imperative. The location affects all aspects of the mine plan development and the potential environmental impacts, which could result from it. For underground mines, an incorrect elevation could result in a gravity discharge or subsidence problem that was not anticipated. Incorrectly sited drill holes could also result in unnecessary permit boundary revisions. Therefore, all drill hole or sampling site locations should be accurately determined by one of the following methods, or other methods, which afford a similar level of detail:

- Topographic map and properly calibrated survey altimeter
- Standard surveying methods
- Remote sensing techniques such as the global positioning system

The use of a topographic map for locating a drilling or sampling site is unacceptable unless adequate points of reference are available to precisely locate the position. If this technique is used, the elevation should always be determined using a survey altimeter, which has been calibrated to the nearest bench mark or point of known elevation. In the steep slope areas of West Virginia, approximating the elevation of a drill hole on a topographic map can result in errors of over 40 feet.

The most widely used method for accurately locating a drilling or sampling site is a standard survey which will position the site with relation to another point or points with known elevations and coordinates. Once the survey is complete, the position of the site can be transferred to a standard 1:24,000 scale topographic or larger scale (i.e., 1" = 400') map as needed.

The use of remote sensing techniques provides an alternative to the more conventional surveying techniques. Global Positioning System (GPS) is a satellite-based navigation system and provides an accurate location in most terrains. The system has been fully operational since 1995 with 24 operational spacecraft, a ground control segment, and user equipment providing navigational services worldwide. Today the GPS space segment operates continuously with between 24 and 27 satellites. An advantage of GPS is that the location of the drill hole can be digitally saved along with attribute data about the drill hole (e.g. drilled depth, water level, pump down rate, water quality parameters, etc.). Information collected can be downloaded and displayed on a topographic or mine map. Sub-meter accuracy for latitude and longitude coordinates can be obtained by post-processing the data. Error in the vertical direction is 3 times greater than the horizontal. To optimize accuracy, the software in the GPS units can be configured to record positions only when strict criteria are met. However it would be prudent to check critical elevations against a calibrated engineering altimeter. GPS receivers are available from numerous vendors including, but not limited to, Magellan Systems Corporation, Trimble Navigation, Corvallis, Garmin, and others.

2. **Geologic Logs**

Documentation of the characteristics of rock or spoil materials collected during drilling or highwall sampling is accomplished by the use of written records called "geologic logs". These geologic logs should be developed in the field, during actual sample collection, by a qualified and competent geologist or other sufficiently trained and experienced person. However, the level of detail can be greatly enhanced by examining the collected samples in more detail once they have been transported to a more controlled environment such as a mine office or a laboratory. A graphical illustration can also be used to help clarify the relative thickness and position of the geologic strata. The use of a "drillers log" is discouraged. Drillers logs are often completed by individuals who do not have the background to adequately characterize soils and overburden materials in the detail needed for surface mining applications. An example of a geologic log is shown in figure III-2.

When logging a drill hole or highwall, at a minimum of the following information should be recorded:

a. *Basic site information*

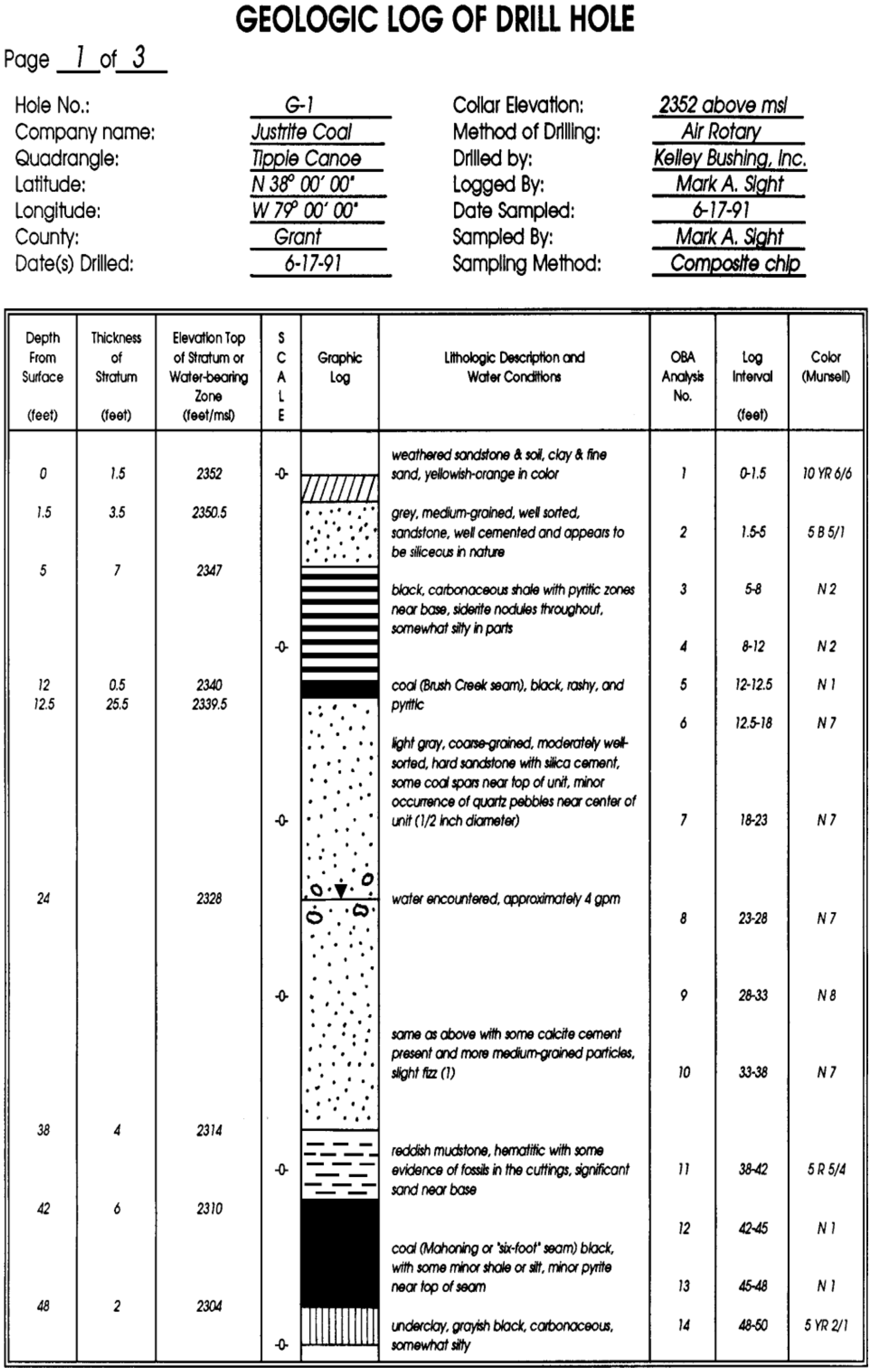
- *Drilling and sampling date(s)*
- *Drilling and sampling methods (detailed description)*
- *Site identification information*
- *Drillers name*
- *Type of drilling equipment (type, model, bit size, core barrel diameter and length, etc.)*
- *Name of geologist or person logging the hole and collecting samples Location information including:*
    - √ *Elevation*
    - √ *Latitude and longitude*
    - √ *Position relative to other drill holes or sampling locations*
    - √ *State, county, quadrangle*
    - √ *Project or company name*

b. *Physical information*

- *Depth and thickness of all strata*
- *Description of all strata: Some of the information listed below will not be available from all types of drilling or sampling methods. For instance, geologic fractures, faults, and bedding characteristics will not be evident from rotary cuttings.*
    - √ *Lithology*
    - √ *Color*
    - √ *Grain size*
    - √ *Identifiable mineralogy*
    - √ *Cementing agents*
    - √ *Fossils (if any)*
    - √ *Streak*
    - √ *Sorting*
    - √ *Bedding (e.g., massive, fissile)*
    - √ *Structural features (e.g., faults, fractures)*
    - √ *Degree of weathering*
    - √ *Effervescence in dilute acid (10% HCl)*
    - √ *Name of coal seam or marine zone*

c. Drilling information

- *Occurrence, depth, and estimated yield of any water-bearing zones*
- *Occurrence, depth, and estimated loss of any water-loss zones*
- *Any loss of cuttings or core (record both depth of occurrence and amount lost)*
- *Documentation of any geophysical or other well logging or testing procedures performed*



GEOLOGIC LOG OF DRILL HOLE

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Hole No.:	G-1	Collar Elevation:	2352 above msl
Company name:	Justrite Coal	Method of Drilling:	Air Rotary
Quadrangle:	Tipple Canoe	Drilled by:	Kelley Bushing, Inc.
Latitude:	N 38° 00′ 00″	Logged By:	Mark A. Sight
Longitude:	W 79° 00′ 00″	Date Sampled:	6-17-91
County:	Grant	Sampled By:	Mark A. Sight
Date(s) Drilled:	6-17-91	Sampling Method:	Composite chip

Depth From Surface (feet)	Thickness of Stratum (feet)	Elevation Top of Stratum or Water-bearing Zone (feet/msl)	SCALE	Graphic Log	Lithologic Description and Water Conditions	OBA Analysis No.	Log Interval (feet)	Color (Munsell)
0	1.5	2352	-0-		weathered sandstone & soil, clay & fine sand, yellowish-orange in color	1	0-1.5	10 YR 6/6
1.5	3.5	2350.5			grey, medium-grained, well sorted, sandstone, well cemented and appears to be siliceous in nature	2	1.5-5	5 B 5/1
5	7	2347			black, carbonaceous shale with pyritic zones near base, siderite nodules throughout, somewhat silty in parts	3	5-8	N 2
			-0-			4	8-12	N 2
12	0.5	2340			coal (Brush Creek seam), black, rashy, and pyritic	5	12-12.5	N 1
12.5	25.5	2339.5				6	12.5-18	N 7
			-0-		light gray, coarse-grained, moderately well-sorted, hard sandstone with silica cement, some coal spars near top of unit, minor occurrence of quartz pebbles near center of unit (1/2 inch diameter)	7	18-23	N 7
24		2328		▼	water encountered, approximately 4 gpm			
						8	23-28	N 7
			-0-			9	28-33	N 8
					same as above with some calcite cement present and more medium-grained particles, slight fizz (1)	10	33-38	N 7
38	4	2314						
			-0-		reddish mudstone, hematitic with some evidence of fossils in the cuttings, significant sand near base	11	38-42	5 R 5/4
42	6	2310				12	42-45	N 1
					coal (Mahoning or "six-foot" seam) black, with some minor shale or silt, minor pyrite near top of seam	13	45-48	N 1
48	2	2304			underclay, grayish black, carbonaceous, somewhat silty	14	48-50	5 YR 2/1
			-0-					

Figure III-2.--Example of Geologic Log

A complete discussion of the physical characterization of the geologic samples is provided in Section A of Chapter IV of this handbook. To assist in logging, Appendix A provides a summary of commonly used geologic terms and their standardized abbreviations, while Appendices B and C provide standardized rock and map symbols.

3. Geophysical Logs

Since "modern" geophysical logging was first introduced in 1927, the uses of these techniques have been largely confined to oil and gas exploration. However, in recent years, the use of these well logging techniques, for ground water and mining applications, has become more common. The primary advantage is that, although expensive, geophysical logging is generally cheaper and faster than drilling and subsequent analysis of voluminous amounts of continuous core. Another advantage is that geophysical logs provide continuous objective records with values that are consistent from well to well and from time to time, if the equipment is properly calibrated and standardized (Keys and MacCary, 1971). In contrast, the more common geologic or drillers logs are subjective, greatly dependent upon personal skills and terminology, and are limited to the characteristics being sought. Geophysical logs can later be reinterpreted if additional information is needed which wasn't originally an issue of concern.

Geophysical logs are useful in that they provide a detailed account of the subsurface geology and relative position of various rock strata. These logs also provide information on the lithology, geometry, resistivity, formation-resistivity factor, bulk density, porosity, permeability, moisture content, specific yield of water-bearing zones, and can be used to help define the source, movement, and chemical and physical characteristics of ground water (Keys and MacCary, 1971). Furthermore, geophysical logging is the only method which can be used to obtain information from an existing well, for which there is no data, and from wells where casing prevents sampling.

Although geophysical logging of a well or borehole provides information that is both cost- effective and detailed, most well drillers, engineers, and geohydrologists lack the skills required to properly conduct and interpret such data. Also, some small, independent logging companies may lack the training to properly conduct and calibrate the logging equipment. Therefore, if geophysical logging is proposed, a qualified logging company, with the ability to interpret the resultant data, should be contracted.

To obtain the maximum benefit from a geophysical well-logging program, the following steps should be followed:

- Plan the logging program based on the type of data needed.
- Carry out drilling operations in a manner that will produce the most uniform hole, with the least disturbance to the subsurface environment possible.
- Take representative geologic and water samples during drilling, using existing logs as a guide, if possible.
- Insist on quality logs made with calibrated and standardized equipment. Make sure that equipment is calibrated for coal and not hard rock use.
- Avoid older analogue recorder equipment occasionally used by small, independent logging companies. Digitized computer recorders provide much more precise definition than the older drum recorders.

- Logs should be interpreted by a qualified individual, who has a thorough understanding of the principles and limitations of each type of logging technique.

Geophysical well-logging techniques can be broken down into two broad classifications - passive and active logs. Passive logs record or measure the natural energy or other characteristics emitted by the rock or rock-fluid system (e.g., gamma and spontaneous potential logs). Active logging equipment emits or stimulates the rock or rock-fluid system with energy while it measures and records the subsequent response to this energy (e.g., neutron, induction, or acoustic logs). Other techniques such as thermal, caliper, gravimetric, or magnetic logging are rarely used for coal-mining related activities. However, such data may be available from oil and gas well logs and may provide some useful information on area stratigraphy and correlation.

In the West Virginia coal fields, most geophysical logging will be restricted to nuclear or radiation methods. The primary reason is that radioactive logging methods can be done through well casings and can be performed on dry or water-filled holes. Most electronic logging techniques require the drill hole to be filled with water, or drilling fluid, to pass the electrical currents between the electrodes. For surface mine applications, these fluid-filled type conditions would normally exist only in deeper drill holes or in areas where drilling is below the level of the major surface water drainage systems (regional water table). Table III-2 provides a brief summary of the various geophysical logging techniques and the properties which they investigate.

C. BASIC DRILLING PATTERNS AND SAMPLING INTERVALS

Lithology and chemical properties can vary over short distances as a result of factors such as depositional environments, leaching and oxidation (i.e., weathering), and structural influences. Thus, all drilling and sampling should be designed to identify conditions that will influence the mining and reclamation plan. Of primary concern is the assurance that the analyses provide an accurate representation of the permit area and adequately characterize, both vertically and horizontally, the overburden strata that will be disturbed during mining. The following section provides guidance on the recommended procedures for designing a geologic sampling program.

LOGGING METHODS	PROPERTIES INVESTIGATED	GEOLOGIC PURPOSE	COMMENTS
ELECTRICAL			
Self Potential (SP)	Records change in naturally occurring electrical potential in the wellbore, as a function of depth	Determination of lithology, stratigraphic correlation, "shaliness" or clay content of strata, permeability	Requires the wellbore to be filled with a water-based drilling mud; wellbore must be uncased; SP curve not as responsive in well-cemented, well-indurated rocks
Resistivity	Natural electrical resistivity of wellbore materials	Determination of lithology, stratigraphic correlation, effective porosity, permeability, true resistivity, water level, salinity of formation water, grain size, and extent of fluid saturation	Requires uncased wellbore; wellbore must be water or fluid filled
Conductivity (induction)	Conductivity of wellbore materials resulting from an induced electrical current	Same as above	Can be run in wet or dry wellbores; wellbores must be uncased
RADIATION			
Gamma	Natural radioactivity of wellbore formations	Determination of lithology, stratigraphic correlation, "shaliness" or proportion of shale	Can be run in wet or dry wellbores; can be run in cased or uncased holes; sensitive to speed of tool; arkosic sandstones can be misinterpreted as shales; log will never give the exact same curve over a given stratigraphic interval because of the random nature of the gamma ray emissions
Gamma-Gamma (density)	Density of wellbore formations, as determined by an induced radioactive source, which emits gamma radiation and photons into the wall of the borehole	Determination of lithology, bulk density, total porosity, cavities, water level	Can be run in wet or dry holes; can be run in cased or uncased holes
Neutron	Indicates the intensity of radiation (gamma rays or neutrons) produced when wellbore formations are bombarded by an induced neutron (radioactive) source	Determination of lithology, porosity, water level, moisture content	Can be run in wet or dry holes; can be run in cased or uncased holes;
OTHER			
Sonic (acoustic)	Compressional seismic wave propagation in wellbore formations by an induced sonic energy transmission	Total porosity, bulk density, general stratigraphic correlations, primary and secondary permeability	Requires an open, water- or fluid-filled borehole
Caliper	Diameter of borehole	Location of fractures, casing or wellbore erosion, some lithology and stratigraphic information	Can be run in wet or dry holes; can be run in cased holes only if looking for ruptured or eroded casings

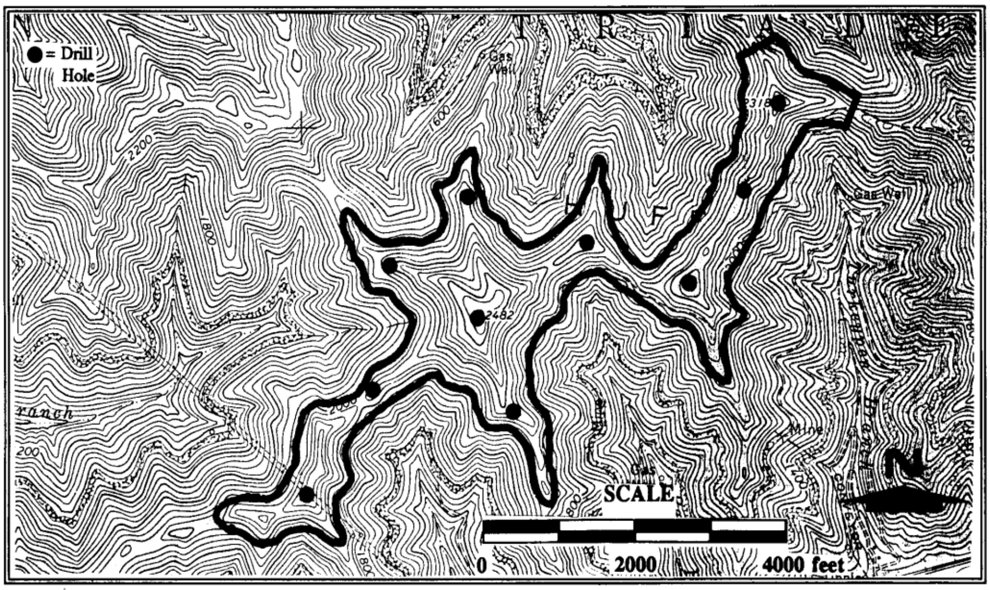
Table III-2.–Summary of Common Geophysical Logging Techniques

1. Horizontal Spacing

Spacing of overburden sample locations is determined largely by areal and site-specific conditions. Recommendations for drill hole spacing range from as close as 200 feet (Dollhopf, et al., 1981) to a maximum of about 2/3 of a mile (Sobek, et al., 1978). Other sources (Sutton, et al., 1981) and (Brady and Homberger, 1989) recommend a grid pattern with spacing of 160 and 100 acres. Based on extensive field investigation and permit data the WVDEP recommends a drill hole spacing of 2000 feet with a minimum of at least two drill hole samples.

In smaller areas, two drilling/sampling sites are still needed to define spatial variability in stratigraphy and geochemistry along with providing control points for the construction of a geologic cross section, however one the two drill holes could come from an adjacent permit sites. However, it must be remembered that this rule of thumb is only a general indicator of the number of drill holes needed for a site.

Topography and site-specific permit geology information may increase or decrease the actual number of drill holes which might be required. Complex or variable geochemical and stratigraphic conditions necessitate more intensive sampling than where overburden properties are consistent over large areas. Based on site-specific equivalent information (discussed in chapter VIII) and regional trends, less drilling and analytical data may be necessary. Likewise, in areas with high stratigraphic and geochemical variability, significantly more data may be necessary. For example, studies performed in Pennsylvania (Tarantino and Shaffer, 1998) showed that for mine sites where acid mine drainage was a potential problem, drill hole spacing became closer, averaging between 15.5 and 18.8 acres of mining disturbance per hole. However, in this same study, it was stated that 30% to 40% of Pennsylvania applications are not required to submit overburden analysis because of the availability of equivalent predictive data. The following sections provide the recommended drilling patterns for various surface mining scenarios.



EXAMPLE

An optimum drilling pattern for a mountaintop removal and a cross-ridge mining operation is provided in Figure III-3a. These patterns are laid out along topographic highs while maintaining a spatial distribution adequate to represent the entire permit area

An optimum drilling pattern for an area mine is provided in Figure III-3a. Drill hole placement is controlled primarily by topography, although actual distances between drill holes does not exceed 1,000 to 2,000 feet. Where possible, holes should be arranged in a grid pattern, ensuring that all overburden strata have been accounted for.

a. Contour Mining and the Mining of Dipping Beds

In other areas, the strata are horizontal, but the topography slopes steeply, or the topography is level but the strata are dipping. In both cases, the topography cuts across the strata at an appreciable angle, and the strata are truncated. In such cases, the drilling pattern should be selectively designed to assure that the drill holes will penetrate the complete overburden section which will be disturbed by mining. While the previous formula might be a general indicator of a minimum number of drill holes, a long narrow permit area might result in more holes/acre being required because of the linear distance involved.

Drilling and sampling should be conducted along the strike or following the topographic contour. Drill holes should be evenly spaced approximately 2,000 feet apart. One row of drill holes is normally adequate for permit areas that are less than about one-quarter mile (about 1,300 feet) wide. Sampling sites should normally be located immediately adjacent to the maximum anticipated highwall so that all strata proposed for disturbance are properly characterized.
However, it may be important to also drill or sample in areas of low or average cover to provide for representative analysis and data collection in areas where a discontinuous zone or strata may be present (or missing) or to consider the effects of weathering on the overburden chemistry (Tarantino and Shaffer, 1998).

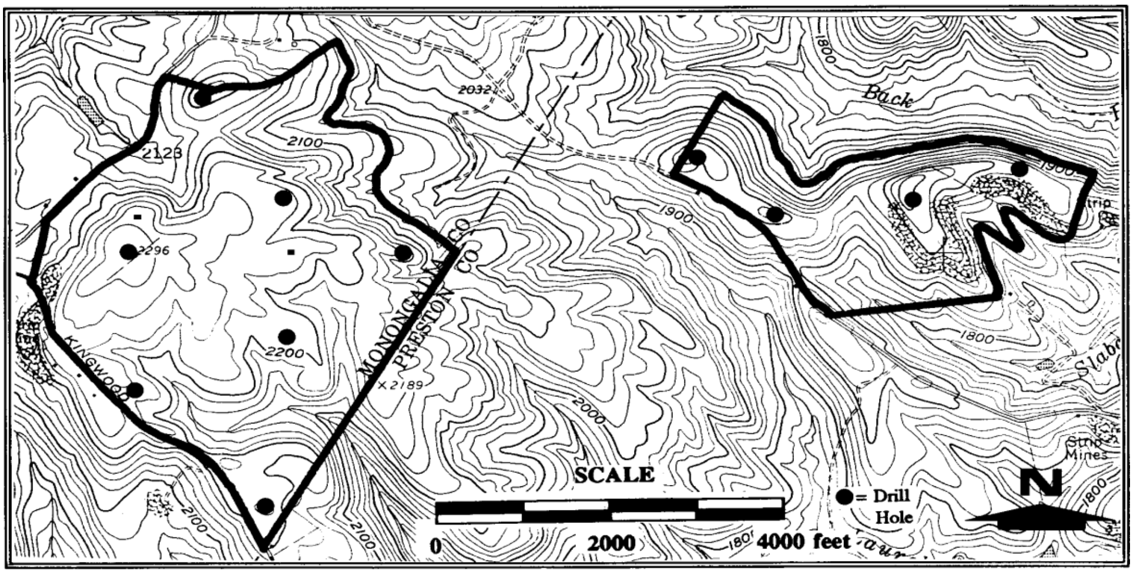
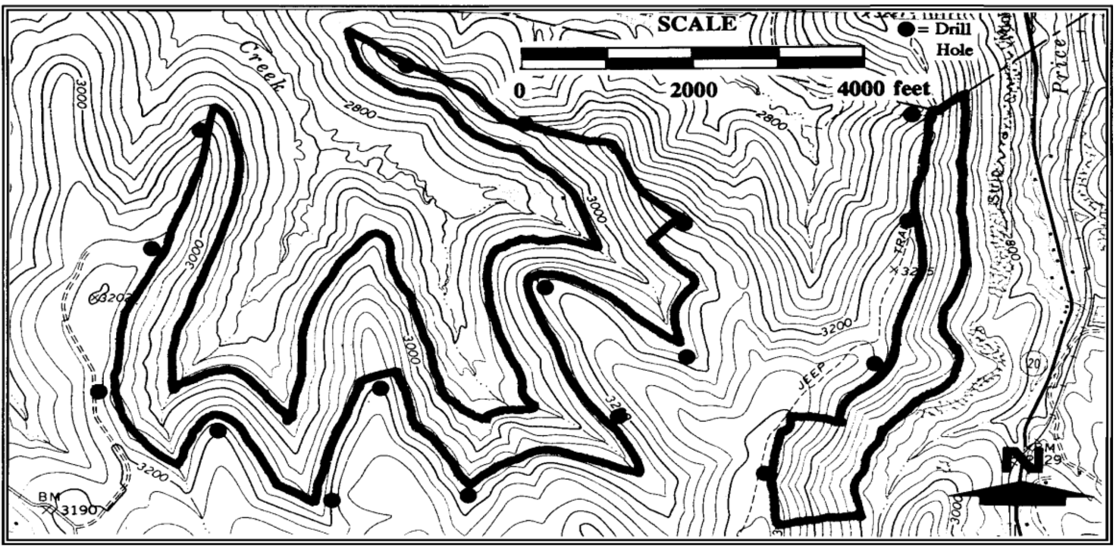


Figure III-3b2. --Example Drilling Patterns for Area Mining Operations



A drilling pattern for contour mining is shown in Figure III-3b

b. Mountain top Removal and Area Mining

In areas of the coalfields where recovery of multiple seams can be accomplished by the mountaintop removal or area mining, spacing of sampling sites will be more random and topographically controlled. In order to ensure that all strata proposed for disturbance have been sampled, drilling will normally be conducted at the topographic high points. Because no remnant highwall will be left, drill holes must be spaced so as to penetrate the maximum thickness of overburden while maintaining the best spatial distribution possible. However, as stated in the previous section, it may be important to also drill or sample in areas of low or average cover to provide for representative analysis and data collection in areas where a zone or strata may be missing or to consider the effects of weathering on the overburden chemistry (Tarantino and Shaffer, 1998).

c. Underground Mining

In the West Virginia coalfields, underground mining operations are usually conducted where the strata are relatively horizontal, even though the topography in the area may range from gentle to steeply sloping. Samples should be collected from areas to be disturbed, including the entry, access, and facilities areas. The drilling/sampling pattern will vary with the type of underground operation being proposed.

1) Face up area:

For faceup areas associated with drift mines, the drilling/sampling pattern should be similar to Figure III-3a For faceup areas associated with slope and shaft mines, one drill hole in the immediate vicinity is recommended. All overburden to be disturbed by the face up must be sampled.

Figure III-3b1.--Example of a Drilling Pattern for Mountaintop Removal Operations

2) Shadow areas:
In addition to geologic samples for surface disturbances associated with the underground mining operation, samples should also be collected and analyzed from the roof, floor, and coal from the area of projected workings. The overburden should be sampled to at least 10 times the height of the coal seam mined in order to account for water traveling through subsidence features cracks. If a mine pool is predicted after mining, the overburden sampling should correlate to the maximum hydrologic head of the mine pool. The drilling/sampling pattern should be laid out every 2000 feet, similar to that outlined in Figure III-3b2. for the entire projection of underground workings. In particular roof and floor materials that could contribute to water quality in the mine and should be sampled.

2. Vertical Composites and Analysis Intervals

Once rock samples have been properly collected, through drilling or highwall sampling, the materials may be composited to reduce the number of samples actually analyzed. However, the samples must be composited in a manner that does not sacrifice the accuracy in determining the potential of the strata to produce acidity or alkalinity. It is recommended that, before samples are composited, the applicant evaluate the entire stratigraphy of the entire rock column for those lithologies that have the greatest potential to produce acid/toxic conditions. The following guidelines are generally applicable:

- Dark gray and black strata, especially the finer grained lithologies, are more likely to be a problem because:
    1. they are more likely to contain significant amounts of very fine grained, reactive pyrite;
    2. they may be particularly high in trace toxic elements; and
    3. gray and black colors indicate that the rock has not been oxidized and may contain the original amounts of pyrite and other important constituents.
- Strata exhibiting colors such as browns, yellows, and reds, have normally been oxidized and weathered. They contain less pyrite and other troublesome constituents than their unweathered counterparts.
- Sandstones that weather to an olive green or greenish yellow color may be almost white or very light gray in fresh cuttings or core samples but may rapidly weather to an olive green color once the material is exposed by mining. Therefore, these type materials could go undetected unless supplemented by highwall or outcrop data. Such sandstones often generate significant acidity and iron despite the acid/base account which often shows it as a relatively benign rock unit.

This simple technique may help to isolate potential problem zones that should be composited on smaller intervals. However, it should be noted that color only suggests the chemical character of a lithology, and other chemical and physical analyses must be conducted for an adequate evaluation. In fact, many dark gray to black shales may prove to be quite alkaline once analyzed. Therefore, these techniques are simply general indicators to assist in compositing intervals for analysis.

Once potentially problem zones have been marked, the geologic samples (rock cores, cuttings, or highwall materials) should be divided into composite intervals, as illustrated in Figure III- 5.
Composite intervals are determined by first separating the entire overburden column into each lithologic unit down to about 10 feet below the lowest coal seam to be mined (Sutton, et al., 1981).

Each lithologic unit is then subdivided to represent maximum composite intervals of about 5 feet to identify vertical changes in geochemical properties. Lithologic units exceeding five feet in thickness should be broken into smaller composite intervals with each composite interval not exceeding five vertical feet.

> *<u>EXAMPLE</u> -- relatively consistent shale unit is 22 feet thick. This unit should be broken down into 5 composite intervals for the purpose of analyses. This could be done by compositing the shale unit into intervals of 1-5, 5-10, 10-15, 15-20, and 20-22 feet.*
>
> *However, to better balance the section, a better composite might be 1-5, 5-10, 10-14, 14-18, and 18-22 feet.*

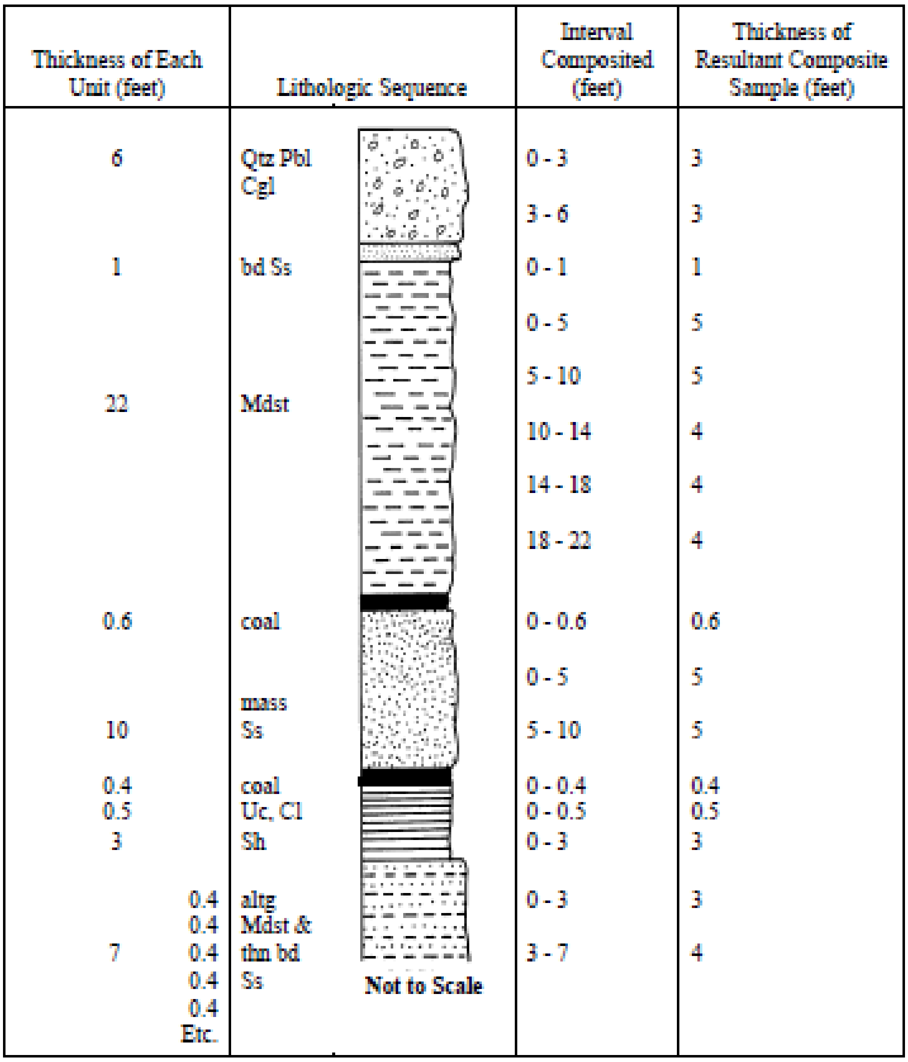
Lithologic units that are less than five feet, but more than 0.5 feet, can be combined into one composite interval for analyses. Lithologic units less than 0.5 feet are normally considered transitional zones and can be composited with the adjacent strata for geochemical analyses, unless especially significant features such as calcareous or pyritic zones are identified.

Likewise, zones of alternating lithologic units, each less than 0.5 foot in thickness can be composited unless calcareous or pyritic zones are observed. Such significant units should be analyzed separately.

It is also recommended that the 1-foot interval above and below any coal seam proposed for extraction not be composited with overlying or underlying strata despite the lithologic similarities. These zones often contain the highest sulfur strata present (Tarantino and Shaffer, 1998) on the site and may have a significant effect on the postmining water quality since groundwater flow may be in direct contact with these materials both in the underground mine workings and across the surface mine pit floor. If these zones contain high concentrations of pyrite or other reactive sulfur forms, a composite with additional zones could significantly mask the presence of such high sulfur zones. Table III-3 provides an example of such a zone being masked through the creation of a 5-foot composite interval. Had only a 5-foot composite been analyzed, the true nature of the pit floor material would have been masked and probably would not have been identified as a potentially acid-forming zone. Such an interpretation could result in an unanticipated perpetual treatment of AMD at either an underground or surface mine site.

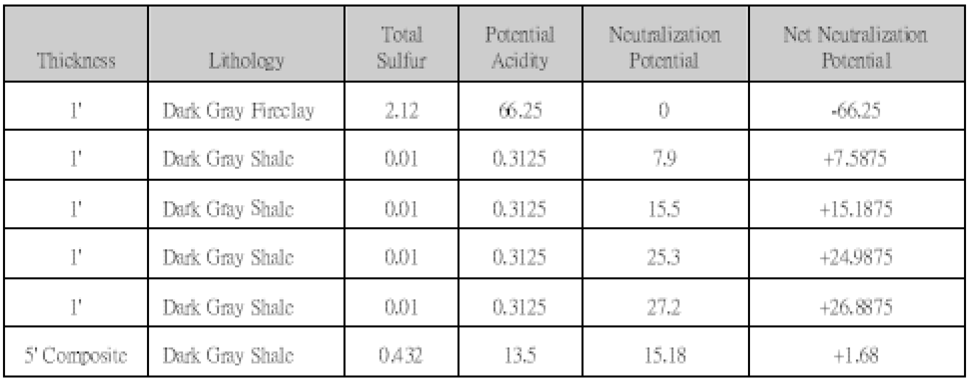
Prior to the actual combining of the identified composite intervals, samples must be dried and reduced to a relatively uniform size to allow unbiased and uniform mixing. Moist samples can cause caking, resulting in the plugging of size reduction equipment or the sample splitter. For drying purposes, an oven with the capability to maintain a temperature of 40o C and the capability to effect 2 oven volume air changes per minute is recommended. However, the air- drying procedure may also be accomplished by spreading the sample in a pan, or other suitable container, until it has dried sufficiently to crush and mix.

Rotary chip samples will normally be of a size sufficient to adequately composite without crushing. However, rock cores and highwall materials will normally require crushing to reduce the rock particles to a size suitable for compositing. Prior to the physical compositing of these geologic materials for chemical analyses, all samples should be crushed (e.g., with a jaw crusher to less than ¼-inch mesh), well mixed and split, so that one-half (or more) of each sample can be retained in case additional tests are required. Rock cores can be split longitudinally, with one-half being crushed, and the other one-half (or more) retained intact for future testing and reference.



Thickness of Each Unit (feet)	Lithologic Sequence	Interval Composited (feet)	Thickness of Resultant Composite Sample (feet)
6	Qtz Pbl Cgl	0 - 3	3
		3 - 6	3
1	bd Ss	0 - 1	1
22	Mdst	0 - 5	5
		5 - 10	5
		10 - 14	4
		14 - 18	4
		18 - 22	4
0.6	coal	0 - 0.6	0.6
10	mass Ss	0 - 5	5
		5 - 10	5
0.4	coal	0 - 0.4	0.4
0.5	Uc, Cl	0 - 0.5	0.5
3	Sh	0 - 3	3
7 0.4 0.4 0.4 0.4 0.4 Etc.	altg Mdst & thn bd Ss	0 - 3	3
		3 - 7	4

Figure III-5. –Example of Composite Intervals



Thickness	Lithology	Total Sulfur	Potential Acidity	Neutralization Potential	Net Neutralization Potential
1'	Dark Gray Fireclay	2.12	66.25	0	-66.25
1'	Dark Gray Shale	0.01	0.3125	7.9	+7.5875
1'	Dark Gray Shale	0.01	0.3125	15.5	+15.1875
1'	Dark Gray Shale	0.01	0.3125	25.3	+24.9875
1'	Dark Gray Shale	0.01	0.3125	27.2	+26.8875
5' Composite	Dark Gray Shale	0.432	13.5	15.18	+1.68

Table III-3.-- Example of dilution or masking effect by over compositing of geologic samples

If a core splitter is not available, the intact section of core can be submitted to most laboratories with a request that each sample be split and one-half retained intact. For analytical purposes, entire lengths of core should be sampled. For example: a three-foot shale unit should be split longitudinally through its entire length, crushed, mixed, and analysed. Because of the chemical heterogeneity of many sediments, selective sampling within the core (such as five inches out of a 12-inch interval as suggested by Sobek, et al., 1978) should not be used unless it can be demonstrated that the stratum is chemically homogeneous. When creating composite intervals, all zones within a given interval should be sampled proportionally so that no portion of the interval is over- or under-represented. For instance, rotary cuttings which were collected on one foot increments during drilling must be composited based in weight or volume (e.g., 1000 grams/one-foot interval). They should never be simply "mixed" together.

Once proportional amounts of material for each interval has been obtained, they should be placed in a large container for mixing. The composite sample should then be thoroughly mixed by hand or other mechanical means. Ideally, the new composite sample should then be run through a riffler (sample splitter) with one half (or more) of the composite sample being retained for future testing. Typically, laboratories will only use or need between 20 and 30 grams of total sample to perform paste pH and the net acid/base analysis. Therefore, it is more beneficial to retain the majority of crushed or split core samples for possible future testing or analysis rather than send large volumes of composited material to the lab, which will discard it.

The resultant composite interval samples should then be placed in new sample bags (cloth or plastic) and clearly marked with a permanent marker or indelible ink. Information on each composite sample should be clearly marked on the label and include at a minimum:

- Site name or project
- Drill hole number
- Drilling date(s)
- Composite interval (e.g., 10-15 feet) and/or identification numbers (eg., samples 5-10) keyed to a log book kept by the geologist
- Person responsible for constructing composite sample

For underground mine workings, only the immediate roof, floor and coal need to be sampled and analyzed for geochemical characterization, unless the operator anticipates exposing other strata during the underground mining process. However, for engineering related applications, such as subsidence prediction, additional sampling for physical and engineering properties may be required. For geochemical purposes, samples of the immediate roof and floor should not be composited and analyzed into any interval exceeding one foot in thickness. All splits and partings should also be analyzed separately from either the coal or the roof and floor materials.

For face-up areas, all strata proposed for disturbance should be sampled and composited as previously described.

Additional information, including step-by-step procedures for sampling, compositing, and storing cores, rock chips, and soil are provided in publication EPA-600/2-78-054, entitled "Field and Laboratory Methods Applicable to Overburdens and Minesoils" (Sobek, et al., 1978) along with published ASTM methods (i.e., D 5782-95, D 2113-99, D 5079-90, and D 6032-96).

D. QUALITY ASSURANCE AND CONTROL ISSUES

The intent of geologic sampling and analysis is to gain representative information for an area based on accurate and reproducible means and methods. The previous discussions were designed to provide general guidance for sample site selection and collection methods. However, prior to any geologic sampling and data collection, a clear objective of the data collection should be determined. A clear objective may be different for environmental applications than for those associated with coal reserve development, reserve estimation, or engineering/mine plan design.
In other words, the needs for determining if a coal reserve is sufficient to warrant the development of a mine site may not provide adequate geologic information to make a determination of the PHC and develop an HRP, under the West Virginia Surface Mining Reclamation Rule. Although these differences will not be discussed in this document, it should be made clear that these different objectives should be determined prior to geologic sampling so that data needs and equipment/personnel expenditures can be optimized. It is obviously more cost and time effective to plan the geologic sampling methods so that remobilization of drilling equipment will not be required. For more detailed information on the benefits of Quality Assurance/Quality Control planning, EPA has developed an approach for environmental applications called “Data Quality Objectives” (EPA, 2000). Likewise, OSM has provided some QA/QC guidance in a document called “Overburden Sampling and Analytical Quality Assurance and Quality Control (QA/QC) Requirements for Soils, Overburden and Regraded Spoil Characterization and Monitoring Programs for Federal Lands in the Southwestern United States (OSM, 1999).

With regards to accurate and reproducible means and methods, adequate information should be documented for each drilling and/or sampling site to determine the events surrounding the collection, storage, and transport of such samples to the appropriate destination or testing laboratory. Although various components of a QA/QC program have been mentioned, the following items summarize issues that should be considered and documented to ensure events and methods utilized in the geologic sampling program are accurate and reproducible, should the need arise.

Reports

During any geologic sampling, it is recommended that the following types of information be recorded and maintained for QA/QC purposes, which could arise during the development or operation of the surface coal mining operation:

a. Site conditions and personnel - The identity of all personnel which were on-site during the drilling or sampling activities and any role or involvement they may have had; information on weather conditions and any unusual events or circumstances which occurred; documentation of working hours and the timing of various events throughout the day documentation of dates, times, and locations of drilling and sampling procedures.

b. Drilling Equipment and Methods - A description of the types of drilling and/or sampling equipment utilized information on drill types (brands and models if available); bit types and size; character of any drilling fluids used; core barrel diameters and lengths; and any other support equipment used during the drilling or sampling (i.e. rotating control heads, pneumatic hammers, backhoes) from boreholes, high walls, spoil/refuse piles, or other geologic or waste material a description of how drilling and sampling equipment was decontaminated or cleaned prior to and during sampling.

c. Sample Collection - Describe how geologic materials were actually collected during drilling or sampling.

For **air rotary drilling**, describe or record of how cuttings were sampled to represent distinct drilled intervals without contamination from other intervals. Identification of what sampling intervals were used in the field and how samples were ultimately composited. A description of any lost circulation of cuttings in wet or moist zones including depth of such occurrences and how/if water or air-water mist was used to recover cuttings adhering to the drill rods and borehole walls.

For **core drilling**, describe any core splitting, size reduction and composition, along with what intervals were used for sampling and later analysis. A description of any core or fluid loss intervals experienced during drilling and the significance of such losses. Drill logs or narratives should record the depths of such occurrences.

For **high-wall, spoil/refuse, or other material sampling**, techniques used to obtain a uniform, un-weathered, and representative sample, which includes information on how it was composited to accurately represent the intended intervals, zones, or time frames (i.e. coal processing waste composites).

d. Sample Identification - A description of how samples were marked for identification in the field and during storage; the storage medium for geologic materials (wood/cardboard core boxes, plastic bags, cloth sand bags, etc.); storage location and environment prior to analysis; and a description of how samples were transported from the drill/sample site to the storage location or laboratory.

e. Sample Preparation - A description of any sample preparation methods utilized, including size reduction and/or core splitting, prior to samples being submitted to a laboratory. Document any equipment, personnel, and dates that samples were altered from those collected in the field.

f. Sample Site Location - Documentation of how individual drill sites or sample collection points were accurately located (both coordinate and elevation): description of surveying types or techniques along with personnel and dates of those conducting the surveys.

g. Other Information (if available) - A description of any unusual drilling responses or long-term delays during the drilling process information on drilling conditions relative to air or fluid circulation rates, penetration rates through various strata, pull-down or hold back pressures.

Chain of Custody

A chain of custody provides a simple method to track the geologic samples, from the time of collection through the time the sample is analysed in the laboratory. It records a basic, historical chain, listing the people that the geologic sample(s) encountered along each step. Although formal chain of custody forms may not be typically used by coal industry or engineering consultant firms, their use is highly recommended to maintain a certifiable “paper trail” concerning the geologic samples. Each time the geologic samples or materials changes hands, from the point of collection to the point of analysis, a chain of custody would have recorded the date and time, along with the identity of such samples. Most analytical laboratories have typical chain of custody forms available but the format is far from standardized. Any format is generally acceptable as long as the “chain” is preserved with documentation of the handling of the materials.