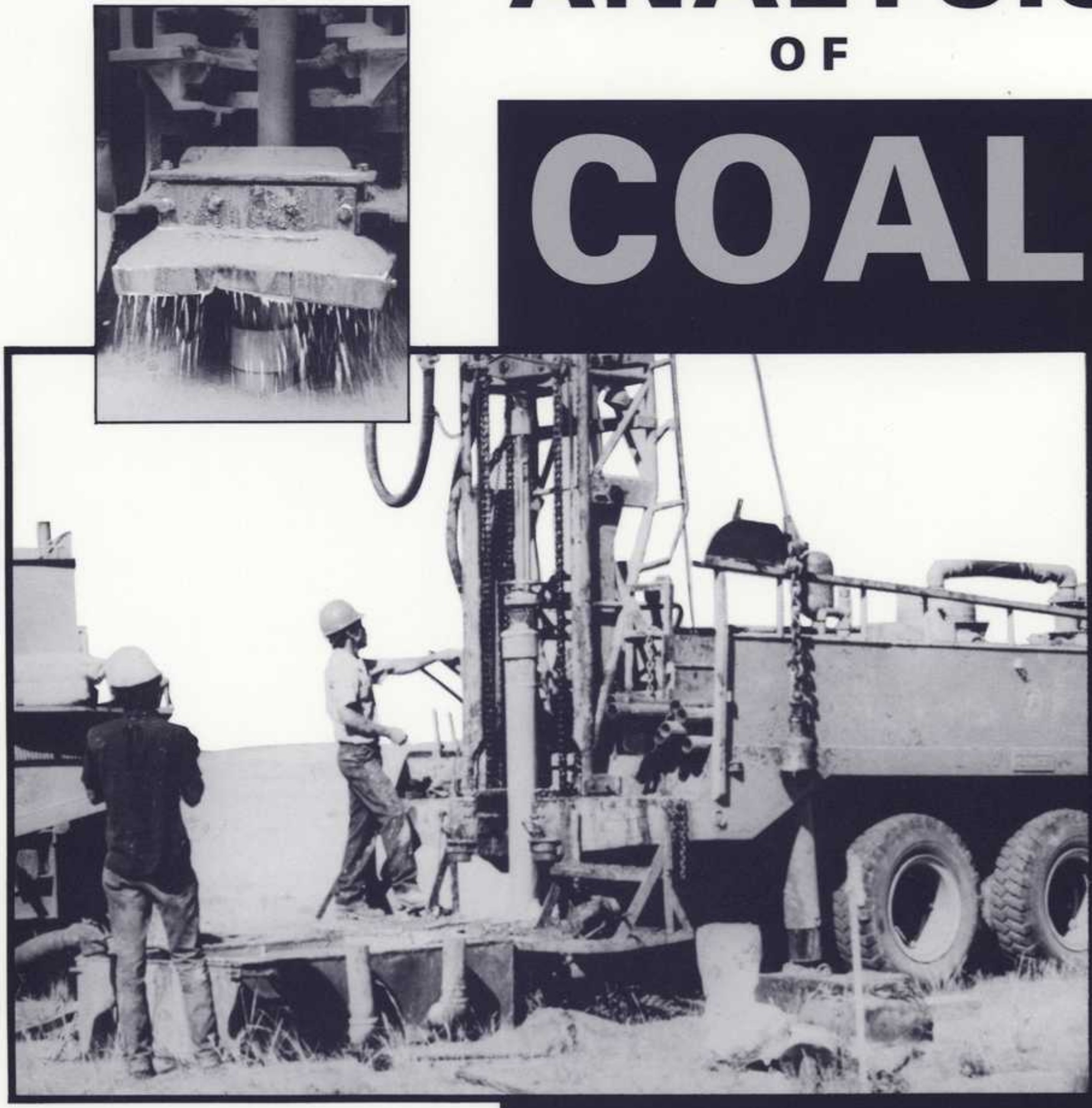
MANUAL ON

DRILLING, SAMPLING, AND ANALYSIS OF COAL



Manual on Drilling, Sampling, and Analysis of Coal

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ASTM SUBCOMMITTEES D05.18 and D05.23

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Foreword

In 1986, ASTM Committee D 225 published Standard Practice for the Collection of Channel Samples of Coal in the Mine (D 4596) which became a consensus standard for the collection of coal samples for rank determination using ASTM Classification D 388 and for other industrial purposes. At that time, Subcommittees D05.18 on Classification and D05.23 on Sampling formed a joint task group to prepare a standard practice for the collection of coal samples from core. Although obtaining coal samples from core has been in common use for decades, information regarding recent advances in drilling technology and geophysical techniques was considered to be too voluminous for inclusion in a standard. The task group therefore synthesized current practice information to produce a manual that could be used in conjunction with a standard practice for sample collection. This manual is the product of that effort which, in turn, enabled the development of ASTM Standard Practice for Collection of Coal Samples from Core (D 5192).

This publication has been prepared by the ASTM Committee D05.18 and D05.23 Joint Task Group on Coal Core Sampling through the contributions of task group members and their respective employers.

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Introduction

THREE ASTM STANDARDS are available for sampling coal: ASTM Practice for Collection of Channel Samples of Coal in the Mine (D 4596), ASTM Test Methods for Collection of a Gross Sample of Coal (D 2234), and ASTM Practice for Collection of Coal Samples from Core (D 5192). The first two standards are applicable only to existing mining operations, test pits, or transportation of coal. The last standard (approved in 1991) was written to aid in the sampling of drill cores of coal. (ASTM D 5192 is reprinted at the end of this manual.) Cores are widely used to supplement sampling coal, particularly in the exploration and development stages of coal assessments. The extraction of a representative vertical section of a coal seam by coring has proven to be an efficient method for obtaining data that can be used to describe and classify the physical and chemical characteristics of a coal reserve. Correlations of seams, determination of apparent rank, plans of mine and beneficiation plant design, estimations of reserve tonnage and environmental impacts, evaluation for coking and steam utilization, gasification, and liquefaction are some of the applications of the information generated from a drilling program.

A coal seam is difficult to sample representatively and analyze because of its variability in chemical and petrographic composition and physical properties. Although core drilling has been proven to be effective in evaluating coal deposits, the various equipment for drilling and coring as well as the various geologic and drilling conditions encountered in the drilling operations can further complicate the process of core drilling. Failure to recognize and fully understand all of the complexities of drilling and coring can result in the collection of insufficient, excessive, or, even more serious, misleading or erroneous data.

The key to a successful coring program is adequate planning. This planning should involve an interdisciplinary team that includes geologists, drillers, mining and coal utilization engineers, chemists, and financial and legal professionals. By developing an understanding of each discipline's needs, a coring program can be formulated that will provide optimum data within the project budget. Each program should have a set of clearly stated objectives and a contingency plan for unexpected situations.

Prior to a coring program, an evaluation of the region should be conducted to determine the feasibility of the project. This evaluation will probably require the use of topographic and geologic maps, aerial photographs, geologic reports, water and oil well logs, and field reconnaissance data. In addition, applicable local, state, and federal safety and permitting regulations should be reviewed for compliance. Essentially all states have some form of exploration permit that must be filed prior to a drilling program; some states also require bonding. Sufficient time to secure these approvals should be allowed.

To help the coal industry normalize procedures in coal core sampling, ASTM Committee D-5 on Coal and Coke recommended the development of a standard practice for collection of coal samples from core (ASTM Practice D 5192). In preparing this standard, a number of concepts and terms were encountered that required explanations and definitions in greater detail than was practicable within the scope of the proposed standard. Because no individual publication could be used to reference all the necessary topics, it became apparent that a reference document needed to be compiled to facilitate the drafting of the core-sampling standard. This ASTM manual is a result of that need, one identified by the ASTM Committee D-5 Core Sampling Task Group, which was charged with developing the standard practice. The Standards Association of Australia's "Guide to the Evaluation of Hard Coal Deposits Using Borehole Techniques" (AS 2519-1982) [*1,2*] was used to help formulate this document.

Because of the heterogeneity of coal and coal deposits, it is impossible to address all aspects of sampling, processing, and analyses within a single set of standard instructions. Therefore this document serves as a compilation of general guidelines for drilling coal and includes a glossary of commonly used terms. Drilling technology and sampling have been primarily developed in petroleum exploration. It is not our intent that this manual be used independently as a guide to the drilling of coal and associated strata. Throughout this publication, references are made to specific authors who deal with the subject matter in much greater detail than can be managed here. It is the responsibility of the user to modify these general guidelines, as necessary, to fit specific needs. Ideally, each company or agency may utilize these guidelines to aid in the preparation of its own field manual to standardize exploration activities.

1

Drilling Equipment

THE BEST CHOICE of drilling equipment for a particular coal exploration program depends on the site-specific objectives. The following items should be considered when outlining a project:

1. Type of evaluation phase (exploration, predevelopment, development, etc.).
2. Time frame for implementation of the program.
3. Total cost (budgeted and projected) of the exploration program including costs of permitting, abandonment, and reclamation of boreholes.
4. Extent of the project area.
5. Geological and geophysical characteristics of the project area including types of subsurface lithologies.
6. Maps of surface features.
7. Access to and mobility within the study area.
8. Depth and thickness of the coal beds.
9. Distribution of drill site locations that will best define the variability of beds of interest.
10. Amount of sample required for planned analyses.

Current drilling technology can be tailored to fit almost any set of project conditions and specifications.

TYPES OF DRILLING SYSTEMS

The types of drilling systems vary depending on the type and hardness of strata that is drilled [3]. Drilling and sampling of soft or unconsolidated strata have been standardized for geotechnical purposes: ASTM Practice for Investigating and Sampling Soil and Rock for Engineering Purposes (D 420); ASTM Method for Penetration Test and Split-Barrel Sampling of Soils (D 1586); ASTM Practice for Soil Investigation and Sampling by Auger Borings (D 1452); and ASTM Method for Thin-Walled Tube Sampling of Soils (D 1587). ASTM Practice for Diamond Core Drilling for Site Investigation (D 2113) describes equipment and procedures used in diamond core drilling for geotechnical purposes and provides basic equipment specifications in use by industry.

Four common drilling systems employed for obtaining subsurface strata samples in coal exploration and development activities are the (1) rotary and (2) reverse circulation (noncore) systems and (3) conventional and (4) wireline-coring systems. Each system is identifiable by its unique method of sample recovery. Figure 1 is a comparative diagram of these four basic down-hole sampling systems. Drilling systems are explained in more detail by Chugh [4], Whittaker [5], Acker [6], and Landua [7].

Non-Core Systems

Rotary Drill System

Rotary drilling involves the rotation of a cutting bit on the end of a string of hollow drill pipes into subsurface rocks [4,5,7]. The system uses either a pump to circulate a fluid (such as water or drilling mud) or a compressor to force air down the center of the drill pipestring, through the bit, and up to the surface along the outer walls of the string. Circulation of fluid or air serves as a medium for transporting cuttings (chips of material produced by the action of the bit) to the surface. Circulation of fluid also cools and lubricates the cutting bit. Figure 2 is an illustration of a typical truck mounted rotary drill rig system. Photographs of a truck-mounted rotary drill rig and a buggy-mounted rotary drill rig are shown in Figs. 3 and 4, respectively. Figure 5 depicts the equipment in the rotary drill assembly.

Rotary bits (Fig. 6) are commonly used to drill to a depth where actual coring can begin [7]. These bits are commonly either tricone roller or drag types or tungsten carbide insert [5]. The design and purpose of rotary drill bits is to cut a borehole through subsurface strata as opposed to recovering a competent core sample. Drag bits are best suited to penetrate soft formations [5]. Carbide button bits, a type of tricone bit, are frequently used in very hard strata.

In some cases, a bit constructed with a synthetic polycrystalline diamond (PCD) cutter may be used in place of the rollercone bit. The PCD is connected to a bit blank by various heat or solder methods. Drill bits made with synthetic diamond cutters cut rock by shear failure rather than compressive failure (as is the case with rollercone bits). Using similar drilling equipment in similar subsurface formations, less down-hole pressure is required when using synthetic diamonds than when using other rotary bits. Rotary drill rig systems should be supplemented with geophysical logging to provide a more effective exploration method for coal beds.

Reverse Circulation Drill System

The reverse circulation drilling system is a specialized system that uses the same basic type of surface equipment as the rotary drill system. The major differences between this system and the rotary drill system are the methods of sample recovery and the design of the subsurface drill rod string. Commonly, casing is set at or near the top of the strata to be drilled. A special drill-head assembly and swivel arrangement are also required.

The drill-pipe string consists of double-walled pipe attached to a rotary bit. Drilling fluid flows down the annular space between the inner and outer tubes of the drill pipe, through the drill bit, and up the center of the inner tube to the

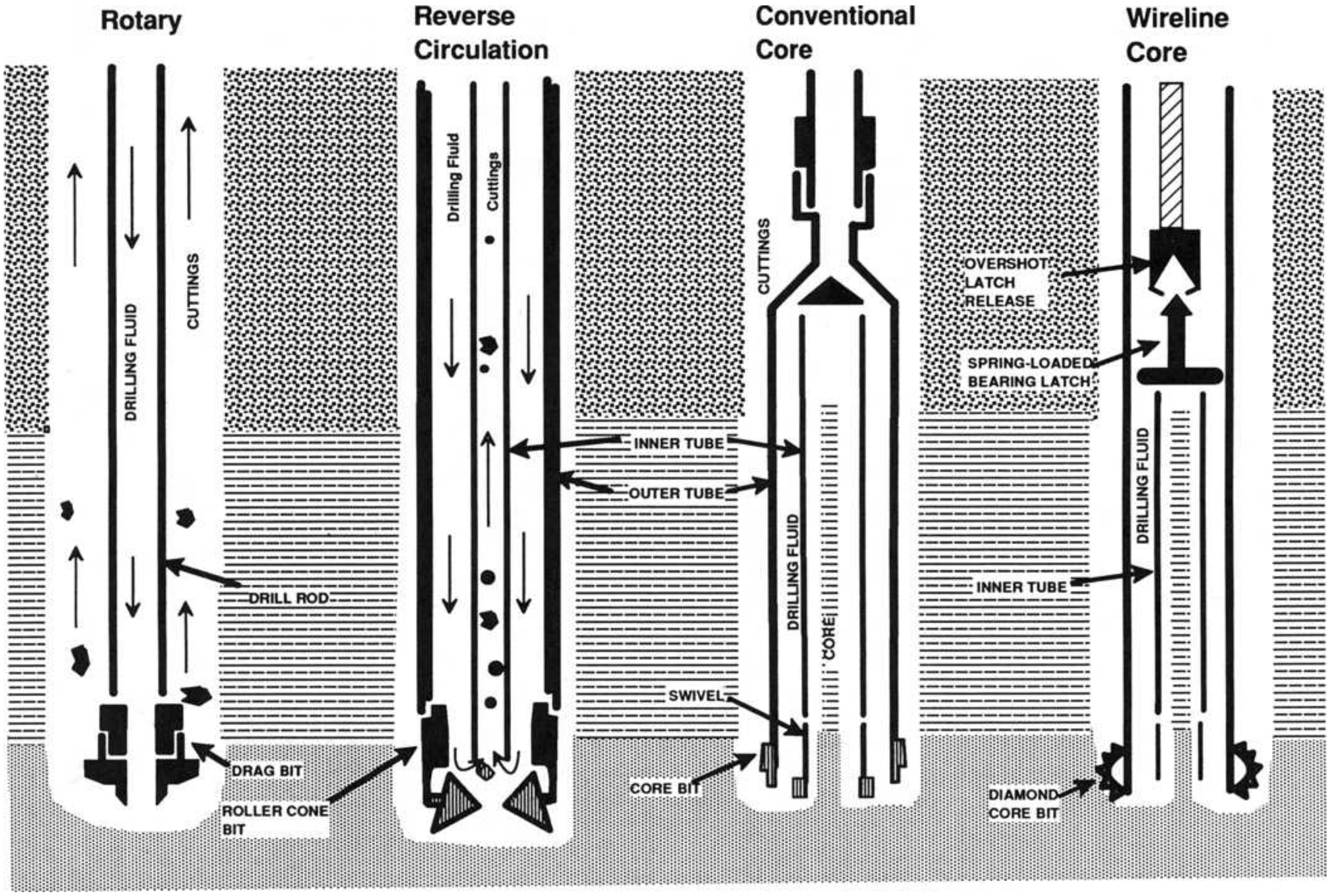


FIG. 1—Downhole drilling and core sampling systems.

surface. Basically, the fluid flow is opposite that of the rotary system (Fig. 1). Borehole returns are continuously circulated up the center of the drill string to the surface where the cuttings are caught in a screen basket and separated from the transport fluid.

This method of drilling combines the speed of rotary drilling with improved sample recovery. A relatively uncontaminated sample can be obtained as compared to the exterior pipe flushing method of the rotary system where the returning sample cuttings are more apt to include material from strata previously drilled.

Penetration rates of a reversed-circulation system are reduced as compared to the rotary drill system and some additional equipment may be required [7]. This method is best suited to strata that will commonly remain intact during drilling and not erode from the action of the cuttings which are flushed to the surface. In general, casing must be installed above the strata from which samples are desired. Because of the circulation path of this system, there is a potential for circulation-loss.

Coring Systems

Drill pipe, casing, core barrels, and coring bit dimensions have been standardized through the efforts of the Diamond Core Drill Manufacturers Association [3].

Conventional Drill Core System

The conventional drill core system utilizes the same surface equipment, drill-rod design, and circulating fluids as the rotary drill system except that the bottom section of the drill-rod string is attached to a core barrel assembly (Fig. 7). Drilling fluid or mud circulates down the inside of the drill pipe, through the core barrel, and out the core bit. After advancing the length of the core barrel through the strata being cored, a cylindrical sample of that material is retained and held in the inner barrel. Fine cuttings produced by the action of the bit are flushed to the surface along the outside walls of the drill-rod string. Retrieval of the core-barrel assembly is then accomplished by hoisting the entire drill-rod string to the surface.

Three kinds of core barrels are commonly used in conventional coring: (1) single-tube, (2) rigid double-tube, and (3) swivel-type double-tube (Fig. 7). Each is described in detail below.

(1) The *single-tube core barrel* is the simplest type of barrel that can be used in coring. As the name implies, the coring assembly consists of a single tube in which the drilling fluid must pass between the core and the inside of the barrel. When properly applied, this type of barrel functions well, but it has two limitations. Firstly, in coring soft, friable formations, there is a potential for the core to be eroded away because of the circulating action of the drilling fluid

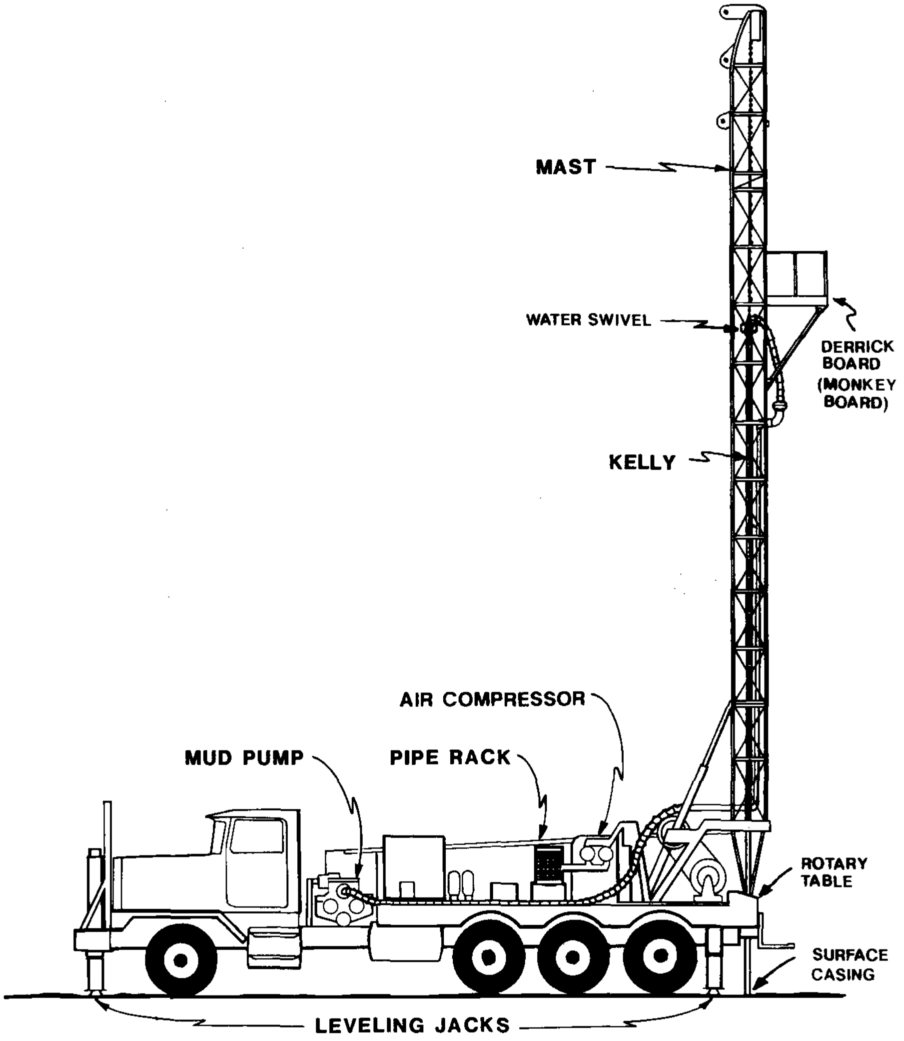


FIG. 2—Truck-mounted rotary drill rig system.

within the barrel. Secondly, it is likely that the core will rub against the inside wall of the barrel as it rotates, which might erode any soft cored material within the barrel. Therefore the single-tube barrel is not recommended for coring soft or easily abraded strata.

The single-tube barrel withstands the heavy feed pressures that are required to penetrate hard or compact strata [3]. When used in this manner, it commonly yields good core recovery and relatively trouble-free operation. It should be cautioned that in coring hard, fractured strata, pieces of core may be washed to the cutting face of the bit. This condition causes grinding of the core, resulting in reduced bit life and core recovery and increased costs.

(2) The *rigid double-tube core-barrel* assembly (Fig. 7) consists of an outer tube and an inner tube which are both fixed to the core barrel head. The inner barrel of the double-tube assembly may be of solid or split-tube design. In the solid tube design, the core is retrieved in a solid-walled pipe and is extruded from the pipe with hydraulic or mechanical pressure. The split-tube barrel consists of two halves of pipe bound together with wrappings of reinforced tape at equal intervals along the length of the barrel. Core samples in the split-tube barrel are easily recovered by removing the tape binders and separating the two halves of the barrel. An advantage of the split-tube is that the core is kept relatively intact and more easily retrieved.

A reaming shell is attached to the bottom of the outer tube which helps to position the inner tube, although the reaming shell is not directly fastened to the inner tube. The reaming shell also reduces wear on the outer part of the barrel and helps to maintain the distance between the core barrel and the borehole wall. Reaming shells can be utilized on other types of core barrels in addition to the rigid double-tube barrel. A disadvantage of this system is that, during coring, both the inner and outer tubes rotate. The advantage of this double-tube core barrel is to reduce core loss by passing the drilling fluid between the inner and outer barrels instead of over the core as is the case with the single tube barrel.

Perforations at the bottom of the inner tube allow the passing of drilling fluid and, from that point, the cutting bit represents the only location at which a core can be subjected to possible erosion. This distance is minimal when compared to the overall length exposed in the single-barrel design. By limiting the erosion problem, it becomes more effective

FIG. 3—Truck-mounted rotary drill rig.

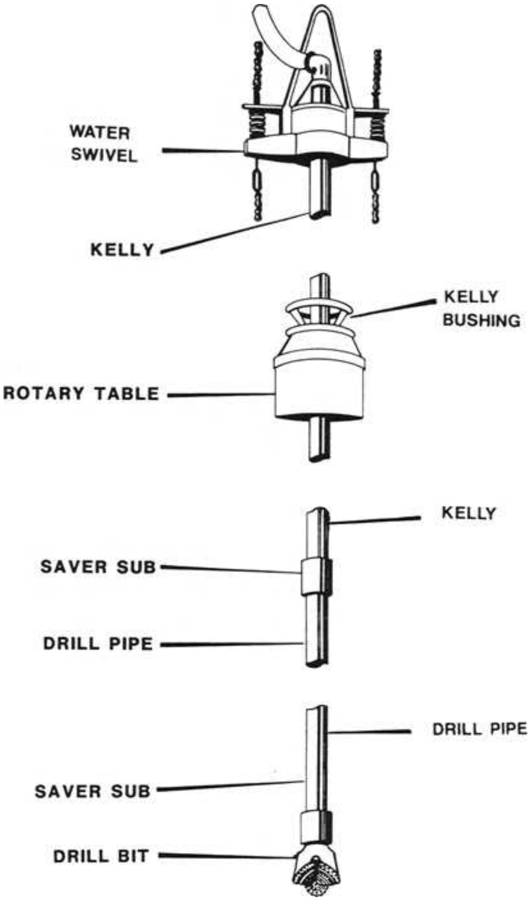


FIG. 5—Rotary drill assembly.

FIG. 4—Buggy-mounted rotary drill rig.

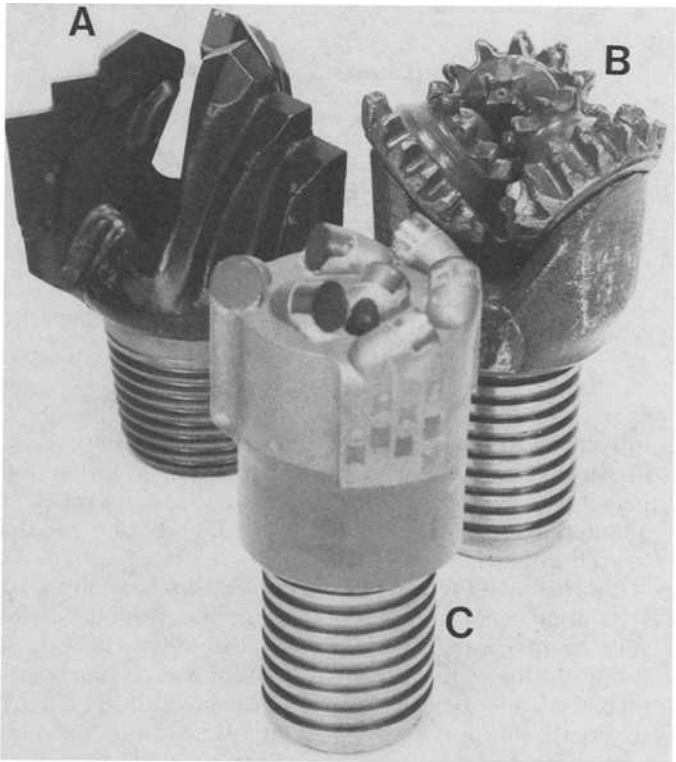


FIG. 6—Examples of rotary drill bits. (*A*) Tungsten carbide drag bit. (*B*) Tricone roller bit. (*C*) Polycrystalline diamond bit.

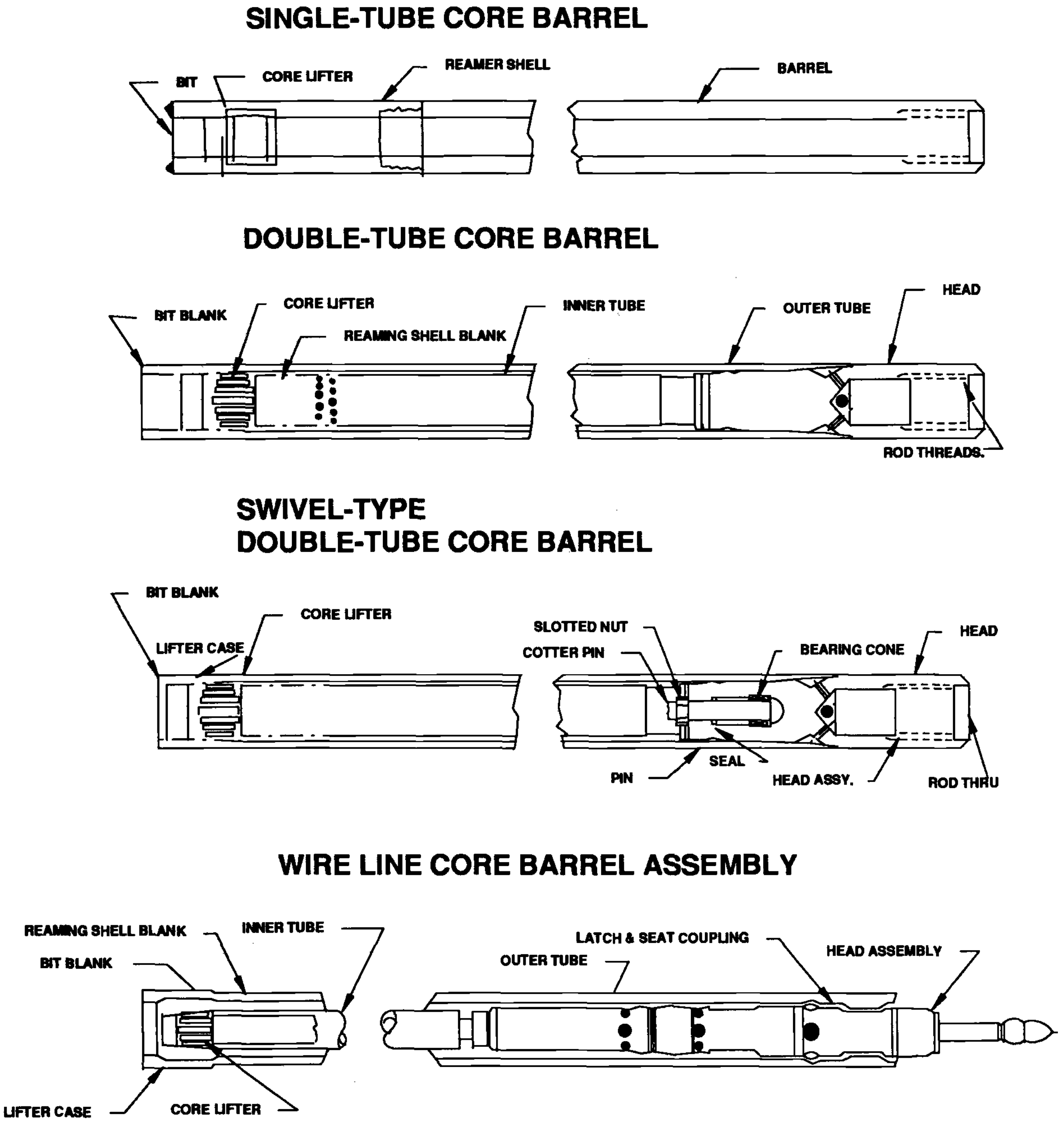


FIG. 7—Examples of single, double, and wireline core-barrel assemblies.

in softer and more broken strata materials. However, the problem of core abrasion resulting from the rotation of the barrel is not eliminated by this design. This barrel is well adapted for use in coring soft to medium-hard formations as well as hard, fractured strata.

(3) The *swivel-type double-tube core barrel* assembly consists of an inner and outer tube just like its rigid double-tube counterpart. The main difference in its configuration is that the inner tube is suspended from the core-barrel head on ball or roller bearings (Fig. 7); this allows the inner barrel to remain stationary while the outer tube rotates independently. This independence minimizes effects of abrasion to the core resulting from rotation. This type of barrel can improve core recovery from soft or fractured formations and reduce distortion of the core.

The bottom of this assembly also contains a lifter case that is attached to the inner tube. This modified design offers two distinct advantages. Firstly, the addition of the lifter case exposes only about 1 cm (½ in.) of core length to any washing action; secondly, the core enters the lifter case almost immediately after it is cut by the drilling bit. The possibility of an early blockage and core damage is reduced because of improved alignment of the lifter assembly. Coupled with the non-rotating inner barrel, the lifter assembly makes this barrel ideal in coring very soft, friable formations. Figure 7 outlines the configuration of this type of barrel.

Large diameter core samples can be obtained by using the conventional drill core system. It does not require the use of additional specialized surface equipment, thereby permitting coring of coal in conjunction with rotary drilling of associated rock units [*7*].

Two limitations when utilizing this system are [*7*]: (1) under present technology, the maximum thickness of strata that can be cored during a single run is 9 m (30 ft), and (2) the overall drilling time may be increased. Up to 70% of the time is spent handling the drill pipe while either retrieving the core barrel assembly or returning it back down the borehole for another run [*5*]. Even with these limitations, however, conventional coring is generally the preferred method of coring in terms of overall project costs.

Both solid and split inner tubes are commonly used; however, a double-tube, swivel-type barrel with a split innertube is commonly preferred for ease of core extraction and maintaining core integrity. Using a chrome-plated innertube should allow smooth, unrestricted entry and extraction of the core from the barrel. Site-specific geology, required parameters of investigation, and equipment availability will ultimately determine final core barrel selection.

Wireline Drill-Core System

The wireline drill-core system utilizes the same coring principles and, other than a different drill pipesystem, also utilizes the basic surface equipment of the conventional system, but it differs in the method of core retrieval. The double tube, core-barrel assembly of the wireline system has been designed so that the inner barrel containing the core sample can be hoisted through the drill pipe string without removing any of the rods or the outer core barrel. Cores from wireline systems are commonly smaller in diameter than those from conventional systems, although thin-wall wireline systems are available that will produce cores of the same or larger diameter than the conventional coring barrel for the same borehole diameter (Figs. 1 and 7).

Using a wireline coring system, consecutive cores can be drilled without retrieving the entire drill pipe string after each coring run [*7*]. However, additional surface equipment is generally required when using the wireline coring method. Also, this method usually requires a greater volume of water to be circulated, which in some cases can make it difficult to maintain water pressure.

CORING BITS

Tungsten carbide and diamond bits are commonly used in conventional coring depending on the lithologies being penetrated. Tungsten-carbide-insert coring bits (Fig. 8) are generally used to core very hard lithologies [*5*]. Optimum penetration rates are dependent on matching the set (configuration and size) of the tungsten carbide inserts to the lithology being drilled. The cost of these bits is significantly less than diamond bits.

Diamond bits are used almost exclusively for coring hard or dense lithologies. These bits are constructed by placing either natural or synthetic diamonds in a mold of specific size and shape and filling with a powdered metal (usually a tungsten alloy). The mold is subjected to heat and pressure to form a solid mass called the crown of the bit. The crown with the imbedded diamonds is then either brazed or mechanically pinned to a steel drill bit hub (Fig. 8).

Two types of diamond bits are used. Surface set diamond bits are made by placing an exposed matrix of diamonds at the surface of the bit crown whereas an impregnated bit has the diamonds uniformly distributed throughout the crown material. As the crown wears away in an impregnated bit, new diamonds are exposed thus producing a consistent cutting edge. An impregnated diamond core bit generally will produce better results that a surface set bit when coring highly fractured or very hard lithologies (quartzite, silicified sandstones, etc.).

A recently developed hybrid core bit combines tungsten-carbide drag bit cutting efficiency with the long life of diamonds. Disk-shaped PCD cutters are fixed to a bit blank using conventional furnace technology and steel or tungsten carbide (Fig. 8). These bits are especially applicable to soft and/or sticky lithologies such as coal.

Coring techniques using diamond drill bits generally require less down-hole pressure and average- to high-rotating speeds. Excessive down-pressure can cause fracturing of diamonds in surface-set bits. Pump pressure and fluid velocity need to be controlled to prevent erosion of both the core sample and the bit-matrix metal. Because of their smoother cutting action, diamond bits can provide better core recovery than tungsten carbide bits in highly fractured coal seams. Most bit manufacturers can provide detailed information to help determine the specific type of bit and design best suited for the particular coring conditions anticipated.

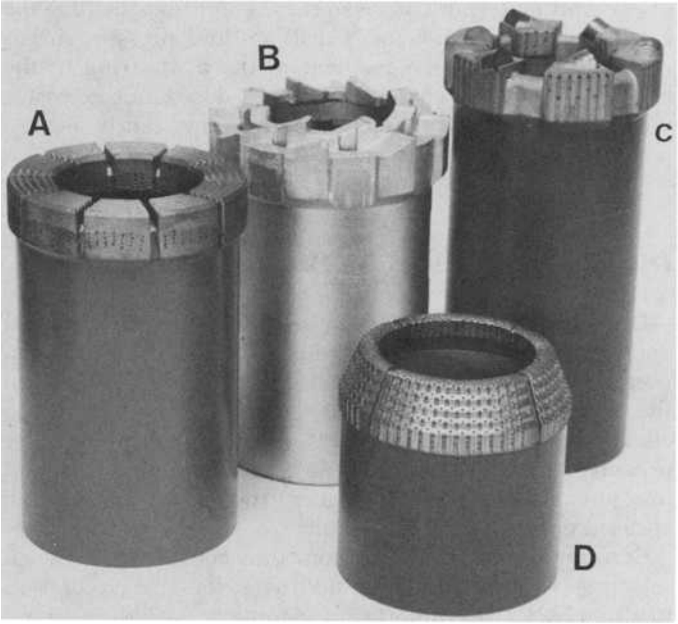


FIG. 8—Examples of coring bits. (*A*) Diamond impregnated. (*B*) Tungsten carbide insert. (*C*) Polycrystalline diamond. (*D*) Surface-set diamond with step crown configuration.

OTHER DRILLING CONSIDERATIONS

Site-specific geology and depth of the target strata will greatly influence drilling productivity in terms of penetration rate and core recovery. Drilling in certain types of lithologies will limit penetration rates. Drilling conditions that may cause problems include partial or total lost-circulation, caving within the borehole, and stuck pipe.

Lost-circulation may occur in: (1) unconsolidated permeable formations (i.e., sands, gravels), (2) cavernous or vugular formations (i.e., limestone, dolomite), (3) faulted and jointed formations, (4) weathered coal, and (5) abandoned underground mine workings.

If there is a possibility of encountering circulation problems, several preventive measures can be implemented [*8*]. Pressure on the formation being penetrated should be kept to a minimum by (1) raising and lowering the drill string slowly to minimize pressure surges, (2) drilling completely through tight sections such as hard or indurated lithologies, (3) rotating the drill string prior to pump startup and gradually increasing fluid pressure, (4) operating the pump with enough pressure to assure better bit cooling and removal of cutting materials, and (5) using mud additives in the drilling fluid.

If complete loss of circulation occurs, lost-circulation materials (LCMs—such as bran, cottonseed hulls, sawdust, or commercial chemicals) can be added to the drilling fluid. These materials should be injected as a slurry into the zone creating the loss and slowly raising the drill string. If this procedure does not solve the problem, several other actions are available: (1) the drill string can be removed from the borehole and a grout plug or cement can be placed at the interval where circulation was lost and the plug can then be drilled out and the borehole continued, or (2) casing can be set at depths to isolate the zone of circulation loss from drilling.

Borehole caving results from the mechanical breakdown of the wall material. Causes of these conditions include the eroding effect of high-velocity drilling-fluid, pressure surges resulting from rapid movement of the drill string in the borehole, high drill-string rotational-velocities or excessive vibration of the drill string, and, most importantly, incompetent characteristics of the strata being drilled.

DRILLING FLUIDS AND ADDITIVES

Drilling fluids and additives are commonly used to cool and clean the cutting bit by removing cuttings and transportating them to the surface [*12*]. Friction is reduced between the rotating drill string and the walls of the borehole by the effect of the fluid. The particles of the fluid carried under pressure can seal the walls of the borehole and prevent fluid loss and inflow of ground water, thereby stabilizing the encased portions of the borehole.

Certain factors must be taken into consideration when selecting specific fluids or additives for the circulation medium [*12*]. Most important to sampling coal, the purpose of the drilling must be considered when using any additive or LCM because the additives can be a source of contamination that can affect analytical results, such as determination of trace elements. Certain lithologies can be more susceptible to chemical breakdown by some additives than others. The capacities of the pumps and compressors and diameters of drill pipe and cutting bits can limit the type of media. The pressure and amount of ground water in the drilled strata can also limit the types of fluids that would perform best. Modifications to the site to allow accessibility for mud delivery and availability of water to the site can require additional costs and time to add the necessary media to continue drilling. Weather or climatic conditions may hinder these additions to the site. Certain down-hole materials may be regulated and require special permitting. Depending on the combination of the above factors, costs for continued drilling with drilling mud additives may be greater than moving the site and drilling another hole.

Compressed air is often the fastest and most economical circulation medium. This method also provides rock and coal samples that are the least contaminated. A disadvantage in drilling with air is that it is generally limited to relatively shallow borehole depths because the fluid pressure of deeper, water-bearing lithologies is commonly greater than pressure from the air needed to keep the hole clear of water.

The controlled addition of water to the air stream creates a mist-fluid that promotes the return of cuttings when damp formations are encountered and prevents booting. Booting occurs when the drilling fluid is ineffective in totally removing the drill cuttings from the borehole. The cuttings left behind form a sheath around the exterior walls of the drill pipe. Occasionally, this sheath works its way up the drill stem and is ejected from the borehole at the collar in long tube-like masses.

A foaming agent and water in the air system may be required when air or an air-mist is insufficient to remove cuttings. The type of formation being drilled will determine the concentration of the foam to be used. Problems that may develop when drilling with air foams include (1) borehole erosion, (2) decrease in the size consist of the cuttings, (3) corrosion of the drill pipe, or (4) excessive fluid entry into the borehole from water-bearing formations.

Gel-foam or stiff foam [*10*] acts as a very light liquid when utilized as a circulating fluid. The gel foam should be added in small amounts to the air system when encountering lost circulation, unstable borehole conditions, excessive water influx, or low pressure conditions. The use of an inhibitive mud may be required at times. An inhibitive mud is used to suppress the swelling of bentonite [*14*]. Inhibitive muds must be compatible with the foaming agent, because some inhibitive muds will also act as defoamers.

In situations where air drilling is not feasible, water can be used as the circulating fluid. Water medium is commonly used where formation pressures are normal or sub-normal and where formations are not highly permeable, water sensitive, or soluble. Commonly, some type of drilling mud is added to the water. Drilling muds are used to stabilize borehole conditions and prevent loss of circulation [*10*]. When using drilling muds, the return velocity of the injected fluid should be maintained sufficiently to help prevent booting.

DRILLING FLUID CHARACTERISTICS

The following section briefly describes some of the more important characteristics of drilling fluids or muds. Characteristics of specific fluids can be found in McDermott [*13*], Gray and others [*14*], and Tschirley [*15*]. Generally, these characteristics are not monitored in any quantitative detail unless problems occur.

The *density* of a particular drilling mud can be an important factor. Mud density can affect the rate of penetration, borehole stability, transport, and settling rate of the sample cuttings. Mud density should be adjusted to manufacturer's specifications to optimize performance; however, often manufacturer's specifications do not realistically handle all field conditions and necessitate some on-site flexibility.

The *viscosity* of a particular drilling mud is the measurement of the carrying capacity of the mud. The viscosity of a mud affects penetration rate, stability, circulating pressure, settling rate of cuttings, and borehole cleaning ability. Viscosity usually is maintained between 32 and 38 seconds per quart as measured with a Marsh funnel. Viscosity will vary depending on the mud density, borehole diameter, pumping rate, and formation lithology.

The *filtration properties* of a fluid determine its ability to form a controlled filter cake on the sidewalls of the borehole. In a drilling mud, the filtration properties affect borehole stability, smooth movement of the drill string, formation damage, and development time. Filter cake should not exceed one sixteenth of an inch in thickness and should be easily removable with back flow.

The *pH* of drilling mud is a measure of the acidity or alkalinity of the mixing water and the drilling fluids being used and affects the rate of mud mixing, borehole stability, mud properties, corrosiveness, viscosity, gel development, and filtration control. The desired operating pH for drilling mud is generally 8.5 to 9.5.

A measurement of *calcium* is an indicator of the hardness of the mixing water because of the presence of dissolved calcium salts. Dissolved calcium affects the rate of mud mixing, filtration control, wall caking, viscosity, and gel development. The amount of calcium dissolved in the drilling fluid should not exceed 100 parts per million.

The *lubricity* of a drilling mud fluid is a measure of the lubricating ability of the fluid to reduce friction in the borehole.

Sand content is a measurement of the solid particles in the fluid larger than 75 μm (No. 200 mesh U.S.A. Standard Sieve Series (USA SSS). The abrasive nature of these particles affects mud weight, equipment life, bit footage, penetration rate, and formation erosion.

Manufacturers of drilling fluid materials and additives provide detailed descriptions of their products [*13,14*]. The descriptions should include primary and secondary functions, recommended usage, and suggested amounts to be used. Drilling fluids and additives can be a source of contamination in a drill core sample by the addition of materials to increase the density of the mud [*14*]. Products that contain sodium, chlorine, phosphorous, lead, zinc, and various other trace metals can affect determination of the sample's inherent chemical composition. Other additives could possibly affect the recovery of coal during a washability test. To detect such sources of possible contamination, drilling fluids and additives should be analyzed.

Another source of elemental contamination is drill stem lubricants. Drill stem lubricants are used during the drilling process to seal the drill stem joints from leakage and to prevent the joints from binding or locking because of excessive torque. Zinc, lead, copper, and titanium can be present in these lubricants. Excess lubricant on the joints can result in the contamination of samples being collected for chemical analysis. To prevent possible contamination, lubricants with nonmetallic additives should be used when samples are collected for trace metal composition or the lubricants or fluids should be tested as a possible source of contamination. Table 1 is a comparison of the trace element compositions of five randomly selected drill stem lubricants; the magnitudes of some of these elements exceed abundances found in many coals.

In summary, an understanding of the advantages and disadvantages of each type of circulating medium and additive is desirable. Down-hole conditions should be monitored, so that problems can be anticipated before a situation becomes severe and prevents drilling progress. If possible, have the necessary additives and materials readily available and keep and monitor complete records of the usage, properties, and compositions of fluids and additives.

TABLE 1—Comparisons of trace element contents of drill stem lubricants, %.

Element	Brand				
	A	B	C	D	E
Al	3.9	0.43	0.55	0.27	0.28
As	. . .	. . .	0.10	. . .	0.07
Ba	. . .	. . .	. . .	17.3	. . .
Ca	0.7	0.02	0.33	0.3	0.94
Cr	. . .	. . .	0.0003	. . .	. . .
Co	. . .	0.0003	. . .	. . .	. . .
Cu	0.16	7.3	0.0004	0.0006	0.0002
Cl	. . .	. . .	. . .	0.0002	. . .
Fe	0.006	0.11	0.3	0.31	0.006
Ga	0.0002	. . .	. . .	. . .	. . .
Pb	0.6	2.4	11.0	0.11	9.7
Mg	0.14	. . .	. . .	. . .	0.54
Mn	0.0002	0.0001	0.0005	0.0002	. . .
Mo	. . .	. . .	. . .	0.001	0.01
Ni	. . .	0.0005	. . .	. . .	0.0001
Pd	. . .	. . .	0.17	0.005	0.26
P	. . .	. . .	. . .	. . .	0.11
K	0.003	0.008	0.11	0.16	0.007
Rb	. . .	. . .	. . .	0.0007	0.0005
Si	0.40	0.46	1.71	1.18	1.69
Se	. . .	. . .	. . .	. . .	0.001
Sr	0.0001	. . .	. . .	0.14	0.0009
S	. . .	. . .	. . .	2.69	. . .
Ti	5.7	0.001	0.002	. . .	. . .
W	0.0006	0.0009	. . .	. . .	. . .
Zn	. . .	0.15	2.77	4.63	0.16
Zr	. . .	0.0007	. . .	. . .	. . .

2

Geophysical Logging

OVERVIEW

Continuously coring each exploration borehole to determine the physical and geologic characteristics of the underlying strata is usually prohibitive in terms of cost and time [*16*]. As an alternative, a number of geophysical instruments have been developed to reliably scan, analyze, and log boreholes [*17–38*].

Other than the actual core itself, the geophysical logs are commonly the most important set of field data. These logs provide precise data from which the thickness and depth of coal beds can be determined and the lithology of associated strata can be inferred. They are also valuable aids for correlating seams and other marker beds and for evaluating geotechnological and groundwater parameters. Where well-calibrated logs and sufficient analytical baseline data are available, the logs can often be used for certain coal-quality estimations.

The instruments that were developed to produce these geophysical or electric logs are called *probes* or *sondes*. These instruments are cylindrical tools which are lowered to the bottom of a borehole (Fig. 9) and which take measurements as they are raised through the borehole at a constant speed. Information is electrically relayed to the surface where it is displayed on auxiliary instruments, transferred to a chart recorder as a permanent log, or converted to a digital signal that is compiled by a computer and recorded on a tape or disk [*39*].

Geophysical logs generated from older logging units used uncalibrated analog instruments, whereas many newer units employ digital systems with calibrated instruments. With digital systems, probe sensors transmit coded signals to the surface where the measurements are recorded on magnetic tapes or discs. A log can be produced immediately from the digital information with the use of an online plotter or printer. The digital systems facilitate the application of analytical techniques requiring computer data processing such as estimating coal quality or cross-plotting to infer lithology or strength indices.

TYPES OF LOGS

Usually a combination or suite of down-hole instruments is employed to adequately geophysically log a borehole. Geophysical logs were often referred to as electric logs (E-logs) in the past. The basic suite of four geophysical logs most commonly used in coal logging operations is as follows:

1. Gamma Ray (Natural)
2. Bulk Density (Gamma-Gamma Density)
3. Resistivity
4. Caliper

A supplemental series of logging types may also be employed such as:

5. Neutron Density
6. Laterolog (Focused Resistivity)
7. Sonic (Acoustic Velocity)
8. Spontaneous Potential
9. Verticality (Borehole Deviation)
10. Dipmeter

Table 2 summarizes some of the more important characteristics of these borehole logging methods used in describing coal beds. Figures 10 and 11 compare the recorded chart readouts for some of the basic logging types. The following sections provide a brief summary of geophysical log types that are important to a coal drilling program.

Natural Gamma Log

The natural gamma log measures the amount of radioactivity emitted by the various stratigraphic lithotypes encountered as a detector is moved up a borehole. Certain minerals found in clays, shales, and sandstones contain measurable quantities of naturally occurring radioactive isotopes of potassium, uranium, and thorium which emit detectable amounts of gamma radiation [*16,18,22,26,30*]. By measuring the amount of this radiation, lithologic interpretations of the strata can be made.

Generally coal and clean sands are low in natural radioactivity. The rock that surrounds a coal bed often contains potassium-rich clay and sometimes uranium-based materials. This difference in radioactive characteristics provides the basis for differentiating coal from rock on a recorded natural-gamma log. It should be noted that coal seams can contain uranium-containing minerals. In those cases, the definition of the coal bed is less apparent on the gamma ray log and may even cause a reversal of the gamma response. Since coal and sandstone may have similar radioactivity, the natural gamma log must generally be used in conjunction with other logs to identify coal.

During logging, the amount of natural radiation detected by the down hole probe (sonde) is recorded and expressed in either CPS (counts-per-second) or API (American Petroleum Institute) units. A representative log can be obtained regardless of the type or condition of the fluid in a borehole. Also, a record can be obtained above the fluid level in a borehole as well as through any sections that are cased.

FIG. 9—Geophysical logging unit showing extended probe boom which has lowered probe down borehole.

Bulk Density Log (Gamma-Gamma Density)

The bulk density log (gamma-gamma density) is used to determine the bulk densities of subsurface formations. Coal has low apparent densities in the range of 1.20 to 1.60 g/cm^3. Less porous and more consolidated strata such as shales and sandstones have higher apparent densities, generally greater than 2.00 g/cm^3. Because coal has such low densities compared with other rocks, the recorded density on the charted log is distinctly lower. This characteristic makes this log the singularly most important geophysical log for coal exploration. Older density logs expressed values in terms of relative counts per second (CPS). Most modern logs in use today yield a calibrated density reading in terms of g/cm^3.

As the logging probe is drawn up a borehole, a radioactive source contained within the tool bombards the adjacent strata with gamma-rays. A detector on the probe then measures the amount of gamma radiation back-scattered from the formation. The intensity of radiation (in CPS) back-scattered to the detector is inversely related to the density of the formation (g/cm^3).

A basic difference in bulk-density probes is the distance between the source and the detector. The high-resolution density, bed resolution density, and extremely high-resolution density (EHR) [*28*] tool spacings are compared with the long spacing density (LSD) tool in Table 3. The LSD log has proven to be very satisfactory for general coal exploration; however, especially in the Appalachian Region, where an error in thickness determination of as little as 5 cm may have significant economic consequences, higher resolution density sondes have become very useful.

There are compromises that are made using the higher resolution density tools, however. The decreased source-detector spacing results in a reduced depth of investigation into the strata. The high-resolution density tools are also very sensitive to borehole size or rugosity, thus making a companion caliper log especially important so that caved zones or "washouts" which can look like coal beds can be resolved.

TABLE 2—Summary of drill hole logging characteristics.

Method	Response to Coal	Units	Conditions That Invalidate Log or Make Interpretation More Difficult
Gamma ray	Low natural gamma	CPS or API	Clean sand adjacent to coal bed. Coal bed containing uranium-bearing minerals.
Bulk density (gamma-gamma)	Low density	g/cm^3	Irregular hole diameter (washout). Caved shale adjacent to coal bed. Fractured strata surrounding coal.
Resistivity	High resistivity	(ohm-m)^2	Highly resistant strata next to coal bed.
Sonic	Low velocity High interval transit	ft/microseconds Interval transit time	Loose, clean sand next to a coal bed. Irregular hole diameter. Seam thinner than tool spacing. Fractured strata surrounding borehole.
Neutron density	Low density	Porosity, %	Caving shale next to coal bed. Wet clay adjacent to coal bed. Irregular hole diameter. Fractured strata surrounding borehole.
Laterolog bed	Low conductivity	mhos/m	Highly resistant strata next to coal.
Caliper log	Measures borehole diameter	inches (cm)	Extremely thick mudcakes or drill hole fluid-fractures (washout) or borehole diameter deviations larger than caliper arms.

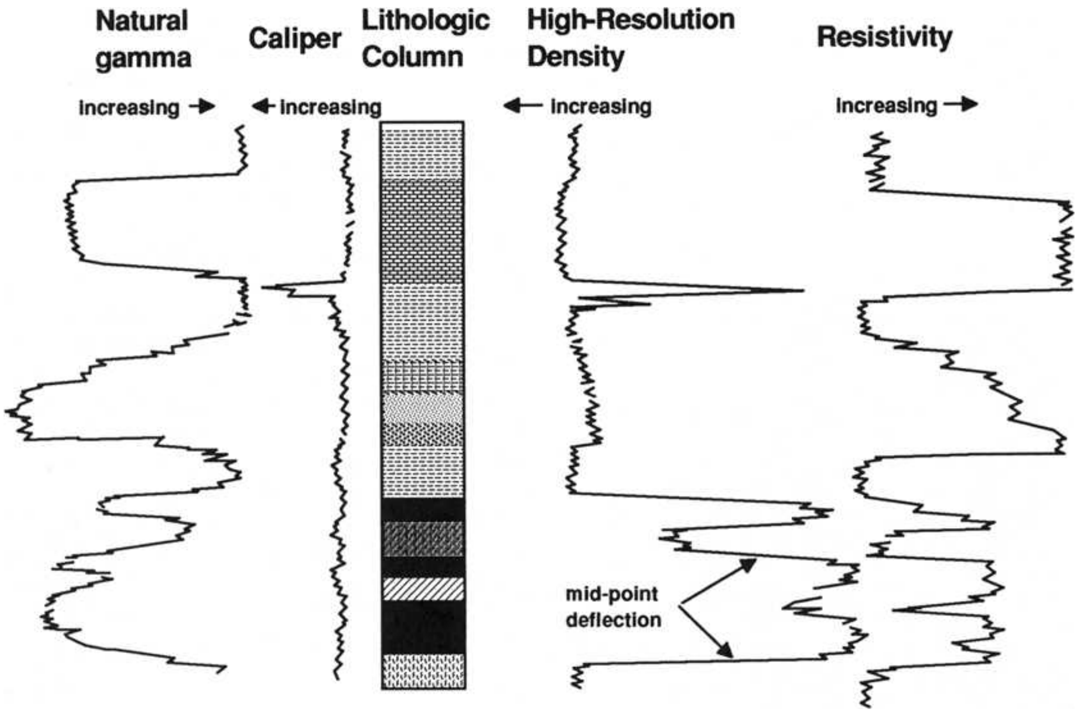


FIG. 10—Typical responses of geophysical logs in rock types commonly encountered in coal drilling.

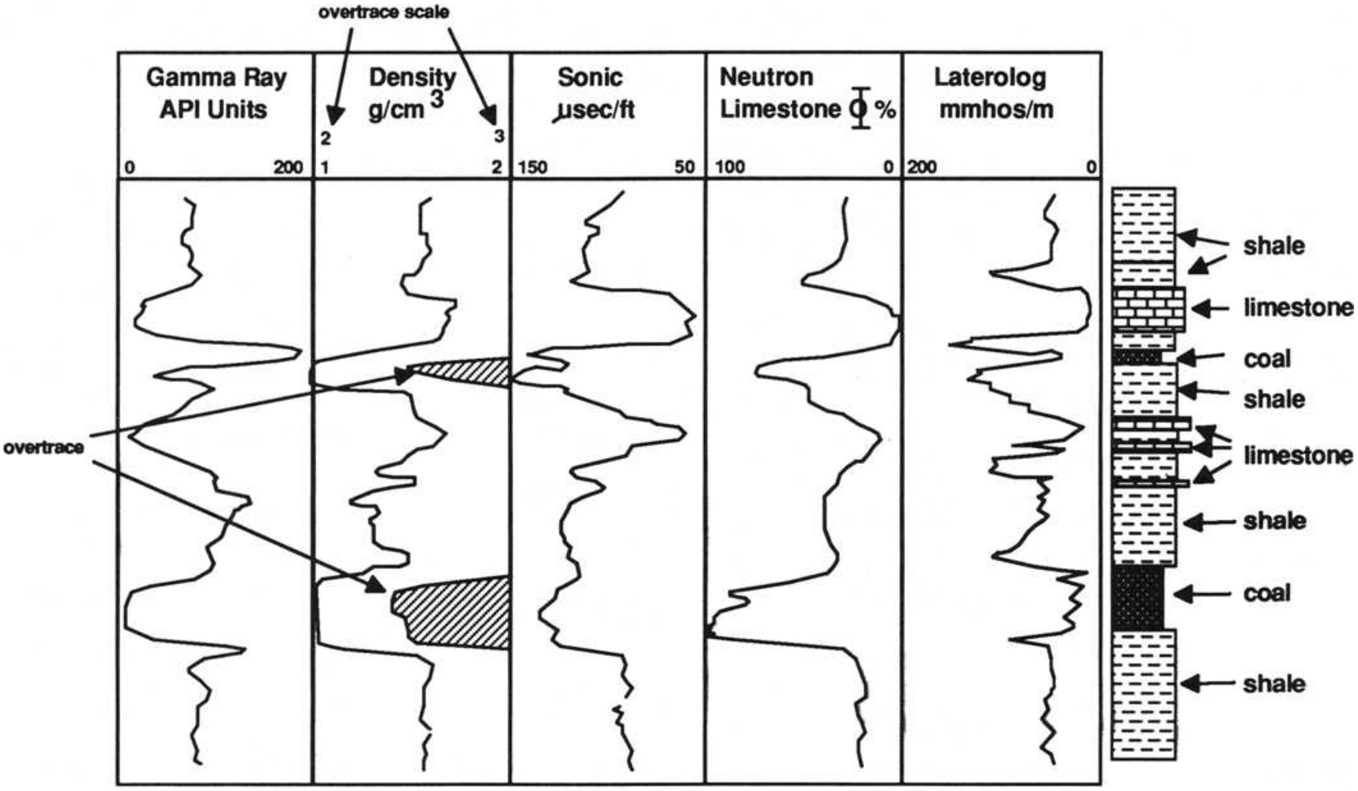


FIG. 11—Five geophysical logs showing lithologic responses in drillholes in the Illinois basin (modified from Ref 18).

TABLE 3—Comparisons of some density probes [37].

Density Tool	Approximate Common Detector/Boundary Source Spacing, cm	Log Resolution, cm
Long Spacing	48	22
High Resolution	5–10	9
Bed Resolution	15	5
Extremely High Resolution	5	2

Resistivity Log

The resistivity log measures the degree of resistance of a lithologic formation (and the fluids contained in the formation) to the flow of an electric current that is passed through it. The capacity of a formation to conduct electricity is not dependent on the minerals that comprise that strata, but rather on their respective physical characteristics (pore geometry) and the amount of mineralized water they contain. On the basis of those factors, the resistivity of a formation is directly dependent upon the resistivity of the water in its pores and its clay mineral content.

Many of the older resistivity logs were derived from a single-point resistance measurement. A single-point resistance tool measures the total electrical resistance between a current source in the probe and the casing of the probe or a surface electrode. Single-point measurements are not quantitative; however, they are still very effective for coal exploration.

In more recent conventional resistivity logging, a probe containing a pair of electrodes at a set spacing is raised through the borehole at a constant speed. Electrical current is passed into the strata encountered along the walls of the borehole and the amount of voltage passed between the electrodes is measured. The voltage differential is then detected and transferred to a chart or digital recorder. The measured voltage difference provides the basis for the resistivity determination. It should be noted that there must be a conductive current medium between the electrodes and the strata being studied. Thus a resistivity probe can only be functional in the fluid-filled portion of a borehole.

Differences in recording voltage of the same formation can result from different spacings between the electrodes in the sonde. Two electrodes spaced about 41 cm (16 in.) apart create what is known as a *short-normal resistivity curve*. This method accurately indicates the tops and bottoms of formations that are thicker than about 41 cm (16 in.), but it does not give a true indication of the resistivity of the natural formation because of the relatively shallow penetration of the current and the considerable effect of the drilling fluid on the current.

A resistivity curve created by two electrodes spaced about 1.63 m (64 in.) apart is called a *long-normal curve*. This log detects lithologic contacts less accurately but is an important aid in determining the extent of invasion of the drilling mud into the strata being studied and can provide a more accurate recording of the resistivity of lithologies and their water contents. The short- and long-normal resistivity logs are commonly run together on one probe, thereby producing adjacent log traces on the chart.

Coal is a poor conductor of electric current and consequently exhibits high resistivity readings. However, tight sandstone or limestone beds will also exhibit similar resistivities as coal. Thus, as with the natural gamma log, the resistivity cannot be used alone in identifying and describing lithologic strata.

Caliper Log

The caliper log measures the borehole diameter. Because of the differing physical characteristics of the lithologies being drilled and the various forces involved in drilling, a borehole may not maintain the same drilled diameter from top to bottom. Soft, friable, or fractured strata are prone to caving.

The caliper probe consists of one or more spring-actuated arms that come in contact with the walls of a borehole as it is raised through the borehole at a constant speed. Multiple arms generally give a better definition of borehole rugosity. As the diameter of the borehole varies up the hole, the arms of the tool will expand or contract to record the changes. This expanding and contracting motion is transmitted to a rheostat inside an oil-filled chamber so that the change in resistance of the rheostat is always proportional to the change in average borehole diameter as measured by the arms. The change in diameter is then picked up as a signal and transferred to a recorder. The interpretation of a caliper log aids in locating and determining the amount of caving within a borehole. Also, it is often useful in identifying washouts which can appear on density logs as low density zones and can mistakenly be interpreted as coal.

Laterolog (Focused Resistivity)

The laterolog (focused resistivity) method measures the resistivity encountered in strata in a borehole by sending out a focused electrical signal. This log is designed to measure the resistivity of the lithology in boreholes which are filled with saline mud.

Neutron-Density Log

The neutron-density log procedures are very similar to those used in the bulk density determination and their chart responses are similar. The neutron logging probe contains a radioactive source which bombards the lithology with neutron radiation (alpha particles) in contrast to the weaker gamma radiation as generated by a bulk-density logging source.

As the logging probe is raised through the borehole, the adjacent strata are bombarded with neutron radiation, some of which is captured by the atomic nuclei of certain elements (such as hydrogen) contained in the strata. This neutron capture is followed by an energy release of gamma radiation which is backscattered and measured by a detector on the probe.

During bombardment, some of the neutron radiation is slowed down because of collisions with the atomic nuclei of the hydrogen. Collisions with the hydrogen nuclei reduce the velocity and energy of the neutrons which enables their capture by hydrogen nuclei. This neutron capture also decreases the intensity of the back-scattered gamma radiation to the detector. This relationship enables discrimination between highly porous water-filled materials and less porous materials. Because hydrogen is common in most fluids and a lithology must be porous to contain fluids, the neutron log gives a good indication of the relative porosity of a lithology. Coal and lignite are hydrogen rich and contain pores which are commonly filled with water. This combination thus yields a high porosity and low intensity index on the neutron log.

Sonic Log

The sonic log measures the transit time of an elastic wave created by an acoustic signal after passing through the strata. Generally, interval transit time is higher for coal than for surrounding rock strata. It should be noted that more highly compacted coal beds exhibit lower transit times and this tends to make positive identification of these beds less exact. The precision of this tool can be also affected by variations in the diameter of the borehole and fractures in the strata.

In terms of response, lignites generally range from about 426 to 492 µs/m (130 to 150 µs/ft) on a recorded chart log. The values for anthracite are usually lower than about 394 µs/m (120 µs/ft).

Spontaneous Potential Log (SP)

The spontaneous potential (SP) log measures the electric potential between the borehole fluid and the strata in the borehole. This log is commonly used in petroleum exploration drilling but generally the SP log will not provide consistent readouts in coal-bearing strata, although it can be useful to interpret sandstone and shale lithologies. The SP log can only be run in uncased fluid-filled boreholes.

Borehole Deviation (Verticality Log)

Borehole deviation (verticality log) is produced by a tool which generally contains three magnetometers.The plot of this log measures deviations from the vertical and is plotted in terms of degrees in tilt and azimuth. The main uses of this tool are to position the borehole path relative to underground mining activities and to determine the verticality of boreholes especially when encountering steeply dipping strata or faults so that accurate bed thicknesses can be determined.

Dipmeter

A dipmeter measures the stratal dip and consists of a three-arm resistivity measurement, a caliper record, and a borehole deviation instrument. The angle and direction of stratal dip is necessary to assess true bed-thickness (measured normal to bedding) and also gives valuable regional structural information in folded and faulted coal basins.

THICKNESS DETERMINATION

Under normal drilling conditions (nearly flat-lying strata) the most reliable thickness determination can be made from the density log and the caliper log. If the roof and floor lithologies are not sand, the resistivity and natural gamma can also be useful, especially if "caves" or "washouts" are indicated from the caliper log.

Generally, the one-half deflection of midpoint on the curve is used to determine bed boundaries (Fig. 7); however, for certain tools it may be necessary to use other criteria, such as one-third, initial deflection, etc. Every geophysical tool manufacturer or service company should have specific instructions for the interpretation of their logs and should be consulted.

Regardless of the method used, the estimated thickness from the geophysical log(s) must be checked against measured coal core sections for final "calibration." This comparison is particularly critical in the cases of gradational contacts of the seam and rock or where the thickness of thin partings can be usually exaggerated. With experience, thicknesses can be determined from geophysical logs precisely within about ±3 cm (0.1 ft) or less depending on the type of tool used.

CALCULATED PARAMETERS

The development of digital, calibrated geophysical logs has expanded the capability to use these logs simply to determine depth and thickness of coal and rocks. With calibration, various responses on the geophysical logs can be used to infer analytical and engineering data. This requires that the tools be calibrated on a regular basis. For example, strength indices, which can give valuable roof support information, can be estimated from the bulk density and sonic logs.

Lithology can be determined from density and natural-gamma logs coupled with resistivity, sonic, and neutron logs. The caliper log can give an indication of strata that are soft, highly fractured, or that can readily decompose during drilling. The bulk density log commonly correlates well with the laboratory determined apparent density of the coal core intervals, which can be used to estimate the ash and calorific content.

It must be cautioned that all of these calculations are empirical and require site-specific calibration from core data. Extrapolation from one deposit to another, even within the same geologic province, could yield erroneous data and information.

SAFETY AND STUCK PROBE PROCEDURES

The logging operator must abide by all state and federal regulations that govern the use of radioactive sources. The four principal radiation safety factors are shielding, distance, time, and monitoring. The best policy is to keep all nonessential personnel as far away from the logging operation as possible while the radioactive source is not in its protective storage container (pig). All logging units should use a radiation survey meter that is calibrated regularly, workers should use radiation exposure badges that are regularly monitored, and all sources and pigs should be regularly tested for radiation leaks.

Prior to initiating a geophysical logging program, the responsibility for the recovery of a geophysical probe should be established in the event that it becomes lodged in the borehole. The procedures and potential liabilities for abandoning a tool that contains even a relatively low-level radioactive source make the abandonment of such a tool undesirable.

If the field personnel are not experienced in "fishing" for down-hole equipment, it is probably best to arrange to contract a company that specializes in retrieving sources in the event they are needed. The fundamental rule to follow in any tool recovery operation is not to initiate any actions that might sever the cable to the probe. Most tool companies and some logging contractors have overshot-tools which are designed to follow the cable down to the probe. Once the cable becomes detached from the probe, chances of recovery are dramatically reduced. If it becomes necessary to abandon a borehole with a radioactive source still lodged in it, the appropriate regulating agency must be notified for specific procedures to follow prior to abandonment.

QUALITY CONTROL

Poor quality logs can result from either operator errors or instrumental malfunction. The final logs should be neat and legible and all the required information on the log heading should be completed.

One very common operator-related problem is recording of a curve at an improper sensitivity. A recorder that has its sensitivity set too high will produce a trace that has excessive drift or is offscale. Too low a sensitivity will give a characterless or smooth trace. A sensitivity setting that effectively uses the space allotted for the log trace without going offscale (except in certain anomalies) should be selected. Other quality-related problems include overplotted or poorly spaced curves, excessive biasing, and recorder pens that skip, run, or draw wide lines.

Logging speeds can also affect the quality of the curves. Logs based on counting rates, such as natural-gamma or density, are especially negatively affected by faster logging speeds. Older analog equipment typically used speeds of about 3 to 4.5 m (10 to 15 ft) per minute. Some digital units can log to speeds of about 18 m (60 ft) per minute, but speeds of about 4.5 to 7.5 m (15 to 25 ft) per minute are most frequently used. Some of the high-resolution probes require speeds as low as 0.3 to 0.6 m (1 to 2 ft) per minute; faster chart speeds will produce an expanded log which is at a larger scale, thereby enhancing the log characteristics of the specific depth intervals or through the lithologies of interest. Expanded logs are commonly produced for coal seams to enhance the quality variations of the seam.

Instrument errors can be either very obvious or subtle. Any reading at or near zero or any sudden change in the character of the log should be investigated. The quality of the logs can gradually deteriorate over a period of weeks during a drilling project and therefore it is helpful to compare logs periodically. In general, any departure from the norm is likely to be an indication of an equipment malfunction.

Geophysical logs document important data in drilling and coring programs. Demand the best log quality that a particular logging unit is capable of producing and do not be reluctant to request that a log be run again if it is unsatisfactory.

CORE HANDLING PROCEDURES

Valid laboratory analysis of a core sample is dependent on the proper removal from the barrel and handling of the core at the drill site. To maximize the productivity and quality of the results obtained, a good working relationship and effective communication should be maintained between the field geologist or engineer and the driller.

All parties should work together to maintain a well-organized and efficient drill site. Address all safety matters in the drill site area. Follow all federal, state, and local safety regulations. The driller should exercise particular care and caution when retrieving a full core barrel from the borehole to prevent breakage and/or loss of core to the borehole during the retrieval process.

A stable work platform is recommended for the handling and examination of a coal core. The platform may consist of saw horses with a core tray or trough laid across them (Fig. 12). There are several types of sturdy core trays such as halved PVC pipe, metal pipe, and constructed wooden trays. At a minimum, the core tray should be longer than the inner core barrel. The core tray can be perforated or inclined to allow drainage of excess drilling fluid. Establish consistent handling procedures so that the top and bottom of each core run can be readily determined and labelled.

Before coring, the condition of the inner core tube should be examined. Solid-inner tubes should be thoroughly flushed with clean water to remove any remaining sample residue adhering to the inner surface. Split-inner tubes should be flushed with clean water, both halves wiped clean prior to assembly, and taped according to manufacturer's specifications (Fig. 13). To reduce wear and damage to core barrels, only recommended tools designed by the drill core manu-

FIG. 12—Core tray on sawhorse with PVC tubes on drill site in Wyoming (coal core is covered with dampened cloth to inhibit moisture loss).

FIG. 13—Removing filament tape wrappings of split-tube core barrel after coring.

FIG. 14—Solid tube core barrel prior to extruding core.

facturers should be used to push cores and reassemble barrels.

Under no circumstances should lubricants or additives be applied to the inner surfaces of a barrel to facilitate core capture and extraction. Although this procedure may be advantageous to the driller, it can contaminate the core samples.

EXTRACTING CORE FROM A SOLID-INNER TUBE

Care should be taken when extracting the core from a solid-inner tube barrel (Fig. 14) to maintain the physical integrity of the core. A simple extraction method is to pull the inner tube out of the core tray leaving the core behind and intact within the tray. In cases where the core is slightly stuck to the tube, a rubber or wooden mallet may be used to gently tap the outer surface of the tube and free the section of the core. In addition, a wooden or metal plunger with a diameter slightly less than that of the inner tube may be used to gently push the core out into the core tray. In cases where a plunger is not available, the inner tube can be tilted to about a 30 deg angle to horizontal and tapped gently to free and remove the core.

In cases where the core is stuck inside the inner tube, a portable hydraulic pump or the drill rig's air or water circulation system can be utilized for extraction (Fig. 15). One end of a hose is attached to the pump or drilling rig's circulation system and the other end is attached to the top end of the inner tube. While gently tapping on the outside of the barrel, air or water pressure is applied gradually until the core is freed and extruded. Let no one stand in line of the open end of the inner tube. Working in below-freezing temperatures poses additional problems; all cores should be

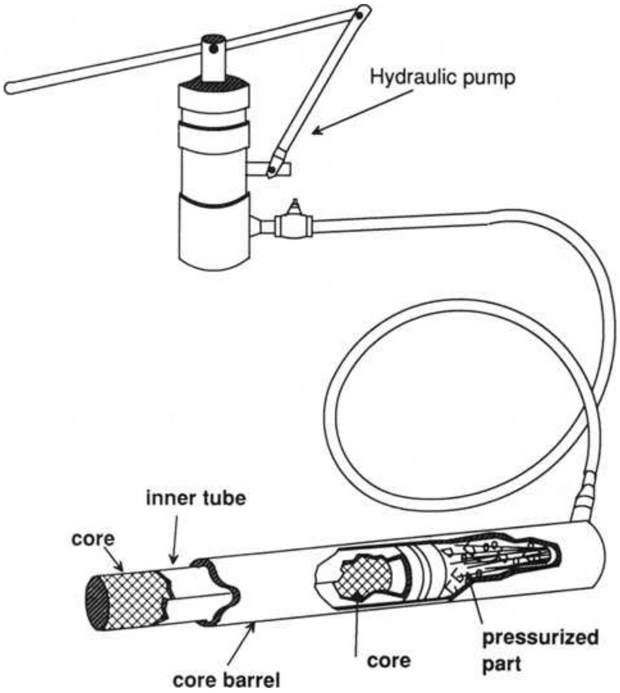


FIG. 15—Hydraulic equipment for extruding coal core.

extracted as soon as possible to prevent freezing of the core to the inside of the tube.

EXTRACTING CORE FROM A SPLIT-INNER TUBE

When utilizing a split inner-tube (Fig. 16) for coring, the following procedure is recommended. The tube should be placed in the core tray and a quick visual inspection should be made to determine if there are any noticeable "bulges" in the diameter of the tube. Large bulges can indicate that jamming occurred during coring; the result of jamming is compaction of the cored interval. After the visual inspection of the tube is completed, the top half of the tube is carefully removed. Any portions of the coal core that adhere to the top half of the tube should be removed, by hand, and placed in their proper position in the other half of the tube. Measure and record all core lengths and then slowly roll the lower half of the tube 180 deg, thereby leaving the undisturbed core in the tray. Again, any portions of the coal core that stick to the lower half of the tube should be removed and placed in their proper position in the tray.

FIG. 16—Describing core to determine coal/rock contacts and core recovery using a split-tube core barrel.

When making consecutive core runs, it is advantageous to utilize two separate split-inner tubes. This increases productivity by allowing the drill crew to resume coring using one tube while the core in the other tube is being extracted.

3

Description of Coal and Rocks

DRILL CUTTINGS

The lithology and approximate thickness of the strata being penetrated during drilling can be monitored by describing the cuttings after they are separated from the borehole fluid returns. Precise description of the cuttings is necessary for determining the depth and type of marker strata above and below the targeted coal seam as well as the depth and thickness of the coal seam. Precise descriptions of drill cuttings is especially important if core is not taken and critical if geophysical logs are not run. Cuttings should be collected at regular depths to avoid problems with lag time when penetration rates vary.

The logging of drill cuttings should be performed by the field geologist/engineer and the driller separately and compared for completeness. A consistent log format is recommended to help ensure complete records of the locality being drilled. A format compatible with computerized coding facilitates the evaluation process. The description of cuttings should include the rock types, color, grain sizes, special characteristics, hardness, and the depths to the top and bottom of each coal bed and all other identified strata.

Cuttings obtained while drilling with air are the simplest to log. These materials will be relatively uncontaminated with upper borehole materials or drilling mud. When drilling with air, water-bearing formations can be detected and the depth at which ground water was encountered should be noted on the log. When drilling with air, there is a relatively short time interval between penetration of a formation and the first appearance of its cuttings at the surface. This period or lag-time is dependent on return air velocity and volume, borehole depth, lithology, and penetration rate. Lag-time increases with increasing borehole depth, diameter, or decreasing air velocity/volume.

When drilling with fluids as the circulating medium, longer lag-times should be expected because fluid return velocities are typically less than air medium velocities. Cuttings obtained when drilling with fluids are more likely to contain contamination from upper borehole materials. After drilling has passed through a coal bed, it is common for coal fragments to continue to appear in the cuttings. Comprehensive lithologic descriptions and experience must be used to distinguish new material from cuttings derived from previously drilled intervals.

Difficulties in describing cuttings are increased when drilling with mud. To better identify lithologic changes, more frequent sampling of the cuttings may be necessary. To facilitate descriptions, the cuttings can be caught in a wire mesh strainer and then rinsed with water to remove the drilling mud. Special care and attention are necessary to precisely determine the top and bottom depths of a coal bed. Changes in the drilling rate and pull-down pressure can be good indicators of lithologic boundaries to an alert driller.

Coal cuttings from rotary drilling can be collected for analysis, but it is impossible to obtain a representative sample of the coal seam in this manner. If cuttings collection is required, the sample can be collected using a wire-mesh strainer, drained, and properly sealed (refer to section on Field Packaging of Coal Cores). Obviously, the reliability of the analytical results is questionable for samples obtained in this manner. Petrographic analyses, such as the determination of vitrinite reflectance to estimate the rank of the coal bed, are probably the only valid use of coal cuttings for testing.

DRILL CORE

The level of detail for core descriptions will depend on the processing and analytical scheme intended for that particular sample. Cores intended for petrographic analysis, X-ray radiography, washability testing, and mine interval benching should be packaged after cleaning and transported to the laboratory. A coal core should not be broken any more than necessary in the field.

The time that the core is exposed to the weather conditions should be also minimized [*40,41*].This practice is especially important when coring low rank coals where moisture loss from the coal can be rapid in hot, dry, or windy conditions. If a coal core cannot be logged immediately, it should be covered with a damp cloth to prevent moisture loss, particularly during hot or windy weather.

The core should be gently rinsed with clean, fresh water before examination and description. The measured length of the core should be compared with the measurement of the cored coal seam interval reported by the driller and inferred from the geophysical log, if available. Any lost or missing intervals should be determined and then noted on the log sheet. Any expansion because of broken core should also be recorded. A determination of the percent of core recovery on a length basis should then be calculated to validate the core as representative of the coal seam interval. The equation for calculating core recovery on a length basis is:

$$\%\ \text{Length Recovery} = (C/D) \times 100$$

where

C length of recovered coal core, and
D drilled thickness of coal seam (from drillers or geophysical log).

A consistent log format should be utilized on coring projects. A format compatible with computerized coding is recommended. The physical description of a coal core should include the following information [*41–43*]:

1. Measured length of described interval.
2. Color.
3. Coal type.
4. Thickness and abundance of banding.
5. Layering of vitrain (xylain) and attritus.
6. Natural fracture (cleats, slips, joints, etc.).
7. Mineralization.
8. Hardness.
9. Distinctive features.
10. Nature of roof and floor contacts (e.g., sharp, gradational, rooted).

Rock core (noncoal) should be described in detail as much as possible. Rock type, grain size, color, and sedimentary structures are useful major descriptors. Consistency in core descriptions facilitates evaluation of core data. One method to make core descriptions more uniform is to develop a reference set of photographs of representative core sections [*44–46*]. The photographs can be used by drillers and geologists/engineers to describe cores and thereby produce more consistent descriptions. Photographing the rock and coal core collected can also serve to document the features described and can be kept as a permanent record of the core.

ADDITIONAL QUALITATIVE DESCRIPTIONS

Various qualitative schemes have been developed in industry, government, and other organizations to describe physical characteristics of core. These descriptions are based on empirical relationships derived from historical data and developed on a site-specific or case-specific basis. The descriptions have been applied to predict the behavior of strata in terms of rock mechanics, minability, hydraulic characteristics, and effects on coal quality. Appendix I outlines some examples of indices for weatherability, rock quality, fracture spacing, orientation, etc.

4

Sampling of Coal Cores

INTRODUCTION

COAL has often been described as one of the most difficult materials to sample because of its heterogeneity [*47*]. It is the end product of a sequence of biologic and geologic processes, the complexity of which should at least be appreciated whenever coal is appraised for a specific use [*48*].

The ultimate objective of a coring program is to collect a group of representative samples that define both the vertical and lateral variability of a coal seam(s) in a given resource area. The key to a successful sampling program is adequate preplanning. Sufficient flexibility must also be incorporated into the plan to resolve unanticipated conditions encountered in the field.

It is neither practical nor advisable to set rigid sampling guidelines. No two coal deposits are ever identical, particularly in terms of coal seam variability, mining scenarios, and utilization requirements. The purpose of this section is to outline significant criteria to consider in developing and conducting a sampling program. These concepts must be adapted to address each particular situation.

Sampling is probably the most critical part of any evaluation program. No amount of care taken in the coring and analytical procedures can remedy mistakes made in the sampling process, thus reinforcing the necessity for thorough planning.

PLANNING

Planning is probably the most important phase of the sampling program. Many exploration dollars have been spent on acquiring useless data resulting from sampling mistakes or on recording an area to correct previous deficiencies. Even potentially more serious and costly are development decisions that are unwittingly based on data which suffered from sampling problems and which are not representative of the deposit under investigation. While no plan is ever completely foolproof, adequate planning will maximize the benefits of a coring project. Variations in coal lithotypes and quality, the intended purpose in sampling and analyses, the anticipated mining approach, and the minimum sample size required for proposed tests should be considered in the planning stage. The planning stage should involve a multidisciplinary team including geologists, mining and coal preparation engineers, coal utilization specialists, such as combustion and chemical engineers, and coal chemists. The input from this team approach will help insure that the maximum benefits from the coring program are obtained.

LITHOTYPE AND ASH VARIATIONS

Both coal and noncoal lithotypes can vary greatly within a vertical section of a coal seam [*42*]. This variability can result in significant fluctuations in ash yields as well as other coal parameters. Often, these variations may be difficult to detect visually. The use of geophysical logs, which can be very sensitive to lithotype variations, can be particularly useful. X-ray radiography is another coal analytical descriptive technique that can help define ash variability [*41*]. A comparison of a geophysical log and X-ray radiograph of a coal core is shown in Fig. 17.

It is important, particularly in the early stages of exploration, to sample the entire coal seam in layers or sections [*41,42,49*]. As a better understanding of the vertical and lateral variability of the seam is acquired, the need for extensive subsampling can often be reduced. Environmentally deleterious elements such as sulfur are often concentrated in specific horizons in a seam. For instance, sulfur contents are commonly higher near the top and/or bottom of the seam and adjacent to channel areas [*37,44*]. Knowledge of such distributions permits the evaluation of such options as selective mining or blending to reduce the amount of deleterious elements in the mined product. Without separate samples of the individual layers of a seam, the potential of various beneficiation options may not be possible.

The extreme case of lithotype variability is the presence of noncoal layers or partings. The handling of partings is probably the single most frequent source of confusion in sampling a coal core. The best approach is to sample each parting separately, especially in the initial exploration phases. There are numerous instances where partings were arbitrarily discarded or not analyzed. These situations render the remaining sample(s) nonrepresentative, making it impossible to accurately forecast the as-mined quality. Splits of the sample intervals for a seam can always be physically recombined, and the recombined whole-seam samples can be analyzed or values approximating a whole-seam analysis can be mathematically composited from the analyses of the interval samples. Once a parting is either discarded or included in a coal sample, it is impossible to assess its impact on the seam quality.

Sample compositing needs must be considered in the planning phase. For certain coal parameters such as the Hardgrove Grindability Index and especially ash fusion temperatures, mathematical compositing may not be appropriate. These parameters are not necessarily additive, like ash or sulfur values. For these cases, recombining splits of these samples on a weighted basis and analyzing the composited split is a prudent alternative. It is also impor-

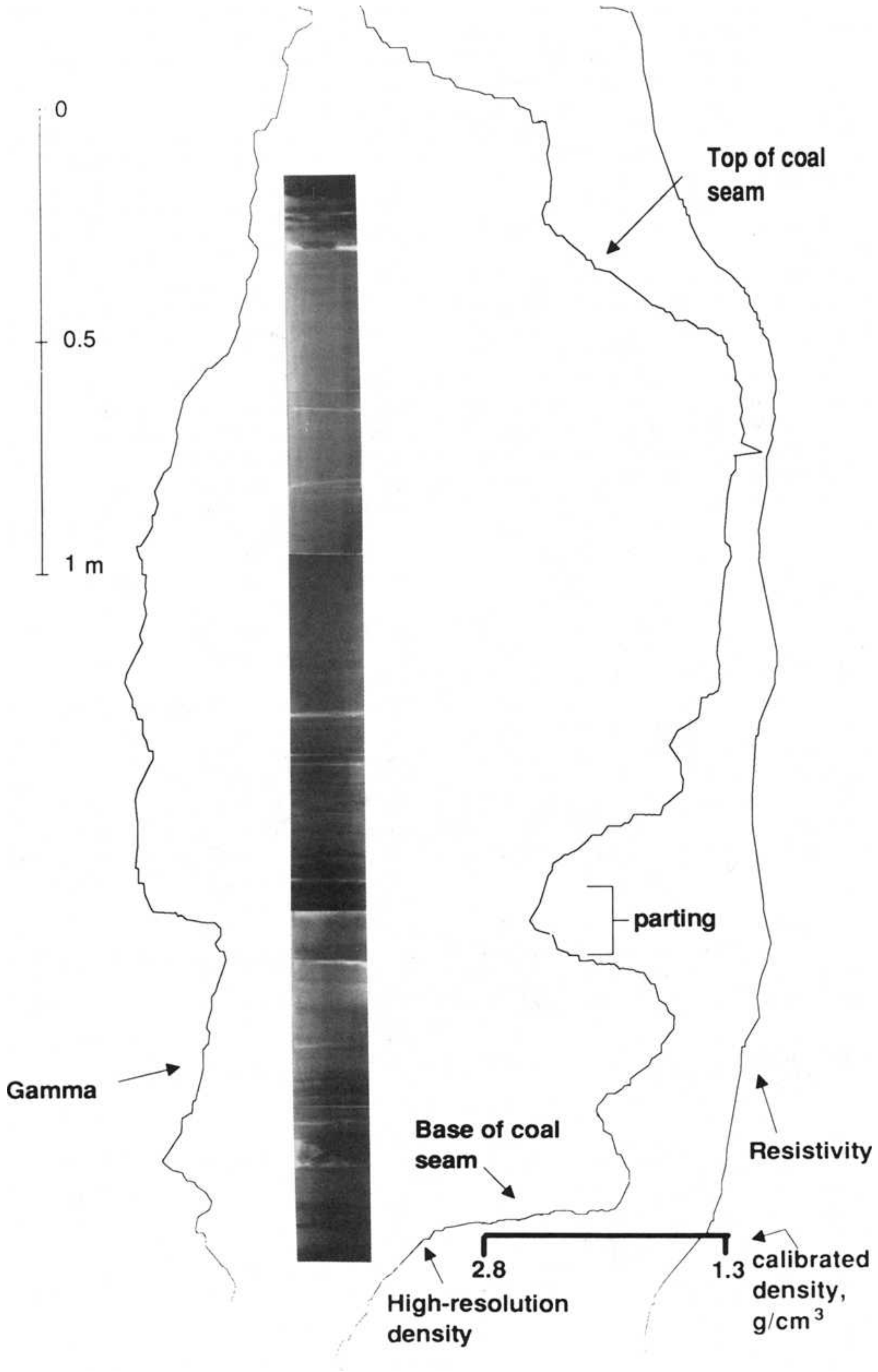


FIG. 17—Comparison of geophysical logs (gamma, high resolution density, and resistivity) of a coal seam to an X-ray radiograph of the coal seam. (Dark areas on radiograph depict high-ash layers.)

tant to consider the method in which the proportional amounts of each sample are calculated. Often, the mistake of simply using a volumetric approach (dividing the length of each sample by the total length of the interval to be composited) is used. If the densities of each interval are similar, the volumetric method is appropriate; however, in cases where there are significant density differences, such as minerals that compose partings compared to coal, the volumetric method is flawed. The apparent density should be determined for each lithologic interval and then used to calculate composite values.

Table 4 shows the effects of using weighted methods by volume (thickness) as compared to density to calculate coal quality averages for a whole seam from data that were obtained on interval samples. As shown in the example, the volumetric method overestimates the calorific value of the seam by over 900 Btu/lb, and underestimates the ash by over 5.0% and the sulfur by almost 0.2%. The weighted-average by density method should also be used to calculate the correct proportions when physically combining samples for additional analyses.

PURPOSE OF SAMPLING

The intended use of the data, the purpose of collecting coal samples, and the kinds of analyses to be performed on the samples dictate the type and nature of the samples that should be collected (Fig. 18). Sampling of coal is a critical exercise that must keep in mind the end purpose [*41,51*]. The suite of tests to be performed on a core as well as sampling strategies are different depending on whether the anticipated utilization of a deposit is to generate steam, to produce metallurgical coke, to convert to synfuels, or to generate multi-use fuels such as obtainable in clean coal technology [*52*].

For example, if coal rank is to be determined, special sampling criteria must be followed. All mineral (noncoal) partings more than 1 cm ($\frac{3}{8}$ in.) thick and mineral lenses or concretions more than 1.27 cm ($\frac{1}{2}$ in.) thick and 5 cm (2 in.) wide shall be excluded from the sample (ASTM Practice D 4596). It should be noted that currently only apparent rank can be determined from the drill core (ASTM Classification D 388).

One important concept to keep in mind is that end purposes often tend to be moving targets due to such factors as market shifts, new mining, preparation, and utilization technologies, energy economics, and environmental regulations. For example, many coal reserves in the early 1970s were originally evaluated as potential synfuels and metallurgical coal resources. As markets disappeared or declined, these reserves have been re-evaluated for steam coal potential, often with some difficulty. For example, some deposits originally explored for coking coal did not have one calorific value determination for the whole drilling program [*53*].

A concept often overlooked in the design of a new boiler is a determination of an optimum coal quality for that boiler to reduce initial plant capital costs for emission controls, coal and ash-handling systems, operation, and maintenance. Typically, the plant-design engineers are simply given an average quality with semiarbitrary ranges. If a slight increase in the average quality and/or a reduction in the magnitude of quality variations through such practices as selective mining or in-pit blending could result in significant reduction in plant costs, then the economic tradeoffs should be evaluated. Adding flexibility to address these kinds of questions in the design of a coring program is usually beneficial in the long run.

To effectively deal with a continually changing marketplace and answer the "what if" questions, a good understanding of the variability in the significant coal parameters is essential. A good policy for at least a selected number of sample points is to undertake as complete a testing program as possible [*53*]. An appropriate suite of analyses, which will generally provide sufficient data to determine both the metallurgical and steam potential of the deposit they represent, is given in Table 5. If costs restrict the number of tests to be performed, the analyses indicated with an asterisk in Table 5 should provide basic characterization. In the case of washability tests, analyses should be run on both the raw and washed core samples whenever possible.

TABLE 4—Calculation of whole seam composite analyses from interval samples by volume and mass.

Whole Seam Quality Calculated by Volume

	Thickness, m	Vol%	% Ash	Vol% × %Ash	% S	Vol% × %S	Calorific Value (CV)	Vol% × CV
Coal	2.90	48.3	5.0	2.42	1.0	0.48	14 050	6 786
Parting	0.50	8.3	80.0	6.64	0.1	0.01	1 000	83
Pyrite	0.01	0.2	66.6	0.13	53.4	0.11	550	1
Coal	2.60	43.3	10.0	4.33	0.8	0.35	13 975	6 051
Whole Seam	**6.01**	**100.0**	...	**13.52**	...	**0.95**	...	**12 921**

Whole Seam Quality Calculated by Mass

	Thickness (Th), m	Density (D), g/cm³	Th × D, g	Mass %	% Ash	Mass % × %Ash	% S	Mass % × %S	CV	Mass% × CV
Coal	2.90	1.30	3.77	43.7	5.0	2.19	1.0	0.44	14 050	6 140
Parting	0.50	2.60	1.30	15.1	80.0	12.08	0.1	0.02	1 000	151
Pyrite	0.01	5.10	0.05	0.6	66.6	0.40	53.4	0.32	550	3
Coal	2.60	1.35	3.51	40.7	10.0	4.07	0.8	0.33	13 975	5 688
Whole Seam	**6.01**	...	...	**100.1**	...	**18.74**	...	**1.11**	...	**11 982**

Coal only = Sample taken to include all mineral partings
Whole Seam = All material between roof and floor of seam
Bench = Separate samples of partings and coal between partings
Facies = laterally extensive subunits of the seam

		Classification by Rank	Apparent Rank	Geologic Studies	Resource Evaluation	Reserve Quality	Environmental Quality	Product Quality	Washability Testing
CHANNEL	Coal Only	X		X				?	
	Whole Seam		X			X	X	X	X
	Bench		X			X	X		X
	Facies		X	X		X	X		X
CORE	Coal Only		X		X			?	
	Whole Seam		X			X	X	X	X
	Bench		X			X	X	?	X
	Facies		X	X		X	X	?	X

FIG. 18—Types of samples and purposes for which samples are used.

TYPES OF ANALYTICAL TESTS

The tests in Table 5 are listed with their appropriate ASTM standard and subdivided into chemical, rheological, and petrographic tests. In some cases, a test (such as ash yield) is applicable for both metallurgical and steam coal assessments. Since only bituminous coals produce coke, appropriate metallurgical tests are indicated for bituminous coals only.

Table 5 is intended to be used as a general planning guideline. Every core program should be specifically designed to address the anticipated use(s) of the coal reserve and any special situations which may be anticipated for each coal deposit being evaluated. The following sections briefly summarize the use of the data generated by each test listed in Table 5.

Chemical Tests

Moisture

Moisture is a commercially important parameter used to establish taxes, rank, and other analytical values such as grindability. This value is a basic parameter needed to evaluate the quality of a coal. The moisture content of core samples often includes not only the inherent moisture of the coal seam but also any surface moisture from groundwater and/or drilling fluids.

Volatile Matter

Volatile matter values are used for selecting coals for blending in coke production, determining coal rank according to ASTM, selection of coals for combustion and liquefaction, and for smoke control. Volatile matter values are commonly a specification in coking and steam coal contracts.

Ash Yield

Ash yields are used to determine the optimum cleaning method, contract specifications for coke making and combustion, and the selection of pulverizers.

Sulfur

Sulfur values are used in contract specifications for combustion and coke manufacturing, estimating the amount of

TABLE 5—Analytical tests used to characterize the metallurgical or steam coal quality of drill core samples.

Test	Metallurgical	Steam	Applicable ASTM Standard
Visual Description	X	X	none
Chemical			
Proximate	X	X	D 3172
Moisture[1]	X	X	D 3173
Volatile Matter[1]	X	X	D 3175
Fixed Carbon[1]	X	X	D 3175
Ash[1]	X	X	D 3174
Equilibrium Moisture[2]		X	D 1412
Sulfur[1]	X	X	D 3177
Ultimate	X	X	D 3176
Carbon	X	X	D 3178
Hydrogen	X	X	D 3178
Nitrogen	X	X	D 3179
Oxygen	X	X	D 3176
Sulfur	X	X	D 3177
Forms of Sulfur	X	X	D 2492
Chlorine	X	X	D 2361, D 4208
Ash Composition	X	X	D 3682
Ash Fusion[1]	X	X	D 1857
Trace Elements		X	D 3683
Calorific Value[1]	X	X	D 3286, D 2015
Rheological and Physical			
Gieseler[1]	X[3]		D 2639
Dilatation Tests (Audibert, Ruhr)	X[3]		none
Free-Swelling Index[1]	X[3]		D 720
Hardgrove Index[1]	X	X	D 409
Petrographic			
Maceral Analysis[1]	X[3]		D 2797, D 2799
Vitrinite Reflectance[1]	X[3]	X	D 2797, D 2798

[1] Minimum test required to properly characterize the coal.
[2] Especially important for drill core samples from low rank coal.
[3] Bituminous coals only.

sulfur liberated during combustion, and determining the optimum cleaning method.

Forms of Sulfur

The pyritic and organic sulfur values are used to evaluate the efficiency of cleaning processes for the removal of pyrite. The level of sulfate values may indicate if the coal is weathered.

Ultimate Analysis

Carbon, hydrogen, nitrogen, sulfur, ash, and oxygen values are used to calculate calorific values. Carbon data can be used as an index to coal rank.

Chlorine

Chlorine values can be used to indicate the presence of Na or K that may cause fouling problems in high temperature boilers.

Ash Composition

Ash composition values are used to evaluate and solve problems in clinkering, boiler fouling and slagging, removal of fly ash from boilers, and estimating ash-fusion temperatures.

Ash Fusion Temperatures

Ash fusion temperatures are specified in coal contracts because they indicate the melting tendencies of the coal ash and will indicate if the coal is suitable for use in a wet or dry bottom boiler.

Trace Elements

Trace element values may indicate the possibility of pollution problems caused by certain metals liberated during coal combustion or from the leaching of refuse piles.

Calorific Value

Calorific value is the most important characteristic of coals considered for combustion and a primary parameter specified in steam coal contracts. It is also a principal parameter in the ASTM classification of high volatile bituminous and lower rank coals.

Rheological and Physical Tests

Gieseler Fluidity

Fluidity values are mainly used to assess the coking properties of coal and are specified in contracts. The values are used in determining coal blends to produce quality metallurgical coke. The Gieseler test is very sensitive to weathering and can be used to detect coal oxidation.

Hardgrove Grindability Index (HGI)

HGI values indicate the relative ease or difficulty in pulverizing coal. The HGI will aid in determining the selection of pulverizers.

Dilatation Tests

The coking power or the amount of expansion measured in coal samples is commonly determined using the Gray King test (ISO/R505: "Determination of the Gray King Coke Type of Coal").

Free-Swelling Indices (FSI)

FSI is a measure of the agglomerating tendency of coal heated to 800°C in a crucible. Coals having a high index are referred to as *caking coals;* these having a low index are referred to as *free-burning coal.* A low FSI of a known caking coal can also indicate oxidation resulting from weathering.

Petrographic Tests

Maceral Analysis

The maceral analysis is performed using a microscope to determine the volumetric percentages of the various macerals present in a coal. The maceral composition has a profound effect on coke making and such information is useful when blending coals to produce high-quality coke.

Vitrinite Reflectance

The vitrinite reflectance values are measured microscopically and are a direct indication of the degree of coalification in bituminous and anthracitic coals. Vitrinite reflectance increases as coal rank increases (ASTM D 388, Appendix). Vitrinite reflectances are useful when blending coal to produce high-quality coke and are commonly specified in coal contracts.

MINING METHODS

Another essential step in the planning process is to ensure that the sampling scheme conforms with the anticipated mining approach. Underground mining methods are dependent on the thickness and dip of the coal seam and condition of the roof and floor strata. Some of the options for underground mining that impact core sampling are:

- The seam is so thick that it must be mined in specific benches.
- Bad roof rock requires that a layer of top or head coal remains unmined for support.
- Bad floor rock requires that a layer of coal be unmined to serve as a floor on which heavy mining equipment can operate.
- Selective-mining practices can be used to eliminate the inclusion of partings in the mined product.

Surface or strip mining allows greater flexibility in mining thick seams as well as handling unique in-seam quality problems. Some of the options to consider for surface mining are:

- The seam is so thick that it will be mined in benches.
- The seam contains parting(s) or bench(es) of inferior quality that can be selectively removed.
- In-pit blending can be used to create a consistent quality mined-product.

One characteristic common to both methods of mining is the incorporation of varying amounts of roof and floor strata with the coal during mining. This characteristic is termed *out-of-seam dilution* or simply *dilution*. Some suggest including some of the roof and/or floor into the core samples to allow for the inevitable contamination during mining (SAA 2519-1982). This is not a recommended practice except perhaps in an actual mining operation where the exact amounts of dilution can be reasonably forecasted. Once dilution material has been included with the sample, the sample is no longer representative of the seam. It is best to sample the roof and floor separately. Then, they can be composited in amounts that are compatible with the planned mining scheme.

The amount of dilution incorporated with the coal is dependent on a number of factors including quality, color, degree of induration and competency, and sharpness of roof and floor contacts with the seam. In cases where there is a sharp contact or marked difference in color and/or degree of induration between the dilution material and the coal, the effects of dilution are more easily controlled. The type of mining equipment and the constraints of the quality specifications in a contract also play an important role in controlling the amount of dilution.

All of these factors can also be applied to the handling of partings. The pronounced effects of the incorporation of noncoal material with coal are clearly illustrated in Table 4. The inclusion of a parting increased the ash yield of the whole seam to over 4%. The effects of dilution or inclusion of partings only a few centimeters thick can significantly affect coal quality. This emphasizes the need to sample each unit separately to assess its individual contribution to coal quality.

Various "rules of thumb" have been advocated for sampling both dilution material and partings. Common practice has been to sample from 0.15 to 0.31 m (0.5 to 1 ft) of roof and floor for dilution estimates. These thicknesses for dilution would be unacceptable, especially in the case of thin seams. Similarly, some of the common conventions for dealing with partings can also cause problems [*41*]. For example, it has been generally assumed that it would be impractical to selectively mine partings less than 15 cm (6.5 ft) thick; therefore this non-coal material was included in the coal core sample. The development of the surface continuous miner, however, now allows selective removal of partings only several centimeters in thickness; likewise, it can reduce dilution effects and afford more efficient thin-seam recovery. A rule of thumb often seems like a safe choice since it implies widespread acceptance, but the best practice is to incorporate as much flexibility in the sampling program to accommodate as many mining options as possible. Previous experience, if available, is helpful, but allowances for different scenarios such as the application of different mining equipment or new technologies should always be considered.

MINIMUM SAMPLE MASS

Each analysis requires a certain minimum sample mass. Certain procedures, such as washability tests, require particularly large samples. It is critical, therefore, that the minimum total sample mass be predetermined to ensure that there will be sufficient sample from which the necessary test and storage splits can be obtained. It is probably a good idea to allow for more than the estimated minimum mass wherever practical. This will allow for a reserve sample in the event test reruns, additional tests, or compositing are required. One method of increasing sample mass is to obtain a larger diameter core (Table 6).

CORE RECOVERY

The subject of core recovery is included here with the sampling section because it is an integral factor in the collection of a representative sample. Coal core recovery is best done by the field personnel responsible for sampling [*40*]. Consulting with the drilling crew can often provide valuable core recovery information because experienced drill operators can often detect interval(s) of core loss.

As previously discussed, the most common method of calculating core recovery is to compare the total length of the recovered core with the total thickness of the coal seam as determined from the geophysical logs. If the core is badly broken and difficult to measure, the mass of the recovered core can be compared with the theoretical mass calculated from the core diameter, density, moisture content, and the

TABLE 6—Masses of core based on density of coal.

Density of Coal, g/cm³	Mass Per Core Sample of Different Diameters (Units As Indicated)						Tonnage	
	5.1 cm, kg/m	2 in., lb/ft	7.6 cm, kg/m	3 in., lb/ft	15.2 cm, kg/m	6 in., lb/ft	Metric Tons Per Hm²-m	Short Tons Per Acre-Ft
1.30	2.64	1.77	5.93	3.98	23.70	15.94	13 000	1768
1.35	2.74	1.84	6.16	4.14	24.61	16.55	13 494	1836
1.40	2.84	1.91	6.38	4.29	25.52	17.16	13 994	1904
1.45	2.94	1.98	6.61	4.44	26.42	17.77	14 494	1972
1.50	3.04	2.04	6.84	4.60	27.35	18.39	14 994	2040
1.75	3.55	2.38	7.98	5.36	31.90	21.45	17 493	2380
2.00	4.05	2.72	9.12	6.13	36.46	24.52	19 996	2721
2.25	4.56	3.06	10.26	6.89	41.01	27.58	22 492	3027

length as determined from the geophysical log. The percent recovery can be determined by dividing the actual measured mass of the core by the theoretical mass.

Anything less than 100% recovery jeopardizes the validity of the sample in terms of its being representative. For example, a 3 m (9 ft) thick coal seam with a 0.15 m (0.5 ft) thick parting was cored and the parting was lost in drilling. Because this recovery (95.2%) met the minimum recovery acceptable (95%), the core was analyzed. Later, another hole had to be drilled and the core analyzed to acquire more accurate quality data. In a coring operation, 90 to 95% recovery is routinely considered acceptable, but those recovery percentages can yield data that are useless or, even worse, misleading. At times, 100% core recovery is not possible or practical because of hole conditions or project budget. In such situations, comparisons of the lithotype descriptions with the geophysical logs may lead to realistic assumptions being made to determine the thickness and quality impacts of lost-core intervals.

Commonly, for core holes located immediately adjacent to an existing borehole (twinned), only one hole will be geophysically logged to save costs. Coal seam thickness and character can change significantly laterally even in distances of 8 m (25 ft) or less. To ensure proper core recovery determinations, this practice of selectively geophysically logging holes should be discouraged. Furthermore, it is important to relate vertical quality variations in the seam to the geophysical log responses. These arguments underscore the need to geophysically log every cored borehole.

SAMPLING PROCEDURES OF COAL CORE

Once in the field, a diagram of the proposed core sampling approach which was developed in the planning stage is very helpful. Figure 19 illustrates some of the common sampling schemes used for thick coal beds. Any scheme chosen must incorporate some degree of flexibility. This is particularly true if a plan to sample by strict interval thickness is adopted. For example, using a strict 1-m sampling interval for thick seams, the lower 0.6 m of the top seam, the partings, and the upper 0.3 m of the floor rock were included in sample intervals with coal and analyzed together (Fig. 19). Depending on the purpose for the sampling, these data, because they are constrained by a strict sampling scheme, will produce data of limited value. Strict footage schemes can work in some cases; however, changes in lithology or coal type should always be the primary criterion for selecting sampling intervals.

Occasionally situations arise that do not conform to the original sampling scheme. For example, it may be difficult to distinguish boundaries between coal and noncoal layers because of similarities in color and/or gradational contacts. If the geologist examining the core has problems differentiating between the layers, it is likely that these conditions will also pose problems for selectively handling the material during mining.

If there is any question as to how a seam should be sampled, it is preferable to seal and box the core intact (see next section) and send the core to the office or laboratory. There, it can be examined and described in greater detail than in the field and compared with the corresponding geophysical logs and descriptions of cores and logs from other nearby boreholes. The geophysical logs can provide detailed definitions of lithologic changes that are often difficult to detect visually. Data from nearby geophysically logged boreholes can be used also to ensure that the different layers are sampled consistently in all of the cores.

Postponing the final sampling also allows consultation with the exploration team to obtain a consensus on how to handle any situations that were not anticipated in the planning stage. This practice is especially useful in any initial exploration program where it is often more difficult to develop a specific planned sampling scheme.

In conclusion, because each coal deposit is unique, focusing on fully documenting coal seam variability is the key to a successful sampling program. Perhaps the best practice to follow is: "When in doubt, break it out." The subsamples can always be combined or composited, but once benches have been sampled together it is impossible to assess their individual contributions to seam quality.

FIELD PACKAGING OF COAL CORES

One of the important tasks associated with coring is to properly package the core sample for transport to the laboratory. The type of container or packaging method to be used depends on the intended processing and analysis regimen to be performed. Choice of a container should be based on the types of tests to be performed by the testing laboratory, especially whether the sample will be subjected to destructive or nondestructive testing. Plastic material, which is impermeable to liquids and gas, will reduce moisture loss.

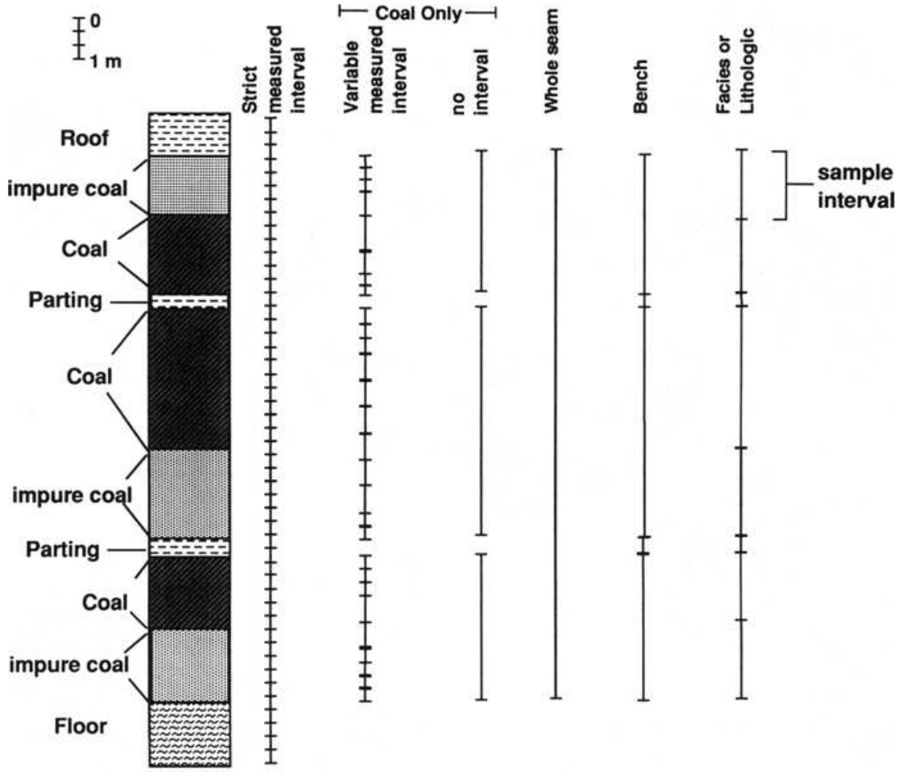


FIG. 19—Common sampling schemes for coals.

A partial list of packaging materials may include the following types of commonly available or constructed containers that, used separately or in combination, to protect the sample:

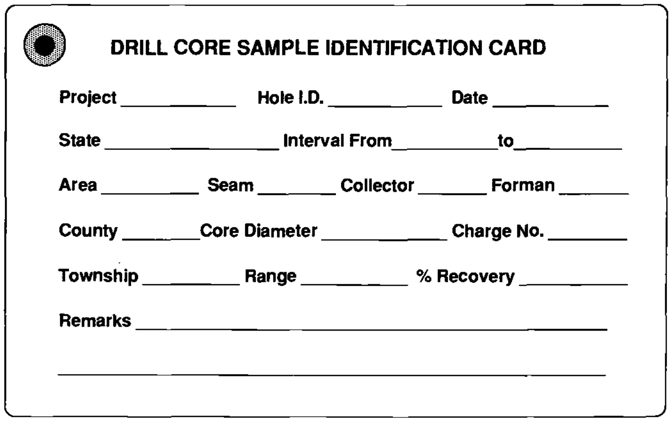
1. Polyethylene bags.
2. Polyethylene sleeves.
3. Commercial boxes (cardboard, plastic, or wood).
4. Wooden boxes (specially constructed).
5. PVC pipe (split in half lengthwise).

Core samples that will be analyzed by destructive methods can be packaged in the field in polyethylene bags [*40*]. Transparent bags are recommended so that coal samples can be easily differentiated from rock samples. If possible, bag size should be chosen to contain the entire interval in one bag. Polyethylene material should be at least 0.2 mm (4 mils) or thicker. Sample identification tags (Fig. 20) written with indelible ink should be attached to the bag. As a precaution, a second sample tag should be sealed in a plastic resealable sandwich-size bag and placed in the bag with the sample, in case the outside tag is lost.

Caution should be used when filling the bags because coal cores can fracture into sharp-edged fragments that easily cut the plastic. After a bag has been filled it should be held at the top, twisted shut with a wire, and then secured with a few wraps of filament or duct tape. For added insurance, the packaged sample should be placed neck first in a second bag and again resealed and labeled. This practice will help prevent moisture and material loss due to perforated sample bags. In such cases, sample identification can be written on the outside bag or on a label that is placed between the two bags.

In circumstances where a coal core sample must remain relatively intact, it can be rolled in a polyethylene sheet or slipped into a clear polyethylene sleeve having a diameter that is slightly larger than the core itself. Plastic sleeves or tubing are available in continuous rolls or can be obtained in specific lengths with one end presealed.

Care should be used to properly label and identify the top and bottom ends of the core after the sleeve has been sealed and to prevent reversal during subsequent handling and logging activities. Recommended containers for intact core include: special wooden core boxes [*42*] or split PVC pipe (Fig. 21) in an appropriate length and diameter [*41*]. Extrusion of the core can then be made into one half of the pipe or into the wood box lined with a sheet of plastic. After



DRILL CORE SAMPLE IDENTIFICATION CARD

Project ____________ Hole I.D. ____________ Date ____________

State __________________ Interval From ___________ to ____________

Area __________ Seam ________ Collector _______ Forman _______

County ________ Core Diameter _____________ Charge No. ________

Township _________ Range __________ % Recovery ____________

Remarks ____

____

FIG. 20—Drill core sample identification card.

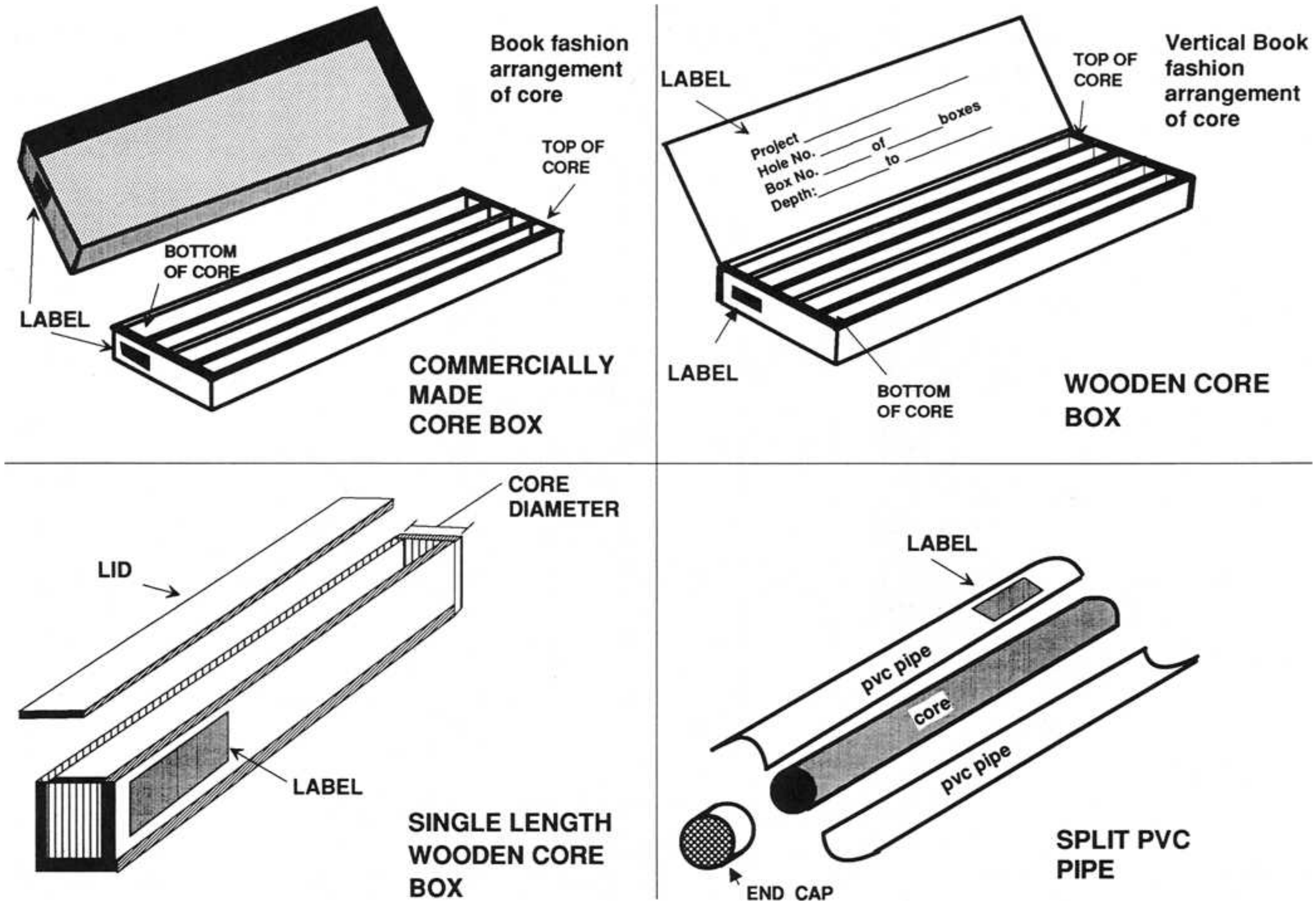


FIG. 21—Examples of core boxes or containers.

extrusion, the core may be examined, measured, logged, and sealed. In the case of using PVC pipe, after placing the core into the pipe (Figs. 22 and 23), the core and container can be slipped into a polyethylene sleeve. Prior to transport, the core should be packed to prevent disturbance during shipment or handling.

Several types of commercial core boxes (Fig. 21) are available for storing, transporting, and shipping sectioned drill core samples from the drill site. These containers are usually 0.6 m (2 ft) by 0.45 m (1.5 ft). The interior of these boxes is divided to hold several 0.6-m (2-ft) sections of core. The number of intervals a box will hold depends on the diameter of the cores being packaged. Boxes are constructed of water-resistant heavy cardboard, plastic, or wood. PVC pipe or wooden core boxes constructed on site can also be used (Fig. 21).

Drill site information should be written on the box lid and tray. This practice will reduce the possibility of errors caused by either rotated or interchanged lids for a series of containers holding a single cored interval.

In using a core box, a solid length of core must be broken apart into specific lengths dictated by the length of the core box used. A system for placing the core into the box should be followed (Figs. 21, 24, and 25). This practice will help to avoid possible misinterpretation or reversal of the core sections as they are placed into the box. To avoid this problem, one of two systems are generally used:

FIG. 22—Transferring coal core from tray to PVC tube half.

FIG. 23—Placing of second half of PVC tube on core sample.

FIG. 24—Transferring of coal from split-tube barrel into plastic sleeves and placed into core box.

(1) *Book Fashion*—With the rows running from left to right, the core is placed in the box with the top of the section placed in the upper left-hand corner (Fig. 21). Each following core section is laid in the next row with the top to bottom of the section arranged from left to right.

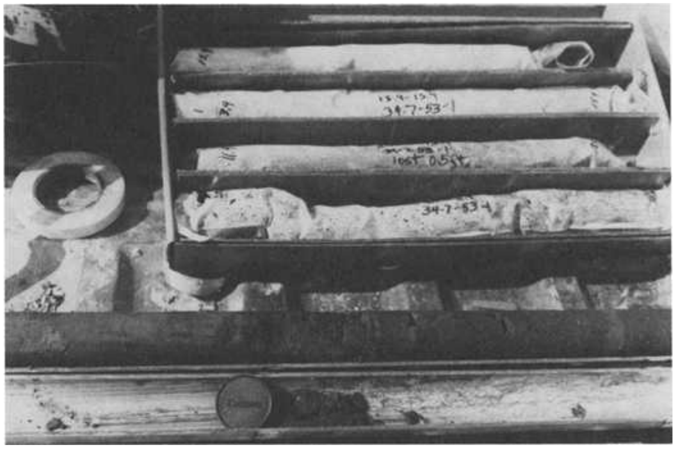


FIG. 25—Coal core packaged in plastic sleeves and arranged in vertical book fashion in core box.

(2) *Vertical Book Fashion*—In a box placed lengthwise (rows running away from the individual), the top of the core is placed in the upper left-hand corner of the box (Figs. 21 and 25). Each following core section is placed in the next row to the right, parallel to the previous segment, with the top of the core at the top of the box.

For both fashions, viewing the core is from left to right or top to bottom of each section. The difference in the two fashions is the corner that marks the beginning of the total interval contained in the box.

Where possible, the top and bottom ends of the core should be clearly marked on the packaging material and on the inside of the box at the proper location for added insurance. Intervals that were lost during drilling or removed for other purposes should be represented in their proper sequence position in the box with an appropriate length of filler material (such as wooden spacers). Failure to properly identify the top, bottom, and missing intervals of a core diminishes its value.

5

Laboratory Analysis of Coal and Rock Drill Core Samples

OVERVIEW

As soon as a coal sample is received by the laboratory, an initial inventory should be performed. The shipping containers should be inspected for damage or perforations in the plastic bagging that could affect the integrity of the sample. Each sample should be clearly identified and accompanied with a set of processing and analytical instructions. Any problems identified during the check-in inventory should be reported to the field collector before proceeding with any further sample preparation.

Any nondestructive or partially destructive physical tests should be performed prior to sample processing. The types of physical tests that can be conducted are dependent on the condition of the core. Some of the physical procedures include X-ray radiography, macroscopic analyses, apparent relative density, rock mechanics, and gas-emission testing.

X-RAY RADIOGRAPHY

X-ray radiography is a nondestructive test can be done upon receipt of a lengthwise section of coal core. The procedure is best performed by moving a section of core at a uniform speed through a unit that produces a collimated beam of X-rays (SSA 2519-1982) [*41*], although sections can be also radiographed using a single-point source X-ray. All radiation that passes through and is not absorbed by the various components of the core is recorded on X-ray sensitive film or a photodiode array located at the bottom of the unit producing a radiograph or, in some units, an X-ray image displayed on a cathode-ray tube (CRT). The collimated-beam technique produces a much clearer photographic image as opposed to the static procedure used in medical and welding examinations. Relatively pure coal bands with low mineral contents absorb less radiation and register on the photographic film as dark images (light bands on the CRT). Rock bands containing minerals readily absorb the rays and register as clear images (dark images on the CRT). With these patterns, the stratigraphy within a coal bed can be observed and recorded.

The applications that an X-ray radiograph have to offer are primarily descriptive. A permanent record of the lithotypes that compose a coal seam is produced without disturbing the original core. Minerals such as calcite, pyrite, and siderite can easily be identified using the X-ray radiograph and megascopic description. A semi-quantitative assessment can be made of the distribution of mineral matter and general coal quality in the seam by using the X-ray radiograph and geophysical logs (Fig. 17). Carbonaceous shale can be distinguished from non-banded coals having low mineral contents.

MACROSCOPIC ANALYSIS

Detailed descriptions and photographs of the coal core may be desirable to verify the field description. Field description methods described by Schopf [*42*] and other authors in *ASTM STP 661* [*43*] are also applicable to laboratory description. The basic method is to describe the thickness of the lithologic subunits of the coal bed such as banded coal, nonbanded coal, impure coal, or mineral parting. A refinement of this method is to describe the characteristics of the coal subunits. Other methods are given by Schopf [*54*], Cameron [*55*], Goscinski [*56*], and others.

The macroscopic appearance of coal is affected differently by various lighting conditions and types of surfaces examined such as cut, polished, cleat, or fracture surfaces. Some differences between characteristics described in the field and in the laboratory will result because of differences and variations in the lighting conditions and weather. Conditions in the laboratory, therefore, should be kept as constant as possible. Each core should be examined in the same work area and under the same lighting conditions, preferably fluorescent lamps. The types of core surfaces that can be examined may be dictated by which analyses will be performed. Cut surfaces of coal are difficult to describe. Polished surfaces can be difficult and time consuming to prepare, requiring the core to be first cut lengthwise. If sectioning is to be done, care must be taken to ensure that the sample remains representative for other analyses. In cores that were drilled through dipping strata, care must be taken to arrange the core pieces so that lengthwise cuts are made at the same angle to the dip of the layers. In some cores that are broken, lengthwise sectioning may not be possible. If the integrity of the core can be sacrificed at this stage, the core can be split with a chisel, preferably along cleats. These split surfaces make it easier to describe textures and minerals, but this step should not be done if other testing that requires intact core sections is planned.

APPARENT DENSITY AND SPECIFIC GRAVITY

The apparent density of core sections can be determined by first weighing the mass of the core and then measuring the volume of water displaced by the section. The value is commonly expressed in g/cm^3. To determine specific gravity, sections of core of uniform character are weighed both in air and submerged in water. The specific gravity is then calculated by dividing the total weight in air by its apparent weight in water; the value therefore has no units.

These determinations are a measure of relative bulk density for the size of core tested and includes any voids or pore space which may be present in the core. It should be noted that the results obtained by these method will be lower than the true density of the coal material and slightly lower than density values determined on crushed coal samples [*38*]. Due to the nature of these tests, an increase in the mass of the original sample from moisture pickup during submersion is possible. This additional mass must be considered and adjusted from any subsequent mass calculations that will be used for determining the total moisture content of the as-received core sample.

Apparent-density determinations can be used in compositing intervals in the correct proportions by mass and also calculating the volumetric core recovery. Using the as-received mass, the known diameter, and the apparent relative density of the core enables one to calculate the theoretical core recovery of the sample based on mass instead of a length measurement. It should be noted that a 100% recovery in length may not be indicative of the actual recovery over that measured interval due to possible core erosion during drilling.

Unfortunately, there is no ASTM standard for determining the apparent density of crushed coal, although modification of ASTM Test for Specific Gravity and Porosity of Lump Coke (D 167) has been used. A common practice, however, is to weigh a portion of crushed coal and then place it into a partially filled graduated cylinder to measure the volume of fluid displaced. Density is calculated by dividing the mass of the coal by the volume measured. A surfactant can be used to reduce the problem of tiny air bubbles adhering to the coal particles. Although generally more accurate than the core immersion technique, the crushed coal method still does not measure true density [*45*].

With experience in a given area, it is often possible to generate relationships between apparent density and ash for specific ranks of coal (Fig. 26). These relationships are often reliable enough to permit the estimation of the relative density with a good degree of confidence from core data which originally lacked density data. One of the primary applications of density is to calculate in-place tonnages of a coal reserve. Table 6 shows the effect of the calculation of tonnage by using appropriate density values.

ROCK MECHANICS

Rock mechanic determinations are an attempt at mathematical analysis of the forces acting along the joints and bedding planes of natural rock *in situ* [*58*]. Rock mechanics data are measurements of failure under load (psi) or deformation of the specimen. These measurements can then be used to calculate Young's modulus, Poisson's ratio, and the strength estimate for actual field stress conditions. Rock mechanics testing on core of coal, roof, and floor is becoming more common. As new methods, such as computer simulation, are developed to aid in predicting ground behavior during and after mining, the results of rock mechanics tests can continue to be incorporated into these simulations.

Basically, three steps are involved in rock mechanics analysis: (1) sample collection, preparation, and testing; (2) data collection and analysis; and (3) application of results to *in situ* conditions for prediction of ground behavior. Specimens cut from core are commonly used for rock-mechanics testing rather than using the core sample. Generally, the specimens are cut with a length-to-diameter ratio (*L/D*) of 2, but an *L/D* of 1 is also acceptable for certain tests or to conserve core material. Some tests require an *L/D* of 3.

Planning the testing scheme before drilling is advisable to assure proper core handling. Some of the testing and property measurements derived from such testing are briefly described in the following paragraphs.

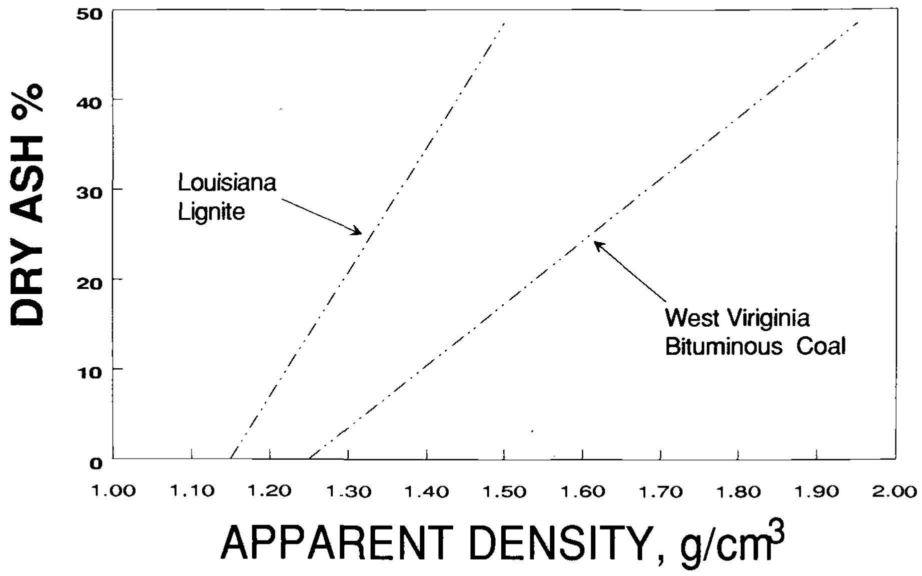


FIG. 26—Examples of sample apparent density (as-received basis) versus ash yield (dry) for lignite and bituminous coals.

The *uniaxial compressive strength test* is a measurement of compressive strength determined in one direction made by applying stress, assuming that two of the three principal stresses are zero.

The *triaxial compressive strength test* is a test in which a cylindrical specimen, encased in an impervious membrane, is subjected to a confining hydrostatic pressure and then loaded axially until the specimen fails [*59*].

The *Brazilian test* is a method for the determination of the tensile strength of rock or other brittle material by applying a load vertically at the highest point of a test cylinder or disk (the axis of which is horizontal), which is itself supported on a horizontal plane [*60*].

The *four-point flexural test* involves loading rock specimens along points or line contacts so that bending can occur. A flexural strength or modulus of rupture is measured.

The *direct shear test* requires a cylindrical specimen to be loaded normally and then a horizontal force is applied gradually until the specimen fails. The horizontal force at failure divided by the cross-sectional area of the specimen is the shear strength.

The most difficult part of rock mechanics is relating laboratory tests results to actual field conditions. Many anomalies exist in rock masses that cannot be explained by laboratory analysis alone. Some attempts to use larger specimens have been made, but for practical purposes the use of larger layered specimens is generally cost-prohibitive.

Many approaches to these relationships have been used in designing underground openings. Coulomb Criterion, Mohr's Criterion, and Griffith Theory are all acceptable models for bridging the gap between laboratory data and field stress conditions.

Other factors that affect these relationships are confining pressure, moisture, time, temperature, and especially material and geological discontinuities. New methods of direct stress condition measurements through boreholes have been developed in recent years. When planned in conjunction with exploration drilling, these specially designed probes may offer additional information not obtainable in the laboratory.

Applicable ASTM standards used in rock mechanics testing are listed below:

• D 420:	Recommended Practice for Investigating and Sampling Soil and Rock for Engineering Purposes
• D 653:	Terms and Symbols Relating to Soil and Rock
• D 2113:	Method for Diamond Core Drilling for Site Investigation
• D 2664:	Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens without Pore Pressure Measurements
• D 2113:	Diamond Core Drilling for Site Investigation
• D 2845:	Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock
• D 2938:	Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens
• D 3148:	Test Method for Elastic Moduli of Intact Rock Core Specimen in Uniaxial Compression
• D 3584:	Recommended Practice for Indexing papers and Reports on Soil and Rock for Engineering Purposes
• D 3967:	Test Method for Splitting Tensile Strength of Intact Rock Core Specimens
• E 400:	Method for Spectrographic Analysis of Ores, Minerals and Rocks by the Fire Assay Preconcentration Technique
• F 432:	Specifications for Roof and Rock Bolts and Accessories

GAS EMISSION TESTING

The United States Bureau of Mines (USBM) direct-method test for determining the gas contents of coal samples [*61*] is the technique most commonly used in the United States. Because this procedure requires finely crushed samples, it is a partially destructive test and this should be considered when planning additional analyses.

The direct-method test for methane was developed by CERCHAR in France. This test was utilized primarily to estimate the coal seam gas content in areas just ahead of the working face in underground coal mines. Typically, coal cuttings are collected from horizontal drill holes, sealed in a container, and gas-emission volumes are measured. After a period of time, the sample is crushed to a fine powder, thereby releasing the remaining gas. Using this procedure, a majority of the gas is measured. The amount of gas that escaped during the drilling and sample recovery process cannot be directly measured, but may be estimated using the relationship that the volume of gas emitted from a coal particle is directly proportional to the square root of time (for the first few hours of desorption).

The test consists of three segments: calculated lost, desorbed, and remaining gas. Calculated lost-gas corresponds to the volume of gas desorbed during the sample-drilling process and prior to sealing the sample in a canister. This volume is estimated by a graphical method using gas emission data collected during the first few hours after sealing the sample in the canister. The desorbed-gas volume is the total amount of gas measured once the sample has been sealed in the canister. Remaining gas is determined after gas emissions are less than 10 cm^3/day for one week. The remaining-gas is obtained by crushing a representative amount of sample to less than 75 μm particle size (minus No. 200 USA SSS) in an inert atmosphere and measuring the volume of gas emitted during the crushing process. The total gas content of a sample is the volume of the remaining-gas plus the volume of the calculated lost- and desorbed-gas divided by the sample mass.

The field collector must be present at the drill site when the coal seam is drilled. To calculate the "lost-gas" portion of the total gas content, the exact times of coal seam encounter, start of sample retrieval, and elapsed time until the sample is sealed in the container must be recorded.

SAMPLE PROCESSING

Before processing a core sample, a decision must be made as to whether sieve and/or washability tests are desired. The crushing procedures differ significantly depending on this decision. Once a sample has been crushed to 2.36 or 4.75 mm (No. 8 or No. 4 USA SSS), it virtually precludes performing sieve analyses and washability tests with meaningful results. While it is possible to perform a washability test on 2.36 or 4.75 mm (No. 8 or No. 4 USA SSS) coal, this fine crushing will enhance liberation of ash and sulfur (pyrite), often yielding optimistic cleaned-coal quality predictions. Figure 27 illustrates a typical sample preparation flow diagram for washability testing.

If no sieve analyses or washability tests are required, the sample is weighed and crushed to less than 2.36 mm (minus No. 8 USA SSS). Some samples may require air-drying in order to feed properly through the reduction and dividing equipment.

After reduction to less than 2.36 mm (minus No. 8 USA SSS), the sample is divided using a riffle. One of the resultant subsamples is weighed and air-dried to bring it to equilibrium with the ambient laboratory conditions. This air-drying helps to stabilize moisture losses or gains during

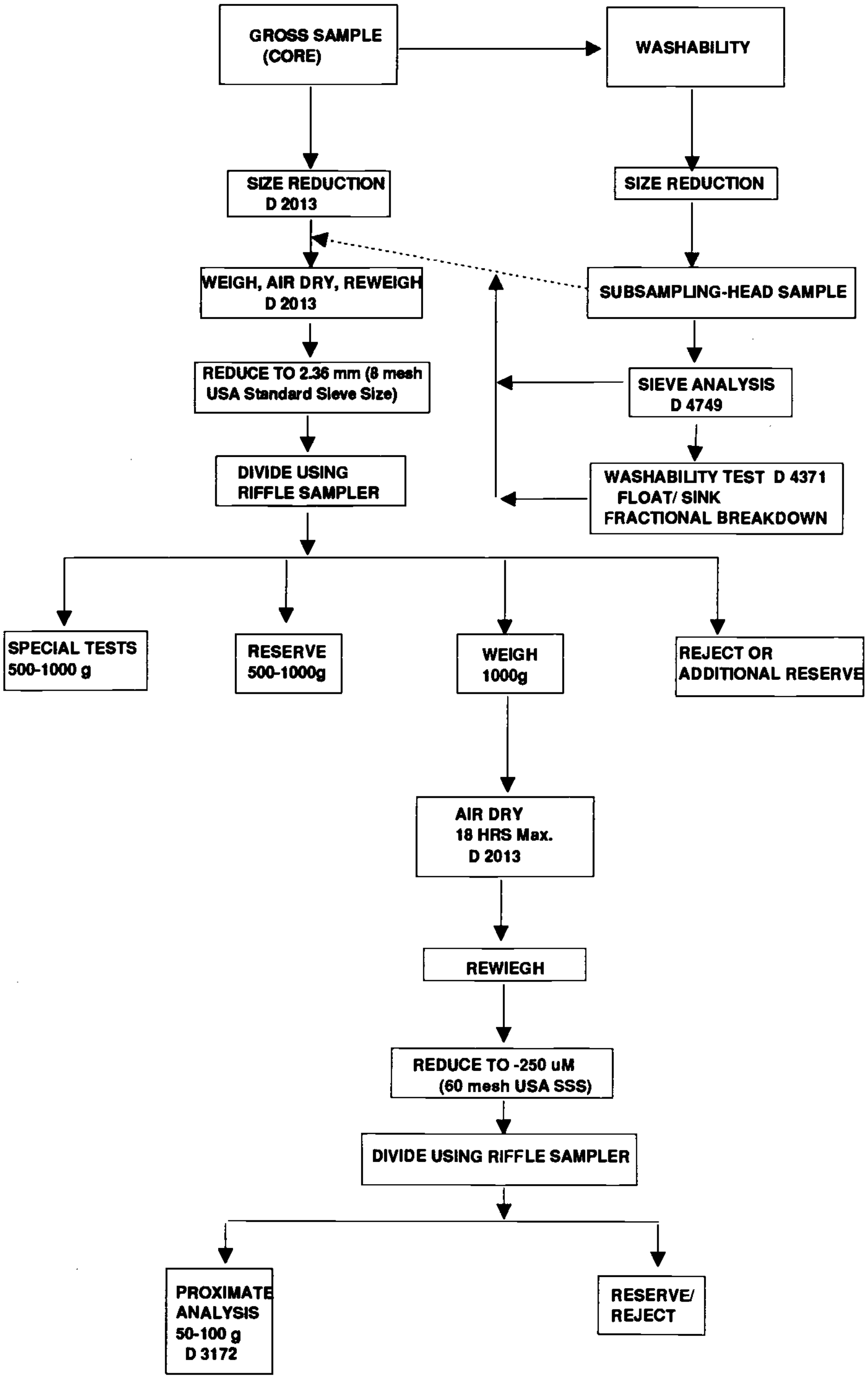


FIG. 27—Flow diagram for division of core sample.

subsequent weighings and analyses. The moisture lost during this drying is reported as "air-dry loss" (ASTM D 2013). Unfortunately, this air-dry loss is occasionally confused with surface moisture. Surface moisture is the difference between the total moisture as determined in accordance with ASTM D 3302 and equilibrium moisture as determined in accordance with ASTM D 1412.

A subsample can be prepared for other special tests. Examples of these special tests include the ASTM Test for Grindability of Coal by the Hardgrove-Machine Method (D 409) and ASTM Test Method for Equilibrium Moisture of Coal at 96 to 97 Percent Relative Humidity and 30°C (D 1412).

A reserve subsample is always a prudent precaution. If an analysis needs to be rerun or if additional analyses are needed later, the reserve sample is indispensable. The reserve sample is also used if several samples need to be physically combined for composite analyses. The size of the reserve and special sample are dependent upon the mass of the original sample and the suite of the analyses planned. If sample mass is small, the analyses should be prioritized to ensure sufficient material for the most important tests. It should be cautioned that reserve samples have a limited shelf life. Oxidation and loss of volatiles and moisture can occur even though the samples are sealed in plastic. Before conducting additional tests on a reserve sample, it is always a good idea to perform a proximate analysis to compare to the original analyses as a check for sample deterioration.

SIZE REDUCTION

For core samples, size reduction is usually the first preparation step prior to sieve analysis or washability tests. This procedure involves crushing to a common size consist. The reduction can be done manually, mechanically, or by using a combination of both techniques. The diameter and length of the core, as well as the planned program of analysis, influence the choice of crushing alternatives.

Manual crushing or "hand cracking" involves the hammering of large core sections or chunks of coal over a preselected topsize sieve with only enough force to allow the coal to break apart along its natural cleats and fractures. Mechanical size reduction can be accomplished with a jaw-type crusher with adjustable jaw openings. Cores designated for raw analysis only can be introduced directly to a Hammermill-type crusher for reduction to a less than 4.75 or 2.36 mm (minus No. 4 or No. 8 USA SSS) size consist.

Stage crushing (ASTM D 2013) is the term used to describe the process of crushing all coarse oversized material either manually or mechanically to pass through the topsize sieve opening selected for the overall size consist. After the initial crushing, the sample is sieved and the over-sized material is crushed again. This procedure is repeated until the entire sample passes the selected sieve. For 4.7 cm (1⅞ in.) diameter cores, some common topsizes (round-hole sieves) used for processing are 2.5 cm (1 in.), 1.9 cm (¾ in.), 1.27 cm (½ in.), 0.95 cm (⅜ in.), and 0.64 cm (¼ in.), respectively. Drill cores of 7.6 and 15.2 cm (3 and 6 in.) diameters are usually sized according to personal preference, to sieve sizes available, and to the maximum jaw-crusher opening.

SUBSAMPLING

After a drill core sample has been crushed, it may be necessary to subsample the material prior to further processing and analysis for use as an original condition sample. This practice is often referred to as "cutting out a raw head sample." A situation where this procedure is applied is the determination of the total chlorine content to avoid contamination of the coal sample by organic halogenated float/sink media. Subsamples can be obtained either manually or mechanically. Manual procedures can be followed by referring to the cone and quartering method as described in ASTM Method of Collection and Preparation of Coke Samples for Laboratory Analysis (D 346). Mechanical subsampling can be accomplished through the use of a riffling device (ASTM D 2013).

Caution should be exercised to ensure that the sample size is sufficient if washability tests are planned. Table 7 is from ASTM Test for Determining the Washability Characteristics of Coal (D 4371) and specifies the recommended mass for conducting washability tests. In many cases, the recommended masses for raw coal from Table 7 may be neither applicable nor practical for core samples. For this reason, core diameter should be as large as possible and subdivision of the core for any purpose prior to washability testing should be avoided, if possible (ASTM D 4371).

SIEVE ANALYSIS

In some instances, the higher rank coals may require only a sieve and raw analyses of a coal core. This procedure entails sieving a core sample into its component size distribution and then analyzing each respective size fraction in a raw condition. This type of processing will enable one to generate a relative quality profile of the coal by size. It should be cautioned that the resulting size analysis data obtained by this means will not be the exact size consist of the ultimately mined product. It is impossible to duplicate mining conditions at the exploration stage of reserve development. These data, however, are useful in estimating the relative size distribution and characteristics of a coal.

TABLE 7—Minimum coal mass required to obtain for four to six specific gravity fractions for washability testing (ASTM D 4371).

		Mass Needed for Washability Analysis of That Size Fraction	
	Size Fraction	kg	lb
200 × 100 mm	(8 × 4[1])	2720	(6000)
100 × 50 mm	(4 × 2[1])	980	(2000)
50 × 25 mm	(2 × 1[1])	225	(500)
25 × 12.5 mm	(1 × ½[1])	90	(200)
12.5 × 6.3 mm	(½ × ¼[1])	25	(50)
6.3 × 2.36 mm	(¼ × No. 8[2])	9	(20)
2.36 × 1.40 mm	(No. 8 × No. 14[2])	5	(10)
1.40 mm × 600 μm	(No. 14 × No. 30[2])	2	(5)
600 × 300 μm	(No. 30 × No. 50[2])	1	(2)
300 × 150 μm	(No. 50 × No. 100[2])	0.5	(1)
150 × 75 μm	(No. 100 × No. 200[2])	0.5	(1)

[1] Inches, round-hole sieves.
[2] U.S. standard sieve sizes.

WASHABILITY TESTING

Sieve size and/or washability tests are simply methods of breaking a coal sample into its component parts by size and density. Many bituminous coals will require beneficiation primarily because mineral material is included in the coal seam during deposition and dilution material from the floor and roof commonly compose part of the mined product. Also, pyrite in nodules, lenses, or cleat in the seam may dictate physical cleaning specifically to reduce the overall total sulfur. To simulate theoretical physical beneficiation of these coals, a bench-scale procedure known as *washability* or *float/sink testing* is used (ASTM D 4371). Washability procedures are performed by immersing the coal in a series of liquids of increasing specific gravity. The product material (float) is skimmed from the surface of the first bath and the reject material (sink) is transferred to the next higher specific-gravity liquid. Each respective density fraction is then individually analyzed chemically yielding a set of data which comprises a density and quality profile of the coal sample. Depending on the method to treat the fines in the mining operation, a froth floatation test rather than a float-sink test may be run on the extremely fine material.

The problem of obtaining adequate amounts for core samples for testing has already been discussed in the section on Subsampling. Obtaining size fractions large enough to simulate actual mining conditions is often a limitation using core samples. Therefore, in addition to maximizing the mass of the sample, using the largest diameter core barrel possible to drill a core sample permits a wider range of size fractions to be analyzed.

The choice of the proper number of size and density fractions to use is important given the limited amount of material available for testing from the core samples. As the number of sieve-size fractions increases, the number of density fractions run per size fraction should decrease. This approach will help ensure having enough material per size and density fraction to enable a proper and representative chemical analysis per ASTM standard mass limitations (ASTM D 2013). If it appears that a sieve size and washability test of a core is overextended, the laboratory has the opportunity at this point to recombine some or all of the components, review the initial data, and proceed in an alternative manner that will help preserve the integrity and representativeness of the core sample in accordance with ASTM D 2013. The integrity of the initial raw sample is not compromised because the components can be recombined either mathematically or physically (compositing) to its original basis.

In summary, this procedure may be used in core studies to determine the quality washability characteristics of coal reserves. Care must be exercised in the design of the coring programs, including the consideration of appropriate geostatistics, so that the potential recovery and quality of the coal reserves, as defined by the washability analysis of the cores, have particular significance (ASTM D 4371).

6

Evaluation of Core Data

DATA REVIEW

THE COMPUTER has streamlined both the transfer of data and the evaluation of the analytical results. Many commercial laboratories now offer electronic data transfer as a part of their service. The data can be transferred in various forms on floppy disks or magnetic tape in formats compatible with individual systems or in various standard data base formats. This reduces both data input time and errors.

Once the analytical data are received, they should be checked for any obvious problems. One method that has proven to be an effective approach in evaluating coal test results is the use of data interrelationships and crossplot graphs [*37*]. By plotting relationships such as dry ash versus dry calorific values or moisture contents, suspect analyses can often be readily identified. Data that deviate significantly from these crossplots can be examined for possible laboratory errors or anomalous situations like partial weathering or atypical maceral assemblages. By checking previous crossplots in a given geographic area, the consistency of laboratory data over several years can often detect subtle changes in laboratory or field procedures. For example, a sudden decrease in the dry ash versus as-received moisture plots in one area was traced to an inexperienced field geologist who was not keeping the core covered to prevent drying while logging the coal.

LIMITATIONS ON THE USE OF CORE DATA

When care has been taken to ensure that the samples collected are representative of the coal being investigated, core data are an effective method of predicting and modeling in-seam quality. However, because it is impossible for the coring process to exactly duplicate anticipated mining conditions, there are limitations to using the data. Some of these limitations include predictions of as-mined size consist, moisture, rank classification, and coal-quality variability.

One of the best methods to bridge this gap is by comparing all available exploration core data to production data from the same property or from existing nearby mines that have similar geological and mining conditions.

SIEVE ANALYSIS

The problem of predicting the size consist of the coal from core samples was discussed in the Sieve Analysis and Washability Testing sections. The topsize of the core samples is limited by the diameter of the core barrel used. Also, the coring process often can fracture the coal more severely than can actual mining. Therefore coal-preparation schemes should never be based on core data alone unless sufficient experience is available in a given geographic area to relate predicted quality from core data and actual production yields.

MOISTURE IN COAL CORES

Utilizing core data to predict the as-delivered moisture values can often cause difficulties, especially in the case of low rank coals. The problem is twofold:

1. Surface moisture is frequently added by the coring process. The as-received moisture values from an analysis not only includes the bed or inherent moisture of the coal, but also any moisture introduced from the drilling fluid used, from groundwater, and/or from washing the core at the surface. Furthermore, the additional mechanical stresses induced by the coring process tends to fracture the coal, thereby creating more surface area to be wetted. Another probable contributing factor that can increase fracturing is the release of the confining pressure on the coal core sample.
2. The effect on moisture by various conditions during mining are often difficult to quantify. Some of these conditions include the addition of groundwater, partial drying at the exposed mine face and during coal handling, use of water sprays to suppress dust, and variable amounts of precipitation in surface mines.

The equilibrium moisture test (ASTM D 1412) is designed to circumvent the problem of surface moisture by directly measuring the moisture-holding capacity of a coal sample which approximates the inherent moisture of the sample. Unfortunately, the equilibrium moisture test does not provide accurate inherent moisture estimates for many low rank coals including lignite and some subbituminous coals [*62*].

For these cores, equilibrium moisture can still be used; however, the relationship between equilibrium and inherent moisture values must be determined empirically [*62*]. Solid, unfractured sections of core or chunks of coal with no visible surface moisture from a fresh mine face or test pit in the immediate vicinity of the area under investigation can be sampled [*42*]. If some surface moisture is present, it can often be removed by blotting the sample with paper towels. It is assumed that the moisture levels of these special samples should closely approximate the inherent moisture content. By running companion proximate and equilibrium moisture analyses, a correction factor between equilibrium and inherent moisture can be derived. While this empirical method is not a perfect solution, it may afford a better approximation of the inherent moisture levels of low rank coals than the use of raw equilibrium moisture test results alone [*62*].

One practice that should be discouraged is air-drying the core to remove surface moisture. Because the rate and amount of moisture loss is impossible to control, this procedure is very subjective and simply introduces another variable. Because it is easy to overdry the core, evaluation of the core data can be confounded, particularly in the case of low rank coals where rates of moisture loss can be rapid.

CLASSIFICATION OF COAL BY RANK

Coal rank is the classification of coals according to their degree of metamorphism or progressive alteration in the natural series from lignite to anthracite (ASTM D 388). The classification is applicable to coals that are composed mainly of vitrinite.

The properties that determine rank for higher rank coals are fixed carbon or volatile matter on a dry, mineral-matter-free basis, whereas the lower rank coals are classified according to calorific value on a moist, mineral-matter-free basis. Agglomerating character is used to differentiate between adjacent rank groups. The reflectance of vitrinite is also currently being considered as an international rank parameter. The principal ranks of coal in order of increasing maturity are lignite, subbituminous coal, bituminous coal, semianthracite, anthracite, and meta-anthracite.

At present, the only method of standard rank determination is to average the analyses of at least three and preferably five or more face-channel samples (ASTM D 4596) taken in different and uniformly distributed localities, either within the same mine or closely adjacent mines representing a continuous and compact area not greater than approximately four square miles in regions of geological uniformity (ASTM D 388). All roof and floor rock, mineral partings more than 1 cm (3/8 in.) thick, and mineralized lenses or concretions (such as sulfur balls) more than 1.27 cm (½ in.) thick and 5 cm (2 in.) wide shall be excluded from the sample (D 4596).

Core samples qualify for ranking by ASTM D 388 as *apparent rank*. Whenever apparent rank is stated, additional information as to the nature of the sample should be provided. When taking a core sample for apparent rank, care must be exercised to ensure that the sample is representative of the same thickness, retains its bed moisture, and is not weathered. All core and face samples should represent the complete stratigraphic sequence being sampled, noting specifically the exclusions of rock partings, concretions, or mineralized lenses. If any sections are removed from the core sample for apparent rank determination, the representativeness of the sample may be jeopardized, particularly for determining parameters other than those used for apparent rank.

VARIABILITY OF CORE DATA

There are several important factors to keep in mind when utilizing core data to predict raw, as-mined coal quality. The reason for less variability in run-of-mine data compared to core data results from the blending that occurs during mining and coal handling. An example of this variability is illustrated in Fig. 28. In this example, a prospective test pit area was initially cored to determine the in-place quality.

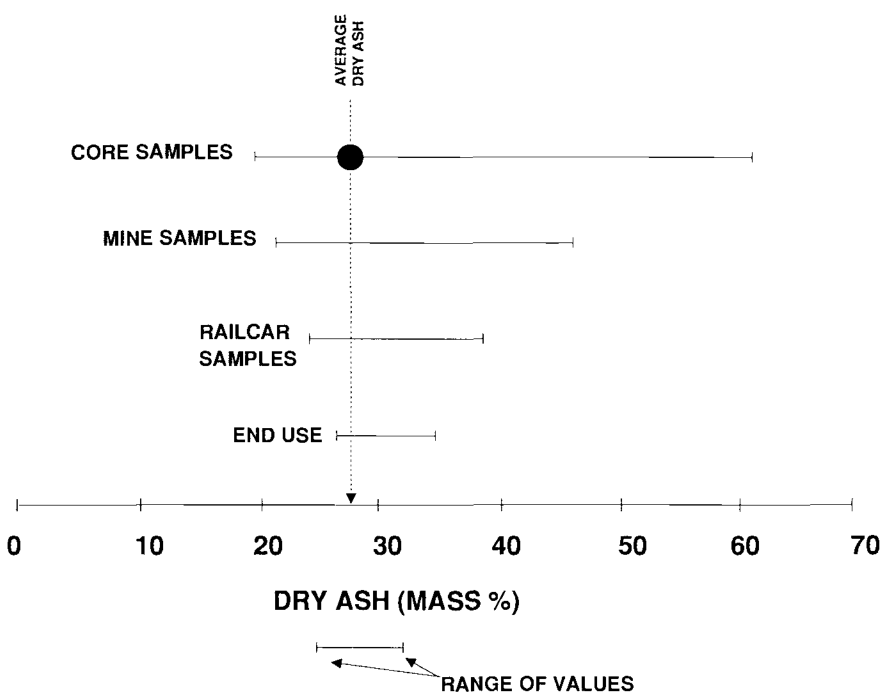


FIG. 28—Effect of homogenization through successive handling on ash yield variability of samples from coring, mining, and delivery.

The same area was later mined. The coal was reduced in size by an in-pit crusher and loaded onto highway truck haulers by a conveyor belt (mined sample). The trucks dumped the coal onto a stockpile and subsequently loaded it onto railcars by another conveyor (railcar sample). The coal was off-loaded from the railcars onto another conveyor and sampled again (end-use sample). The effects of handling on variability of coal quality are pronounced. The ranges of the values decrease and the average values tend to fall more closely in line with the average ash value for the area (estimated from core data) with each successive handling stage.

While it is often difficult to quantify the amount of homogenization that may occur in a given operation, one should at least be cognizant of its potential when addressing coal quality variability from core data. In general, production quality tends to move closer to the averages for the various parameters.

Conclusions

WHATEVER the size and extent of a project to evaluate a coal reserve, data obtained from a carefully planned and executed drilling will add considerably to the accuracy of the conclusions reached by the overall project. A fundamental factor in the success of such a project is coordination of various activities including drilling, geophysical logging, sample recovery and packaging, and laboratory analyses. The purposes for which the data will be used must be evaluated before the drilling begins, because some purposes can determine the course of action or types of equipment or testing that will be done on the core sample. Flow diagrams that can also specify schedules can be important to the success of the project.

Critical to the core sample being representative of the seam are precise procedures during drilling followed by careful handling and packaging of the core sample and finally sequences of testing that will produce analytical data representative of the core sample.

Appendix

Additional Descriptions

OTHER evaluations of the rock may be useful during mine planning. Although these categories are qualitative, they sometimes yield useful information.

Weatherability is defined as the susceptibility of rock to short term weathering. This is of considerable significance in mining engineering when the rock is forming some part of an engineering structure such as a highwall. The system of weathering classification given in Table 8 is suggested as a qualitative measure of weatherability.

Rock quality designation (RQD) for NX core size is defined as the percentage of solid core recovered greater than four (4) inches in length as indicated on Fig. 29. Core loss, weathered, and soft zones as well as natural fractures are accounted for in the determination. Mechanical and artificial fractures should not be included in the calculation. An RQD approaching 100% denotes excellent quality rock mass, whereas values ranging from 0 to 50% are indicative of poor quality rock mass (Table 9).

For core size other than NX, the RQD should be the percentage of solid core that is recovered in pieces which are greater than twice the diameter of the core.

The *fracture spacing index* is defined as the number of natural fracture occurrences within the sample interval. It is conventional to omit mechanical or artificial fractures caused by drilling or handling of the core.

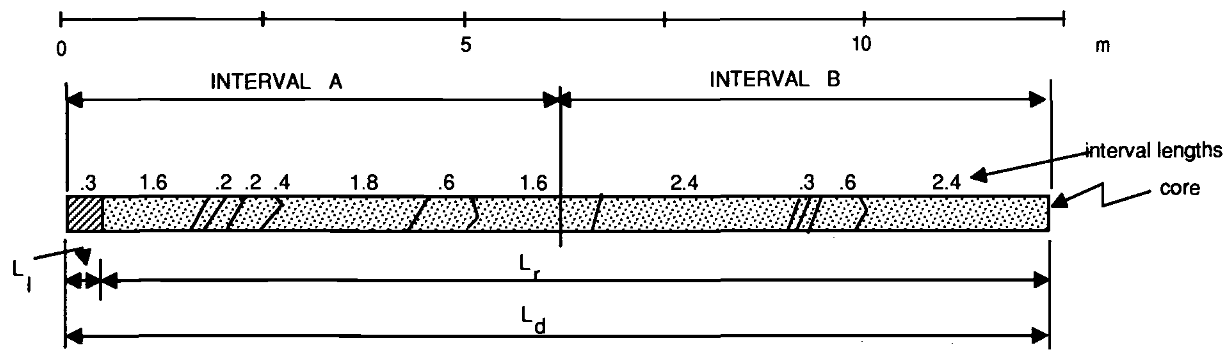
The *orientation index* is a measure of the dip direction of the dominant joint set relative to the rock core axis. The orientation of the joint sets is reported from the perpendicular to the longitudinal axis of the rock core. A zero degree orientation is indicative of a horizontal fracture orientation denoted by a code "H". Figure 30 depicts a series of orientation profiles with their associated abbreviations for logging purposes.

The *roughness index* is a relative measure of the surface condition of the fracture and is based upon the roughness profile corresponding to the surface condition of the rock core joint wall. The index should be identified through visual observation and direct touch. Where the surface condition of the joint walls vary throughout the interval, the most detrimental or weakest code is reported. The roughness indices range from "rough undulating" as best or least detrimental to "brecciated" as worst or most detrimental. Figure 31 outlines some possible roughness profiles that may be encountered and some corresponding codes.

The *opening index* is defined as the separation or aperture of the fracture. The measurement should be reported after the core has been reconstructed. Where the separation varies throughout the interval, the largest separation should be reported. Table 10 summarizes the ranges involved for opening index coding.

TABLE 8—Weathering classifications.

Code	Description
0	Fresh Rock (F)—the parent rock shows no discoloration, loss of strength, or any other effects due to weathering.
1	Faintly Weathered (FW)—the rock shows no discoloration between discontinuities; however, surfaces of discontinuities are discolored or stained.
2	Slightly Weathered (SW)—the rock may be slightly discolored, particularly adjacent to the discontinuities resembling weathered bands or rings up to 0.5 in. in width; discontinuities may be open and have slightly discolored surfaces; the intact rock is not noticeably weathered.
3	Moderately Weathered (MW)—the rock is discolored throughout the rock mass; discontinuities may be open and surfaces will have greater discoloration penetrating inward; the intact rock is noticeably weaker than the fresh rock.
4	Highly Weathered (HW)—the rock is discolored; discontinuities may be open and have discolored surfaces; the original fabric of the rock near the discontinuities is altered; the rock material is partly friable; alteration penetrates deeply inward but original rock is present.
5	Completely Weathered (CW)—the rock is discolored and changed to a soil-like material with the original fabric mainly preserved; the rock material is friable.
6	Soil (S)—the rock is discolored and completely changed to a soil; the original rock fabric is completely destroyed.
−9	Unknown or no reading taken.



$$\text{Recovery (\%)} = \frac{L_r}{L_d} \times 1000$$

$$\text{RQD} = \frac{L_r - \Sigma P}{L_d} \times 100$$

Where: L_r = Length of core recovered
L_d = Length of core drilled
L_l = Length of core loss
P = Length of core pieces $\leq$ 2D
D = Diameter of core

Calculation of Example

TOTAL CORE

$$\text{Recovery} = \frac{1.20 - .3}{1.20} \times 100 = 97.5\ \%$$

$$\text{RQD} = \frac{1.17 - (.2+.2+.4+.3)}{1.20} \times 100 = 88.3\ \%$$

INTERVAL A

$$\text{Recovery} = \frac{6.0 - .3}{6.0} \times 100 = 95\ \%$$

$$\text{RQD} = \frac{5.7 - (.2+.2+.4)}{6.0} \times 100 = 81.7\%$$

INTERVAL B

$$\text{Recovery} = \frac{6.0 - 0}{6.0} \times 100 = 100\%$$

$$\text{RQD} = \frac{60 - (.3)}{6.0} = 95\ \%$$

FIG. 29—Example of core recovery and RQD measurement.

TABLE 9—Rock quality designations.

Quality	RQD
Excellent	90–100%
Good	75–90%
Fair	50–75%
Poor	25–50%
Very poor	25%

CODE	DESCRIPTION	Angle from horizontal
H	HOIZONTAL	0-10
LD	LOW DIAGONAL	10-45
HD	HIGH DIAGONAL	45-80
V	VERTICAL	80-90
N	NO FRACTURE	
B	BRECCIATED OR FAULT GOUGE	
-9	UNKNOWN OR NO READING	

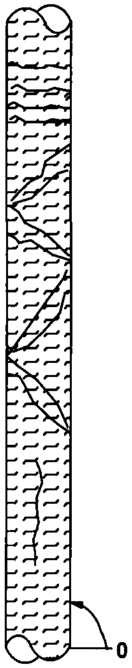
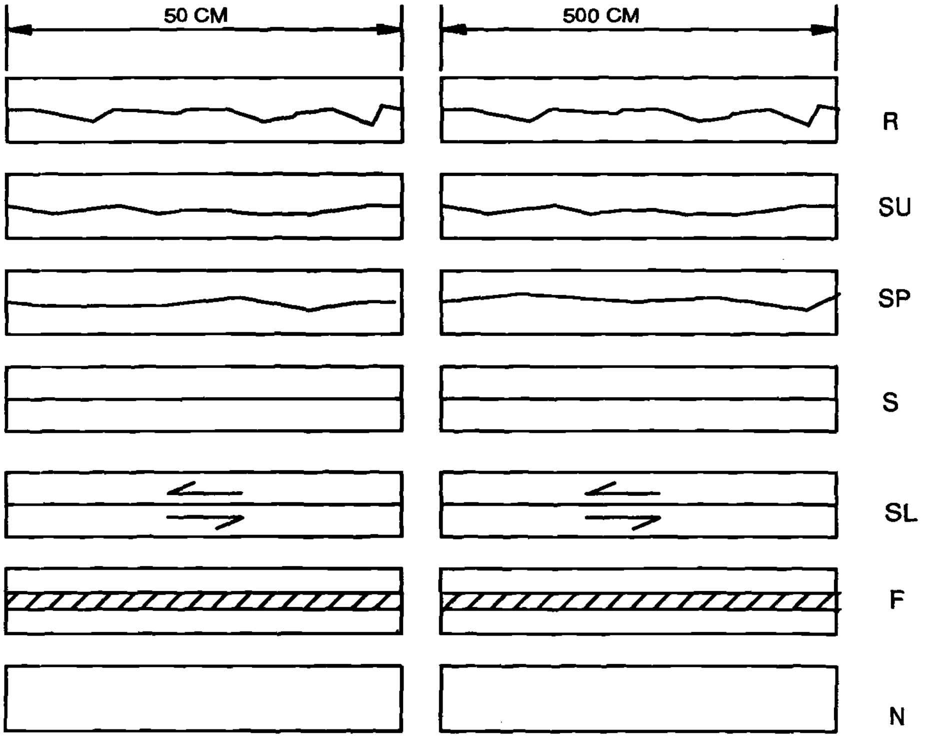


FIG. 30—Orientation profiles of fractures.



CODE	DESCRIPTION
N	NO FRACTURE
R	ROUGH UNDULATING
SU	SMOOTH UNDULATING
SP	SMOOTH NEARLY PLANAR
S	SMOOTH
SL	SLICKENSIDED
F	FILLING
N	NO FRACTURE
B	BRECCIATED OR FAULT GOUGE
-9	UNKNOWN OR NO READING

FIG. 31—Fracture roughness profiles of core showing views of core width and length.

TABLE 10—Opening index codes.

Code	Description	Opening mm	Opening in.
N	No Fracture	0	0
VT	Very Tight	<0.1	<0.004
T	Tight	0.1 to 0.5	0.004 to 0.02
M	Medium	0.5 to 2.5	0.02 to 0.10
O	Open	2.5 to 10	0.1 to 0.394
VW	Very Wide	>10	>0.394
B	Brecciated or Fault Gouge	. . .	. . .
−9	Unknown or no reading	. . .	. . .

The *filling index* describes the type and quality of filling material within the fracture. Any substantial filling thickness should be reported in millimeters and attached as a suffix to the index code. For example, a 10 mm clay filling is encountered in a sample interval. This would be represented by a filling index code CL10. A description of the filling material should be recorded in the "Remarks" section of the log.

Where the filling material varies throughout the interval, the most detrimental filling index is reported. Table 11 lists a series of filling indices that can be used in logging rock materials.

After a core is logged and adequately described and where conditions permit prior to packaging, the core should be photographed for future reference and to provide a permanent record of its physical appearance. When the photograph is taken, a core identification or label and measurement scale should be visible and proper compensation for lighting be made for optimum film exposure.

TABLE 11—Filling index codes.

Code	Description
N	No fracture
Th(i)[1]	Tightly healed, hard, non-softening filling such as quartz
Ua	Unaltered joint walls, surface staining may be present
Sa(i)	Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.
Sc(i)	Silty or sandy clay, minor clay fraction
Cl(i)	Softening or low friction clay mineral coatings (e.g., kaolinite, mica). Also chlorite, gypsum, graphite, etc., and swelling clays.
O(ii)[2](i)	Other
B	Brecciated or fault gouge
−9	Unknown or no reading

[1] Denoted thickness of filling. Example: CL10 = 10 mm of clay filling.

[2] Alphabetical denotation of filling, should be described in more detail under "Remarks."

Example: OCAL3 = 3 mm of Filling of Calcite (CAL)
OSPH4 = 4 mm of Filling with Spalerite (SPH)

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Glossary

A

analog indicator, *n*–A device that translates a measured variable to a pointer deflection of other visual quantity which is continually proportional to and generally calibrated in terms of the measured function. [3]

annular space, *n*–Ring-shaped space between casing and the wall of the hole or between drill pipe and casing. [2]

API gamma-ray unit, *n*–This unit is an arbitrary one and is defined as 1/200 of the difference between the deflections produced on a log by the radiation from two standard formations of different gamma-ray intensity in a calibration pit in Houston, Texas. The two standard formations are artificial. One is of very low radioactivity, while the other has a radioactivity approximately twice as great as an average mid-continent shale, which is about 100 API units. [14]

apparent density, *n*–The mass per unit volume of a material including voids inherent in the material as tested. [15]

apparent rank, *n*–An indication of the correct relative position of the rank of coal samples analyzed but does not imply any standards of coal sampling. Whenever apparent rank is stated for a coal sample, additional information as to the nature of the sample is required. [18]

as-received basis, *n*–Analytical data calculated to the moisture condition of the sample as it arrived at the laboratory and before any processing or conditioning. If the sample has been maintained in a sealed state so that there has been no gain or loss, the as-received basis is equivalent to the moisture basis as sampled. [16]

ash, *n*–Inorganic residue remaining after ignition of combustible substances, determined by definite prescribed methods. [16]

attritus, *n*–A composite term for dull gray to nearly black coal components of varying maceral content, unsorted and with fine granular texture, that forms the bulk of some coals or is interlayered with bright bands of anthraxylon in others. It is formed of a tightly compacted mixture of altered vegetal materials, especially those that were relatively resistant to complete degradation. [2]

B

banded coal, *n*–Coal that is visibly heterogeneous in composition, being composed of layers of vitrain and attrital coal, and commonly, fusain. [16]

bit (drill) blank, *n*–A steel bit in which diamonds or other cutting media may be inset by hand peening or attached by a mechanical process such as casting, sintering, or brazing. Also called bit shank; blank; blank bit; shank. [10]

bit crown, *n*–As used by the drilling and bit-setting industry in the United States, the portion of the bit inset or impregnated with diamonds formed by casting or pressure-molding and sintering processes; hence the steel bit blank to which the crown is attached is not considered part of the crown. [10]

bit footage, *n*–The number of feet of borehole that a bit was able to drill. [17]

book fashion, *n*–The organization of core in boxes so that the top of the core is placed beginning in the upper left-hand corner and the bottom of the core is in the lower right-hand corner. [17]

booting, *n*–The collection of drill cuttings around the drill string and which are ejected from the collar in long tubelike masses. [10]

borehole, *n*–The circular hole through soil and rock strata made by boring. [19]

borehole erosion. *See* **caving.**

Brazilian Test; indirect test, *n*–A method for the determination of the tensile strength of rock, concrete, ceramic, or other material by applying a load vertically at the highest point of a test cylinder or disk (the axis of which is horizontal), which is itself supported on a horizontal plane. The method was first used in Brazil for testing of concrete rollers on which an old church was being moved to a new site. [10]

bulk density, *n*–The weight per unit volume of any material including water. Synonymous with **apparent density**. [15]

bulk density log–*See* **density log.**

burrow, *n*–Tubular openings made by worms and other animals. Usually preserved as fillings; may be vertical, horizontal, or inclined, and straight or sinuous. [2]

button bit, *n*–A type of rollercone bit with tungsten carbide buttons or inserts on the cone faces. The button bit is commonly used in drilling hard rocks. The button bit crushes the rock by compression and produces relatively fine cuttings compared with those produced by a steel tooth or milled teeth roller-cone bit. [7]

C

caliper log, *n*–A continuous mechanical measurement of the diameter and thus rugosity of the borehole. The tool identifies zones where swelling or cavings (washouts) have occurred during drilling. The tool's value is in allowing qualitative or quantitative corrections to be made to other geophysical logs that are affected by borehole size (especially density). [1]

calorific value, *n*–The heat of combustion of a unit quantity of a substance.

DISCUSSION—It is expressed in ASTM test methods in British thermal units per pound (Btu/lb). Calorific value can also be expressed in calories per gram (cal/g) or in the International System of Units, joules per gram (J.g), when required. [*16*]

caves or washouts, *n*—Zones of increased hole diameter caused by rock fragments or unconsolidated material that falls from the walls of a borehole and can block the hole or contaminate the cuttings. These zones can affect the accuracy of certain geophysical logs (especially density). Corrections to other geophysical logs can be made if a caliper log is available. The most common causes of caves or washouts include soft or fractured lithologies, the presence of water-producing zones, and the downhole pressure of the drilling medium (fluid or air) which often causes differential erosion of various strata within the borehole. [*19*]

caving, *n*—Rock fragments that fall from the wall of a borehole and may contaminate the well cuttings or block the hole. [*1*]

cleat, *n*—A joint or system of joints along which the coal fractures. There are usually two cleat systems developed perpendicular to each other. [*1*]

coal ball, *n*—A hard, compact aggregate of mineralized plant debris occurring in a coal seam or in adjacent rocks. [*1*]

coal bed. Synonym for **coal seam.**

coal rank. *See* **rank.**

coal seam, *n*—The stratum, layer, or bed of coal that lies between two other rock layers whose compositions differ significantly from that of the coal. [*18*]

concretion, *n, in a geological sense*—A mass of mineral matter found in rock of a composition different from its own and produced by deposition from aqueous solution in the rock. [*19*]

contamination, *n*—The presence of any material or chemical compound foreign to the inherent composition of the coal. Sources of contamination are commonly drilling fluids which can contain cement, anhydrite, salt, shale cuttings, etc. [*17*]

conventional coring, *n*—1. The cutting and recovering of core in which the entire drill string is removed to recover core samples. 2. As used by individuals associated with petroleum well-drilling operations, to cut and recover core using any type of annular-shaped cutting head other than a diamond bit. [*10*].

core, *n, in drilling*—A cylindrical section of rock (coal) taken as a part of the interval penetrated by a core bit and brought to the surface for geologic examination, representative sampling, and laboratory analyses. [*19*]

core barrels, *n*—Two nested tubes above the bit of a core drill, the outer rotating with the bit, the inner receiving and preserving a continuous section or core of the material penetrated.

DISCUSSION—Two types of inner barrels (split-tube and solid-tube) are commonly used. (1) Split-Tube Core Barrel: Type of inner barrel consisting of two longitudinal halves of pipe bound together by reinforced tape at intervals along the barrel length. The split tube allows easy access to a relatively intact core (by cutting the tape); this is the preferable barrel type for coal exploration, when available. (2) Solid-Tube Core Barrel: Type of inner barrel consisting of a single solid-walled length of pipe. Removal of core is accomplished by mechanical or hydraulic pressure at one end of pipe, thus extruding the core onto a core tray. [*19*]

core catcher, *n*—In counter-flow or reverse-flow continuous core drilling, the sievelike tray or device on or in which the core is ejected continuously from the upper end of a drill string and is caught and held when core is recovered. [*10*]

core recovery, *n*—The amount of the drilled rock withdrawn as core in core drilling, generally expressed as a percentage of the total length of the interval cored. [*1*]

core run, *n*—Technically, the distance cored per round trip, which is expressed in number of feet or in relative terms, as short, long. Core blocks may occur before core barrel is filled; the barrel then is short of being full, resulting in a short core run. Loosely, amount of core recovered per round trip of coring. [*10*]

core sample, *n*—That part of a core of rock or coal obtained so as to accurately represent a thickness of a unit penetrated by drilling. [*19*]

core tray, *n*—An open or lidless core box. [*10*]

Coulomb Criterion, *n*—A criterion of brittle shear failure based on the concept that shear failure will occur along a surface when the shear stress acting in that plane is large enough to overcome the cohesive strength of the material plus the frictional resistance to movement. Cohesive strength is equal to inherent shear strength when the stress normal to the shear surface is equal to stress normal to the shear surface multiplied by the coefficient of internal friction of the material. [*1*]

D

density log (Gamma-gamma log), *n*—Measures electron density within lithologic units, which is related to their bulk density. The density tool records the intensity of gamma radiation (in counts per second) from a nuclear source within the tool after it has been attenuated and backscattered by lithologies within the borehole. Because of the distinctly low density of coals, the density log is especially useful in coal exploration for differentiating coal seams, coal seam partings, and other lithologies. The bias/resolution of density logs can be affected by source-detector spacing (closer spacing increases resolution), borehole size and irregularities (see **caves or washouts**), the presence of casing, and the logging speed. [*19*]

bed-resolution density log, n—Measures formation density using a source of radiation and a gamma ray detector with a short-spacing designed to facilitate the definition of the bed boundary. Also known as *high-resolution density log.* [*17*]

desorbed gas, *n*—The gas collected from a unit of coal core that is contained in a pressurized canister. [*17*]

desorption, *n*—The reverse process of adsorption whereby matter is removed from the adsorbent. [*12*]

deviation log, *n*—A geophysical logging technique for measuring the deviation of a borehole from its intended course. [*4*]

dip, *n*—The angle that a bedding or fault plane makes with the horizontal measured perpendicular to the strike of the structure and in the vertical plane.—*v*, To be tilted or inclined at an angle. [*1*]

dipmeter, *n*—A three-pad or four-pad wall-contact log whose finely detailed microresistivity log curves are correlated to measure depth offsets relative to each other. In conjunction with simultaneous measurements of the caliper and inclination and direction of the borehole, such measurements can be solved for dip and strike of the strata. Both the borehole curves as measured and the subsequent graphic plot of computed dip-strike symbols are called dipmeters, the former a "continuous dipmeter" or dipmeter log, the latter a "computed dipmeter" or "tadpole plot." [*1*]

double-tube core barrel, rigid-type, *n*—A core barrel having both the inner and outer tubes rigidly coupled to a common headpiece. [*17*]

double-tube core barrel, swivel-type, *n*—A core barrel having the upper end of the inner tube coupled to the core-barrel head by means of an antifriction device, such as a roller or ball bearing. Hence, the inner tube tends to remain stationary when the outer tube, which is rigidly coupled to the core-barrel head, is rotated. [*10*]

drag bit, *n*—A type of rotary drill bit with no moving parts and steel cutting blades on the bottom. The fixed blades drag and cut the sediments on the bottom of the well. A drag bit is used for soft formations. [7]

drift, in drilling, *n*—1. The deviation of a borehole from its intended direction or target. 2. The horizontal distance measured from the bottom of the well to a vertical line extending down from the surface location of the well. [7]

drill bit, *n*—The cutting tool used in drilling. [7]

drill core. Synonym for **core**.

drill pipe, *n*—The heavy steel pipe that turns the drill bit in rotary drilling by transmitting the motion from the rotary table of the drilling rig to the bit at the bottom of the hole, and that conducts the drilling mud from the surface to the bottom. It is normally formed of sections connected end to end. [*19*]

drill string, *n*—1. The term used in rotary drilling for the assemblage of drill pipe, drill collars, drill bit, and core barrel connected to and rotated by the drilling rig at the surface. Synonym: *drill stem*. 2. A term used in cable-tool drilling for the assemblage of drill bit, drill stem, cable, and other tools connected to the walking beam at the surface. [*1*]

drill stem joint, *n*—A part of the drill string formed by connection of two threaded parts of the drill stem (a short pin-threaded coupling and a box-threaded length of heavy-wall steel tubing) that connect lengths of drill string. [*17*]

drilling fluid, *n*—Air, mist, water, or drilling mud used to cool the bit and carry cuttings up from the bottom. It is pumped continuously down the drill pipe, out through openings in the drill bit, and back up in the annulus between the pipe and the walls of the hole to a surface pit where it is screened and reintroduced through the mud pump. The drilling fluid is used to lubricate and cool the bit used to carry the cuttings up from the bottom. [*1*]

drilling mud, *n*—A carefully formulated heavy suspension, usually in water but sometimes in oil, used in drilling. It commonly consists of bentonitic clays, chemical additives, and weighting materials such as barite. Drilling muds are used to prevent blowouts and cave-ins by plastering friable or porous formations with mud cake and maintaining a hydrostatic pressure in the borehole offsetting pressures of fluids that may exist in the formation. Synonyms: **drilling fluid**; *circulating fluid*. [*1*]

drilling rig, *n*—A general term for the derrick, power supply, draw works, and other surface equipment necessary in drilling. [*1*]

dry basis, *n*—Data calculated to a theoretical base of no moisture associated with the sample. The numerical value as established by ASTM Test Method D 3173 is used for converting the as-determined data to a dry basis. [*16*]

dry, mineral-matter-free basis, *n*—Data calculated to a theoretical base of no moisture and no mineral matter associated with the sample. The numerical values as established by ASTM Classification D 388 and ASTM Test Method D 2799 are used for converting the as-determined data to a dry, mineral-matter-free basis. [*16*]

E

electric log, *n*—The generic term for a well log that displays electrical measurements of induced current flow or natural potentials in the rocks of an uncased borehole.

equilibrium moisture, *n*—*of coal*. The moisture-holding capacity of a coal sample as determined in accordance with ASTM D 1412 at 96–97% relative humidity and 30°C. [*17*]

exploration, *n*—1. The search for deposits of useful minerals or fossil fuels; prospecting. It may involve geologic reconnaissance (e.g., remote sensing, photogeology, geophysical and geochemical methods) and surface and underground investigations. 2. Establishing the nature of a known mineral deposit, preparatory to development. In the sense that exploration goes beyond discovery, it is a broader term than prospecting. [*1*]

F

face channel sample, *n*—A sample obtained from the plane or surface of a coal seam at the advancing surface on which mining operations are in progress and taken in accordance with ASTM D 4796 to represent a vertical section through the coal seam. [*17*]

failure under load, *n*—Fracture of rupture of a rock or other material that has been stressed beyond its ultimate strength. [*17*]

fault gouge, *n*—Soft, uncemented pulverized clayey or clay-like material, commonly a mixture of minerals in finely divided form, found along some faults or between the walls of a fault, and filling or partly filling a fault zone; a slippery mud that coats the fault surface or cements the fault breccia. [*1*]

faulted, *adj*—Characterized by a fracture or a zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture. [*17*]

filter cake. Synonym for **mud cake.**

fishing, *n*—Searching for and attempting to recover, by the use of specially prepared tools, a piece or pieces of drilling equipment (such as sections of pipe, cables, or casing) that have become detached, broken, or lost from the drill string or have been accidentally dropped into the hole. [*1*]

floor, *n*—Strata immediately underlying a coal bed. [*19*]

floor conditions, *n*—Characteristics of the strata that lie immediately below a coal seam and would form the mine floor were the coal seam mined. [*17*]

foaming agent, *n*—A substance used to form stable bubbles due to aeration or agitation of a liquid. A foaming agent is used with water in most drilling and when excessive water is encountered while drilling with air or gas. [7]

focused-current log, *n*—The resistivity log curves from a multielectrode sonde designed to focus the surveying current radially through the rocks in a horizontal, disk-shaped pattern. This permits sharp definition of bed boundaries and improved measurement of resistivity. [*1*]

friable, *adj*—Said of a rock or mineral that crumbles naturally or is easily broken, pulverized, or reduced to powder, such as a soft or poorly cemented sandstone. [*1*]

froth flotation, *n*—A process for cleaning fine coal in which hydrophobic particles, generally coal, attach to air bubbles in a water medium and rise to the surface to form a froth. The hydrophilic particles, generally the ash-forming matter, remain in the water phase. [*16*]

G

gamma-gamma density. Synonym for **density log.**

geophysical log, *n*—A graphic record (acquired as analog or digital data) of the measured or computed physical characteristics of the rock section encountered in a borehole, plotted as a continuous function of depth. Measurements are made by a sonde, which contains the detectors, usually as it is withdrawn from the borehole by a wire line. Several measurements are usually made simultaneously, and the resulting curves are displayed side by side on the common depth scale. A common suite of logs used in coal exploration includes caliper, density (gamma-gamma), natural gamma, and resistivity (resistance). [*19*]

geostatistics, *n*—Statistical techniques developed for mine evaluation by the French school of G. Matheron. [*1*]

geotechnical, *adj*—Of or pertaining to the application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of materials of the Earth's crust for the solution of engineering problems; the applied science of making the Earth more habitable. It embraces the fields of solid mechanics and rock mechanics, and many of the engineering aspects of geology, geophysics, hydrology, and related sciences. [*1*]

Gieseler fluidity, *n*—The degree of plasticity exhibited by a sample of coal heated in the absence of air under controlled conditions as described in ASTM Test Method D 2639. [*17*]

Griffith's Theory, *n*—A theory of failure based on the assumption that the low order of tensile strength in common materials is due to the pressure of small cracks or flaws. [9]

grindability, *n*—The ability of a coal sample to be reduced in particle size to powder or small fragments by friction as in the action of a mill. [*17*]

grout plug, *n*—A filling of an abandoned borehole or well by cement to prevent the flow of water or oil from one strata to another or to and/or from the surface. [*8*]

H

hammermill crusher, *n*—An impact mill consisting of a rotor, fitted with movable hammers, that is revolved rapidly in a vertical plane within a closely fitting steel casing. [*5*]

Hardgrove Grindability Index, *n*—An index that is relative to the ease of grinding coal to a resultant size consist as determined in accordance with ASTM Test Method D 409. [*17*]

I

impregnated diamond bit, *n*—A sintered, powder-metal matrix bit with fragmented bore or whole diamonds of selected screen size uniformly distributed throughout the entire crown section. As the matrix wears down, new, sharp diamond parts are exposed; hence the bit is used until the crown is consumed entirely. [7]

impure coal, *n*—Coal having 25 weight % or more, but less than 50 weight %, of ash on the dry basis.

Discussion—Bone coal with more than 50 weight % ash is properly called coaly or carbonaceous shale or siltstone. Types of impure coal other than bone coal and mineralized coal sometimes occur, for example, sandy coal. [*16*]

in-pit blending, *n*—The practice during mining of combining coal seams or different layers of a coal seam which have different quality or physical characteristics such that the resultant product will have quality or characteristics intermediate of the coals that are mixed. [*17*]

in-seam quality, *n*—The inherent quality of a coal seam prior to mining. [*17*]

incompetent, *n*—Applied to stratum, a formation, rock, or rock structure not combining sufficient firmness and flexibility to transmit a thrust and to lift a load by bending, consequently, admitting only the deformation of flowage. [*6*]

indurated, *adj*—Hardened. Applied to rocks hardened by heat, pressure, or the addition of some ingredient not commonly contained in the rock itself, such as marls indurated by calcium carbonate or shales indurated by silica. [*1*]

inherent moisture, *n*—In coal, moisture that exists as an integral part of the coal seam in its natural state, including water in pores but not that present in macroscopically visible fractures. On removal of coal from a seam, the water originally present in fractures appears as surface moisture whereas coal containing only pore moisture appears dry.

Discussion—To establish the amount of inherent moisture, it is essential to conform to the conditions for its determination as specified in ASTM D 1412 or D 388. Inherent moisture is considered equivalent to bed moisture, but is not equated to the moisture remaining in a coal sample after air drying, as is the practice in some other countries. [*16*]

interval benching, *n*—The practice of sampling coal by thickness intervals on the basis of lithologic characteristics or predetermined thickness. [*17*]

J

jaw-type crusher, *n*—A type of rock crushing machine consisting of two metal plates that are closer at the bottom than at the top and which reduces the particle size of coal by passing large coal particles between the plates that face and move towards each other in a regular oscillating cycle. [*17*]

joint, *n*—A surface of fracture in a rock, without displacement; the surface is usually plane and often occurs with parallel joints to form part of a joint set. [*1*]

jointed, *adj*—Said of a rock that contains joints. [*17*]

K

kaolinite, *n*—a mineral consisting of a hydrous silicate of aluminum; $Al_2Si_2O_5(OH)_4$. [*20*]

kelly, *n*—A steel pipe of square or hexagonal cross section, forming the top section of the rotary drill string. It is fitted into and passes through the rotary table and is turned by it during drilling, thereby transmitting the rotary motion of the table to the drill pipe. Synonym: *kelly joint.* [*1*]

kelly bushing, *n*—The journal-box insert in the rotary table of a rotary drilling rig through which the kelly passes. Its upper surface is commonly used as the zero-depth reference for well-log and other downhole measurements in a well bore. [*1*]

L

lag-time, *n*—The time delay during drilling between strata penetration and the first return of the cuttings from that stratum to the surface. [*17*]

laterolog, *n*—Trade name for a focused-current log or resistivity log that is generated from a multi-electrode sonde designed to focus the surveying current radially through the rocks in a horizontal, disk-shaped pattern. [*1*]

lens, *n*—A deposit of coal bounded by converging surfaces (at least one or which is curved), thick in the middle and thinning out towards the edges, resembling a convex lens. A lens may be double-convex or plano-convex. [*1*]

lifter case, *n*—The sleeve or tubular part attached to the lower end of the inner tube of the M-design and some of the types of core barrels in which is fitted a core lifter. [*10*]

lignite, *n*—The rank of coal, within the lignitic class of ASTM D 388, such that—on the moist, mineral matter free basis—the gross calorific value of the coal in British thermal units per pound is less than 8300 (19.31 MJ/kg), and the coal is nonagglomerating. [*16*]

liquefaction, *n*—The conversion of coal into nearly mineral-free hydrocarbon liquids or low-melting solids by a process of direct or indirect hydrogenation at elevated temperatures and pressures and separation of liquid products from residue by filtration or distillation or both. [*11*]

lithology, *n*—The description of rock, especially in hand specimen, core, and outcrop on the basis of such characteristics as color, mineralogic composition, and grain size. [*1*]

lithotype, *n*—Any of the constituents of banded coal (vitrain, fusain, clarain, durain, or attrital coal) or a specific mixture of two or more of these. [*16*]

lost circulation, *n*—A condition existing when drilling fluid pumped into the well through the drillpipe does not return to the surface. This condition generally results from the loss of fluid to porous, highly fractured, or cavernous strata. [*8*]

lost circulation materials (LCM), *n*—Materials that are mixed with the drilling fluid to seal the pores or fractures in the strata in which circulation was lost so as to prevent the flow of the drilling fluid into the strata and thus regain circulation. [*17*]

lost gas, *n*—The amount of methane and other gases that is lost between the time that a coal bed is cored and a sample of the coal core can be sealed in a canister for gas testing. [*17*]

low rank coal, *n*—Coal of lignitic or subbituminous rank by ASTM Classification D 388. [*17*]

low-mineral-content coal, *n*—Coal that yields less than 8% ash on an as-received basis as determined in accordance with ASTM Test Method D 3174. [*17*]

M

maceral, *n*—A microscopically distinguishable organic component of coal, but including any mineral matter not discernable under the optical microscope.

> DISCUSSION—Macerals are recognized on the basis of their reflectance and morphology. A given maceral may differ significantly in composition and other properties from one coal to another; for some macerals the variation depends mostly on the rank of the coal. Inorganic impurities of submicroscopic size, considered to be part of the maceral, may amount to several percent in attrital coal. [*16*]

marker, *n*—An easily recognized stratigraphic feature having characteristics distinctive enough for it to serve as a reference or datum or to be traceable over long distances, especially in the subsurface as in well drilling or in a mine working. For example, a stratigraphic unit readily identified by characteristics recognized on a geophysical log, or any recognizable rock surface such as an unconformity or an erosion surface. [*1*]

Marsh funnel, *n*—A standard funnel used to determine the viscosity of drilling mud at the drilling rig site. [7]

massive-bedded, *adj*—Said of a stratified rock that is obscurely bedded, or that is or appears to be without internal structure; many massive beds display laminae and other structures when X-rayed. [*1*]

megascopic, *adj*—Said of an object or phenomenon, or of its characteristics, that can be observed with the unaided eye or with a hand lens. [*1*]

meta-anthracite, *n*—The rank of coal, within the anthracite class of ASTM Classification D 388, such that on the dry and mineral matter free basis, the volatile matter content of the coal is equal to or less than 2% (or the fixed carbon is equal to or greater than 98%) and the coal is nonagglomerating. [*16*]

metallurgical coal, *n*—Coal used in the production of coke to aid in the separation of iron from its ore. [*17*]

metamorphism, *n*—The mineralogical, chemical, and structural adjustment of solid rocks to physical and chemical conditions which have generally been imposed at depth below the surface zones of weathering and cementation, and which differ from the conditions under which the rocks in question originated. [*1*]

mineralization, *n*—The process or processes by which a mineral or minerals are introduced into a rock. It is a general term, incorporating various types (e.g., fissure filling, impregnation, replacement). [*1*]

moisture, *in coal, n*—That moisture determined as the loss in weight under rigidly controlled conditions of temperature, time, and air flow as established in ASTM Test Method D 3302. [*17*]

mud cake, *n*—A clay lining or layer of concentrated solids adhering to the walls of a well or borehole, formed where the drilling mud lost water by filtration into a porous strata during rotary drilling.

mud density, *n*—Relative density of the drilling fluid or mud. [*17*]

mud pump, *n*—A large, reciprocating pump that circulates drilling mud. Examples are the duplex (two-cylinder) or triple (three-cylinder) pumps which draw mud from the suction mud pit and pump the slurry downhole through the drillpipe and bit and back up the borehole to the mud settling pits. After the rock cuttings drop out in the settling pit, the clean mud gravitates into the suction pit where it is picked up by the pump's suction line. [*8*]

N

natural gamma (gamma ray) log, *n*—A record of the natural radioactivity of the lithologies encountered in the borehole environment. During recording of natural-gamma logs, the amount of natural radiation is recorded and presented in either CPS (counts per second) or API (American Petroleum Institute) units. Unlike many other log types, a representative natural gamma log can be obtained where borehole and/or fluid conditions are not optimal or where casing is present. The natural gamma log is most often used in the coal environment for identifying clastic lithologies and differentiating coal seams and coal seam partings. [*17*]

natural radiation, *n*—Energy radiated in the form of radioactive waves or particles from rock. [*17*]

neutron log, *n*—A radioactivity log curve that indicates the intensity of radiation (neutrons or gamma rays) produced when the rocks in a borehole are bombarded by neutrons from a sonde. Because this tool responds to the presence of hydrogen, it indicates the presence of fluids (but does not distinguish between oil and water) in the rocks, and is used with the gamma-ray log to differentiate porous from nonporous formations. [*1*]

nodule, *n*—A small, irregularly rounded knot, mass, or lump of a mineral or mineral aggregate, normally having a warty or knobby surface and no internal structure, and usually exhibiting a contrasting composition from the enclosing sediment or rock matrix in which it is embedded (e.g., a nodule of pyrite in a coal seam). [*1*]

nonbanded coal, *n*—Consistently fine-granular coal essentially devoid of megascopic layers.

DISCUSSION—Nonbanded coal may be interbedded with common banded coal, or form a discrete layer at the top or at the bottom of the seam, or may compose the entire seam. It is formed from natural accumulations of finely comminuted plant detritus and commonly includes a significant amount and variety of remains of pollen grains, spores, planktonic algae, wax and resin granules, as well as other fragments of plants. These materials, containing markedly higher amounts of volatile matter than vitrain and some other attrital components, are more abundant in this variety of coal than they are in common types of banded coal. Also, nonbanded coal may contain more disseminated detrital mineral matter, chiefly clay, than associated banded coals, and in the field it may be difficult to distinguish from bone coal. Nonbanded coal is much less common than banded coal in North America. [*16*]

noncoal layers, *n*—Inorganic layers within a coal seam. [*17*]

O

offscale traces, *n*—Curves on a geophysical chart that exceed the maximum or minimum calibrations of the pen deflection causing the pen to create another separate trace generally on the opposite side of the chart. [*17*]

out-of-seam dilution, *n*—The effect on quality parameters by the inclusion of non-coal seam material such as roof or floor material.

DISCUSSION—Ash yield can be greater in coal as mined than coal as obtained from a face channel sample because, in the former, roof and floor rocks can be included in the sample. This reduction of quality (highest quality coal would yield the least ash) is referred to as *out-of-seam dilution* or simply *dilution*. [*16*]

overshot tool, *n*—A fishing tool; a specially designed barrel with gripping lugs on the inside that can be slipped over the end of a tubing, drillpipe, or geophysical tool that is trapped in the hole. An overshot tool is screwed to a string of drillpipe and lowered into the hole, and over the upper end of the lost pipe or the interbarrel in the wireline system. The lugs take a friction grip on the pipe, which can then be retrieved. [*7*]

oxidation, *n*—The process of modifying the fundamental properties of coal as a result of chemisorption of oxygen in the air or oxygen dissolved in groundwater. Oxidation can reduce the affinity of coal surfaces for oil and seriously impair coking, caking, and agglutinating properties. [*11*]

P

parting, mineral, *n*—Discrete layer of mineral or mineral-rich sediment interbedded with coal along which separation commonly occurs during mining. Layers of bone coal having indefinite boundaries usually are not considered to be partings because they do not form planes of physical weakness. They may merge vertically or horizontally with layers that are bony or coaly shale and that do form planes of physical weakness. [*16*]

permitting, *n*—The act of granting a written license or warrant by governmental authorities for activities relating to the exploration of coal such as drilling, road construction, surface water retention, etc. [*17*]

petrographic composition, *of coal, n*—The general makeup of coal in terms of microscopic constituents, specifically macerals and minerals. [*17*]

pilot hole, *n*—Commonly a drillhole of small diameter that is drilled ahead of a full-sized or larger borehole. Also commonly used to describe the first of two or more holes drilled on a site. Typically the first hole is an open hole used to identify the depths of strata of interest; the subsequent holes are drilled to a certain depth that has been identified in the pilot hole and the strata of interest is cored with greater certainty. [*10*]

Poisson's ratio, *n*—The ratio between linear strain changes perpendicular to and in the direction of a given uniaxial stress change. [*15*]

predevelopment, *n*—Period prior to the establishment of mining. [*17*]

proximate analysis, *n—in the case of coal and coke*—The determination, by prescribed methods of moisture, volatile matter, fixed carbon (by difference), and ash.

DISCUSSION—Unless otherwise specified, the term *proximate analysis* does not include determinations of sulfur or phosphorus or any determinations other than those named. [*16*]

pull-down, *n*—A system of pulleys or sheaves rigged with cable or chains attached to the drive rod or kelly and used to increase the cutting pressure on the bit when the weight of the rod is insufficient. [*10*]

pyrite, *n*—A common mineral that consists of iron sulfide (FeS_2) and has a grass-yellow color and metallic luster (and is burned in making sulfur dioxide and sulfuric acid). [*20*]

R

radioactive source, *n*—A compound or material that spontaneously emits particular radiation such as gamma rays. [*17*]

rank, *n*—Of coal, a classification designation that indicates the degree of metamorphism or progressive alteration from lignite to anthracite in accordance with ASTM Classification D 388. [*16*]

raw head sample, *of coal, n*—A representative sample of coal that has been crushed but not subjected to any size or float/sink separation or other tests or analyses. [*17*]

reamer, *n*—A rotary-drilling tool with a special bit used for enlarging, smoothing, or straightening a drill hole, or making the hole circular when the drill has failed to do so. [*1*]

reclamation, *n*—The restoration of land disturbed by mining or drilling operations to a condition that is in concert with surrounding natural conditions or that is suited for human use. [*17*]

relative density, *n*—The ratio of the difference between the void ratio of a cohesionless soil in the loosest state and any given void ratio to the difference between the void ratios in the loosest and in the densest states. [*15*]

reserve sample, *n*—A sample obtained after a test sample has been extracted and which is saved for additional testing or repeat testing, if needed. [*17*]

resistivity log, *n*—A measure of the voltage differential of strata along the walls of a borehole when electrical current is passed through the strata. The resistivity log requires a fluid-filled hole to constantly provide a conductive medium between electrodes on the tool. The spacing between the electrodes determines the precision of bed boundary relationships in much the same manner as with the density log. The resistivity log is useful primarily in conjunction with other log types. The logs are affected by casing, logging speed, electrode spacing, formation porosity, and resistivity changes in the borehole fluid. [*19*]

reverse circulation drill system, *n*—A drill system involving the circulation of drilling fluid down the outside of the drillpipe and return up through the center of the drillpipe. A double-walled reverse circulation system is a special type of reverse circulation system in which nearly uncontaminated cuttings can be acquired because the fluid does not contact the drillhole wall. [*17*]

rheologic, *adj*—Of or pertaining to the deformation and flow of matter. Tests which determine the rheologic properties of coal include the Geisler plastometer and Audibert-Arnu dilatometer. [*20*]

riffle, *n*—A hand-fed sample divider device that divides the sample into two parts of approximately the same mass. [*16*]

rock mechanics, *n*—The theoretical and applied science of the physical behavior of rocks, representing a "branch of mechanics concerned with the response of rock to the force fields of its physical environment." [*12*]

rock type, *n*—A particular kind of rock based on a specific classification such as a sandstone or shale. [*17*]

rollercone bit, *n*—A rock-cutting tool placed at the bottom of the drillstring made with three or four shanks welded together to form a tapered body. Each shank supports a cone-like wheel with case-hardened teeth that rotate on steel bearings. [7]

roof, *n*—The strata immediately overlying a coal seam. [*19*]

rotary bit, *n*—A general class term for drill bits that are used in drilling by rotation of the drill bit under constant pressure without impact. [7]

rotary table, *n*—In rotary drilling, a power-driven circular platform that rotates the kelly, drill pipe, and drill bit. It is sometimes used as the zero-depth reference for downhole measurements. [*1*]

rugosity, *of a drillhole, n*—The irregularities or roughness of the wall of a drillhole. [*17*]

S

seam correlation, *n*—The interpretation of the connection of coal seams from one locality to another. [*17*]

sedimentary structure, *n*—A structure in a sedimentary rock formed either contemporaneously with the deposition (a primary sedimentary structure) or by sedimentary processes subsequent to deposition (a secondary sedimentary structure). [*1*]

selective mining, *n*—The differential extraction of parts of a coal bed to enhance its quality or to eliminate or minimize the inclusion of unwanted parts of the bed. [*17*]

semianthracite, *n*—The rank of coal, within the anthracitic class of ASTM Classification D 388, such that on the dry and mineral matter free basis, the volatile matter content of the coal is greater than 8% but equal to or less than 14% (or the fixed carbon content is equal to or greater than 86% but less than 92%) and the coal is nonagglomerating. [*16*]

service company, *n*—A company that performs specialized work at the drill site such as logging, sampling, fishing, and fracturing. [*17*]

sieve analyses, *of coal, n*—The designation of size of raw or cleaned coal in accordance with ASTM Test Method D 4749. [*17*]

size consist, *of coal, n*—The particle size distribution of a coal. [*17*]

as-mined size consist—The makeup of the mined coal product by size classes as determined by performing standard sieve analysis tests in accordance with ASTM Test Method D 4749. [*16*]

sonde, *n*—An elongated cylindrical tool assembly used in a borehole to acquire a geophysical log. [*17*]

sonic log, *n*—An acoustic log showing the interval-transit time of compressional seismic waves in rocks near the well bore of a liquid-filled borehole. First used for seismic-velocity information it is now used chiefly for estimating porosity and lithology by the empirical Wyllie time-average equation. [*1*]

spontaneous potential log (SP), *n*—The geophysical log that records changes in natural potential along an uncased borehole. Small voltages are developed between mud filtrate and formation water of an invaded bed, and also across the shale-to-mud interface. These electrochemical components are augmented when mud filtrate moves toward a formation region of lower fluid pressure through the mud cake. Where formation waters are less resistive (more saline) than drilling-mud filtrate, the SP curve deflects to the left from the shale baseline. [*19*]

steam coal, *n*—Coal that is suitable to be combusted in boilers to produce steam that, in turn, powers turbines to generate electricity. [*17*]

strata, *n*—Tabular or sheetlike bodies or layers of sedimentary rock, visually separable from other layers above and below; a bed. [*1*]

stratigraphic sequence, *n*—A chronologic succession of sedimentary rocks from older below to younger above, essentially without interruption. [*1*]

strip mine, *n*—Synonym for **surface mine**.

structural, *n*—The general disposition, attitude, arrangement, or relative positions of the rock masses of a region or area; the sum total of the structural features of an area, consequent upon such deformational processes as faulting, folding, and igneous intrusion. [*1*]

surface mine, *n*—A mining method in which coal is exposed and recovered by removal of topsoil and overburden followed by coal extraction. Following extraction of the coal, the excavated area is reclaimed by replacing the overburden and topsoil and revegetating the surface. [*17*]

surface moisture, *n*—That moisture being the difference between the total moisture as determined by ASTM Test Method D 3302 and the equilibrium moisture as determined by ASTM Test Method D 1412. [*17*]

surfactant, *n*—A surface-active substance (as a detergent). [*20*]

swelling clay, *n*—Clay that is capable of absorbing large quantities of water, thus increasing greatly in volume (e.g., bentonite). Swelling clay shrinks and cracks on drying. [*1*]

synfuel, *n*—Any synthetic crude oil or gas produced by the pyrolysis or hydrogenation of coal or coal extracts and which can be used as a fuel. [*17*]

synthetic polycrystalline diamonds, *n*—Diamonds produced by subjecting a carbonaceous material to extremely high temperature and pressure. [*1*]

T

test pit, *n*—Open excavations, dug by hand or machine, large enough to permit a person to enter, examine, and sample the coal in a natural state. [*17*]

trace element, *n*—An element that is not essential in coal but can be detected analytically in small quantities. Commonly, trace elements refers to those elements in concentrations less than 1% in the whole coal, dry basis. [*17*]

true density, *n*—The ratio of the mass of a material or substance to its true volume, excluding the volume of pores. [*17*]

U

ultimate analysis, *n*—In the case of coal and coke, the determination of carbon and hydrogen in the material, as found in the gaseous products of its complete combustion, the determinations of sulfur, nitrogen, and ash in the material as a whole, and the calculation of oxygen by difference.

DISCUSSION—The determination of phosphorus or chlorine is not by definition a part of the ultimate analysis of coal or coke. See ASTM Test Method D 2361 for the determination of chlorine and ASTM Test Methods D 2795 for the determination of phosphorus.

Moisture is not by definition a part of the ultimate analysis of coal of coke but must be determined in order that analytical data may be converted to bases other than that of the analysis sample. Inasmuch as some coals contain mineral carbonates, and practically all contain clay or shale containing combined water, a part of the carbon, hydrogen, and oxygen found in the products of combustion may arise from these mineral components. [*16*]

underground mining, *n*—An extraction method of coal mining from below the surface of the ground in which a shaft or entry is dug to intersect with a coal seam and the coal is extracted by either room and pillar or longwall mining methods. [*17*]

V

vertical book, *n*—A method of arranging core in a multicolumn core box placed vertically and away from the individual, whereby the top of the core is placed in the upper left-hand corner of the box and the bottom of the core in the lower right-hand corner. [*17*]

verticality log, *n*—A geophysical log which indicates the dip and direction of a borehole such that depths within the borehole can be plotted relative to the position of the borehole at the surface. [*17*]

vitrain, *n*—Shiny black bands, thicker than 0.5 mm, of subbituminous and higher rank banded coal.

DISCUSSION—Vitrain, attributed to the coalification of relatively large fragments of wood and bark, may range up to about 30 mm (approximately 1 in.) thick in eastern North American coals, but may be much thicker in the younger western deposits. Vitrain is commonly traversed by many fine cracks oriented normal to the banding.

In lignite, the remains of woody material lack the shiny luster of vitrain in the higher rank coals and may instead be called previtrain. It is differentiated from attrital bands of lignite by its smoother texture, often showing the grain of wood. Previtrain may be several inches thick. [*16*]

vitrinite reflectance, *n*—The percent of incident radiation that is reflected from the polished surface of vitrinite as measured using a reflected light microscope in accordance with ASTM Test Method D 2798. [*17*]

volatile matter, *n*—Those products, exclusive of moisture, given off by a material, such as gas or vapor, determined by definite prescribed methods which may vary according to the nature of the material.

DISCUSSION—In the case of coal and coke, the methods employed shall be those prescribed in ASTM Test Methods D 3175. [*16*]

W

washability testing, *n*—the analysis of the specific gravity distribution of chemical and physical characteristics of coal.

DISCUSSION—The specific gravity fractions are obtained by subjecting the material being studied to a series of solution, each with a discrete specific gravity, that covers the range of specific gravities in question. In the case of the washability analysis of coal, these solutions are obtained by the mixing of various organic liquids that are relatively inert toward the majority of coal types. The distribution, as determined by the analysis, is affected by the physical condition of the sample subjected to the washability analysis (e.g., the moisture content and the size content of the material). [*16*]

weathered coal, *n*—Coal that has been subjected to the actions of air and water in surface stockpiles, mining faces, and outcrops causing size reduction, oxidation, mineralization, and decrease of any caking or coking properties. [*17*]

wireline drill-core system, *n*—A system in which removing of a core is accomplished with the drill string in place, without withdrawing and dismantling the drill pipes, such as retrieving the core in a retractable inner core barrel and lowering the same or an alternative inner barrel into place inside the drill pipe. [*1*]

Y

Young's modulus, *n*—The ratio of the increase in stress on a test specimen to the resulting increase in strain under constant transverse stress, limited to materials having a linear stress-strain relationship over the range of loading. Also called *elastic modulus*. [*15*]

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[*16*] ASTM Terminology on Coal and Coke (D 121).

[*17*] Terms defined within the context of this manual.

[*18*] ASTM Classification of Coals by Rank (D 388).

[*19*] ASTM Practice for Collection of Coal Samples from Core (D 5192).

[*20*] *Webster's Ninth New Collegiate Dictionary*, Merriam-Webster, Sprinfield, Mass., 1985.

Designation: D 5192 – 91

Standard Practice for Collection of Coal Samples from Core[1]

This standard is issued under the fixed designation D 5192; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes procedures for collecting and handling a coal sample from a core recovered from a borehole.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 121 Terminology of Coal and Coke[2]
D 388 Classification of Coals by Rank[2]
D 1412 Test Method for Equilibrium Moisture of Coal at 96 to 97 Percent Relative Humidity and 30°C[2]
D 2013 Method of Preparing Coal Samples for Analysis[2]
D 2796 Definitions of Terms Relating to Megascopic Description of Coal and Coal Seams and Microscopical Description and Analysis of Coal[2]
D 4371 Test Method for Determining the Washability Characteristics of Coal[2]
D 4596 Practice for Collection of Channel Samples of Coal in the Mine[2]

3. Terminology

3.1 *Definitions*—For additional definitions of terms, refer to Terminology D 121.

3.1.1 *borehole, n*—the circular hole through soil and rock strata made by boring.

3.1.2 *caves or washouts, n*—zones of increased hole diameter caused by rock fragments that fall from the walls of a borehole and can block the hole or contaminate the cuttings and which erode or abrade the sidewall of the borehole by the action of the drilling. These zones can affect the accuracy of certain geophysical logs (especially density). Corrections to other geophysical logs can be made if a caliper log is available. The most common causes of caves or washouts include soft or fractured lithologies, the presence of water-producing zones, and the downhole pressure of the drilling medium (fluid or air) that often causes differential erosion of various strata within the borehole.

3.1.3 *concretion, n—in a geological sense,* a mass of mineral matter found in rock of a composition different from its own and produced by deposition from aqueous solution in the rock.

3.1.4 *core, n—in drilling,* a cylindrical section of rock (coal) that is usually 5 to 10 cm in diameter, taken as part of the interval penetrated by a core bit and brought to the surface for geologic examination, representative sampling, and laboratory analyses.

3.1.5 *core barrels, n*—two nested tubes above the bit of a core drill, the outer rotating with the bit, the inner receiving and preserving a continuous section or core of the material penetrated. The following two types of inner barrels are commonly used.

3.1.5.1 *split-tube barrel, n*—a type of inner barrel consisting of two longitudinal halves of pipe bound together by reinforced tape at intervals along the barrel length that allows easy access to a relatively intact core (but cutting the tape). (This is the preferred barrel type for coal exploration, when available.)

3.1.5.2 *solid-tube barrel, n*—a type of inner barrel consisting of a single solid-walled length of pipe in which removal of the core is accomplished by mechanical or hydraulic pressure at one end of the pipe thus extruding the core onto a core tray. (The core is likely to be less intact than when a split-tube barrel is used.)

3.1.6 *core sample, n*—that part of a core of rock or coal obtained so as to accurately represent a thickness of a'unit penetrating by drilling.

3.1.7 *geophysical log, n*—a graphic record of the measured or computed physical characteristics of the rock section encountered in a borehole, plotted as a continuous function of depth. Measurements are made by a sonde, which contains the detectors, as it is withdrawn from the borehole by a wire line. Several measurements are usually made simultaneously, and the resulting curves are displayed side by side on the common depth scale. A common suite of logs used in coal exploration include caliper, density (gamma-gamma), natural gamma, and resistivity.

3.1.7.1 *caliper log, n*—a continuous mechanical measurement of the diameter and thus the rugosity of the borehole. The tool identifies zones where swelling or cavings (washouts) have occurred during drilling. The tool's value is in allowing qualitative or quantitative corrections to be made to other geophysical logs which are affected by borehole size (especially density).

3.1.7.2 *density log (gamma-gamma log), n*—measures electron density within lithologic units which is related to their bulk density. The wireline tool records the intensity of

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[1] This practice is under the jurisdiction of ASTM Committee D-5 on Coal and Coke and is the direct responsibility of Subcommittee D05.23 on Sampling.

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[2] *Annual Book of ASTM Standards*, Vol 05.05.

gamma radiation (in counts per second) from a nuclear source within the tool after it has been attenuated and backscattered by lithologies within the borehole. Due to the distinctly low density of coals, the density log is essential in coal exploration for identifying coal seams and coal-seam partings. The bias/resolution of density logs can be affected by source-detector spacing (closer spacing increases resolution), borehole size and irregularities (see *caves* or *washouts*), and the presence of casing and logging speed.

3.1.7.3 *natural gamma-ray log, n*—a record of the natural radioactivity of the lithologies encountered in the borehole environment. During recording of geophysical logs, the amount of natural radiation is recorded and presented in either counts per second (CPS) or American Petroleum Institute (API) units. Unlike many other log types, a representative natural gamma log can be obtained where borehole or fluid conditions, or both, are not optimal or where casing is present. The natural gamma log is most often used in the coal environment for identifying clastic lithologies and differentiating coal seams and coal-seam partings.

3.1.7.4 *resistivity log, n*—a measure of the voltage differential of strata along the walls of a borehole when electrical current is passed through the strata. The resistivity log requires a fluid-filled hole to constantly provide a conductive medium between electrodes on the tool. The spacing between the electrodes determines the precision of the bed boundary relationships in much the same manner as with the density log. The resistivity log is useful primarily in conjunction with other log types. The logs are affected by casing, logging speed, electrode spacing, formation porosity, and resistivity changes in the borehole fluid.

3.1.8 *floor, n*—the rock material immediately underlying a coal bed.

3.1.9 *roof, n*—the rock material immediately overlying a coal bed.

3.1.10 *sonde, n*—an elongate cylindrical tool assembly used in a borehole to acquire a geophysical log.

4. Summary of Practice

4.1 At selected sites in a deposit of coal, a borehole is drilled and the core containing the coal and surrounding strata of rock is recovered.

4.2 The coal core is cleaned of drilling fluid, if necessary, properly described, and packaged so that loss of moisture is minimized. From this core, coal and roof and floor material of interest are collected for analysis and testing.

5. Significance and Use

5.1 Coal samples are collected from cores to be used for subsequent chemical, physical, and petrographic testing that is needed for commercial evaluations, for planning mining operations to maintain coal quality, for determining the apparent rank of the coal in accordance with Classification D 388, and for geologic and coal resource studies.

6. Apparatus

6.1 *Steel Measuring Tape*, not less than 10-m (30-ft) long.

6.2 *Rock Hammer, Chisel, or Pick*, with file for sharpening.

6.3 *Water Source*, to provide fresh, clean water for rinsing drilling mud from cut-surface of the core.

6.4 *Waterproof Marking Pencils* that are visible on coal, such as a yellow lumber crayon.

6.5 *Polyethylene Bags, Tubing, or Sheets*, 0.1 mm (4 mil) or thicker.

6.6 *Core Tray*, constructed of wood, plastic, or metal, onto which to extrude the core from the core barrel.

6.7 *Boxes for Core Storage*, constructed of wood, plastic, or coated cardboard or if the core is to remain stratigraphically oriented, use containers such as poly(vinyl chloride) (PVC) pipe.

6.8 *Tags and Waterproof Marking Pens*, for sample identification and for marking depths, orientation, etc., on the plastic sheeting.

6.9 *Notebook and Pencil*, or other means for record keeping.

6.10 *Waterproof Container*, to hold sample tag.

6.11 *Geophysical Logging Unit (optional)*, consisting of recording equipment and sondes for high-resolution density and caliper logs and possibly gamma and resistivity logs.

7. Planning for Sampling

7.1 Obtain information such as geologic, topographic, and land ownership for locating suitable sites for drilling. Choose sites that will best satisfy the purpose of sampling.

7.2 A core approximately 47 mm (1.87 in.) in diameter yields a sufficient sample for most purposes. Minimum sample mass requirements for analytical tests, such as washability testing, may dictate a sample mass that can only be obtained from larger diameter cores or multiple separate cores.

NOTE 1—The diameter and length of the core (or number of separate cores) required to obtain a desired mass of sample may be estimated from the density of coal, approximately 1.3 to 1.35 g/cm^3. The selected diameter of the core can have an effect on the representativeness of subsamples obtained from the core sample for various types of testing. As an example in washability testing, the diameter of the core should be at least three times the largest dimension of the top size of any subsamples to be obtained from the core sample. For information on determining the washability characteristics of coal, see Test Method D 4371 and the report by Wizzard.[3]

A larger diameter core can also be necessary to obtain a more representative sample if the quality of the coal varies greatly from layer to layer in the seam.

7.3 *Increment Sampling*—Where differences of coal quality parameters exist among different layers or benches in the same coal seam or where the seam is thick, it is best to sample and analyze the seam in vertical increments.

7.3.1 *Compositing*[4]—Data obtained from the separate analyses of the vertical core increments can be composited by calculation, preferably by sample mass if sufficient information such as core length and density has been measured for each increment. Alternatively, a composite sample of the entire seam can be produced by combining representative splits of the increments by increment thickness for the determination of whole core characteristics. The use of an ash/density relationship for the specific geographic

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[3] Wizzard, J. T., "The Reliability of Using Channel Samples to Represent Run-of-Mine Coal Washability," *Technical Report TR-82/3*, Department of Energy, Pittsburgh Energy Technology Center.

[4] *Manual on Drilling, Sampling, and Analysis of Coal, ASTM MNL 11*, ASTM, 1992.

area and seam being studied can be helpful in validating direct density measurements. Extreme care and cross-checking should be exercised when combining a sample composite for analysis or when calculating a composite analysis from the analysis of increments. Some coal quality parameters are not additive in a linear fashion and cannot be accurately determined by calculated compositing. Fusion temperatures of ash and Hardgrove grindability and Gieseler fluidity indices are examples of physical properties that are nonadditive and best determined on whole samples.

7.4 *Sampling Plans for Different Purposes:*

7.4.1 Variations in the purpose of sampling and in conditions encountered in the field may preclude the establishment of rigid procedures covering every sampling situation. Therefore, formulate a plan taking into account the conditions of drilling, the purpose of the sampling, and the known characteristics of the coal seam. Characteristics include lateral or vertical variations in coal quality and occurrences of persistent mineral parting or concretions within a seam.

7.4.2 *Sampling Plan for Classification According to Rank:*

7.4.2.1 A minimum of three, but preferably five or more, whole-seam samples are required to characterize the apparent rank of the coal in a given area in accordance with Classification D 388.

7.4.2.2 All roof and floor rock, all mineral partings more than 10-mm (3/8-in.) thick, and mineralized lenses or concretions (such as sulfur balls) more than 13-mm (1/2-in.) thick and 50-mm (2-in.) wide shall be excluded from the sample. Angular or wedge-shaped mineral lenses or concretions that are not continuous shall be excluded from the samples if the volume exceeds that of a parting 10-mm thick. (Refer to Practice D 4596.)

8. Core Recovery

8.1 *Recovery for Classification According to Rank and Some Other Purposes*—The recovery of 100 % of the entire seam is not possible on every core under even the best of field conditions. However, useful information can many times be obtained from cores where less than 100 % of the seam has been recovered. When portions of the interval have been lost, the following information should be recorded: (*1*) the percent recovery and (*2*) the estimated location and thickness of the lost intervals. Use of data from cores that represent less than 100 % of the total seam thickness shall be identified as such and used with caution.

8.2 *Determining Recovery From Comparison of Geophysical Logs and Core*[4]—The most reliable measurement of coal seam thickness can be obtained from deflections on the high-resolution density log and the caliper log. If the roof and floor lithologies are other than sandstone, the resistivity and natural gamma can also be used, especially if caves or washouts have caused material to be lost during coring. Generally, the midpoint (the point at one-half the deflection between the lithologic-density lines) on the log trace is used to determine bed boundaries. However, for certain geophysical tools it may be necessary to use other criteria, such as one-third deflection, initial deflection, etc. Geophysical tool manufacturers or service companies have specific instructions for the calibration and interpretation of their logs and should be consulted by the user.

8.3 Regardless of the method used to determine thickness, check the estimated thickness from the geophysical log(s) against measured coal-core sections for final determination. This is particularly critical in cases of gradational contacts or thin, dense partings for which thicknesses are commonly overexaggerated by the response of the geophysical tool. Generally, thicknesses can be determined from geophysical tools within ±30 mm (0.1 ft) or less depending on the type of tool used.

9. Sampling Procedures

9.1 Handle the section of coal core carefully as it is extracted from the borehole. Additional breakage should be prevented.

9.2 Transfer the core onto a core tray that has been constructed to receive the length and diameter of the core being drilled.

9.2.1 *Split-Tube Core Barrels*—Place the tube in the tray, remove one section of the tube, and roll the core into the tray.

9.2.2 *Solid-Tube Core Barrels*—Place the tube at a slight angle above the tray with one end in the tray, pull the tube lengthwise down the tray and push the core at the opposite end, thereby extruding the core onto the tray while at the same time moving the tube along the length of the tray. Match any broken contacts so that the lengths of the core can be measured.

9.3 Measure the lengths of the core for various lithologies and record the values.

NOTE 2—In steeply dipping coal seams, the measured coal-seam thickness can exceed the true seam thickness. In addition, improper arrangement of broken pieces of the core can also contribute to inaccuracies in determination of the true thickness of the seam.

9.3.1 *Splitting the Core Lengthwise by Sawing*—If necessary, the core can be sawn in the field or laboratory into approximately equal sections of intact core. This should be performed by keeping the core in the PVC pipe or by using a similar support to keep the core intact while sawing.

9.4 Remove all drill mud or cuttings from the core using clean water.

9.5 *Core Description*—Describe and record observations on the character of the coal seam (refer to Definitions D 2796) to the extent of the sampling plan as follows:

9.5.1 The type of coal throughout the length of the coal core. Note any banding, if present. If the coal is bituminous, describe the type of lithologies (vitrain, clarain, durain, fusain, nonbanded, and impure coal) that are present.

9.5.2 The type and distribution of mineral matter, if present, throughout the length of the coal core.

9.5.3 The nature of any fractures or joints in the coal, including any mineralization of cleat.

9.5.4 Drilling marks or erosion of the core.

9.5.5 The lithology of contacts with other rock layers, noting especially those characteristics (such as fossils, burrows, or bedding) that suggest marine or nonmarine condition of their environment during deposition.

9.5.6 The location of the drill site, the surface elevation of the borehole, the depth measurements of the coal seam contacts with other lithologies, and the intervals of coal sampled, using a unique number or series of numbers that identifies any samples that will be analyzed.

9.6 *Field Preparation and Packaging of Samples*—Prepare the core sample according to the purpose of sampling. Bulk sampling is utilized for samples that do not require orientation. For other purposes when vertical orientation is critical, special handling procedures must be followed.

9.6.1 *Bulk Sample to Determine Apparent Rank Only*—For ranking, all mineral layers are excluded according to 7.4.2.2. The excluded layers should be sampled and analyzed separately for resource assessments. If sampling for other purposes, mineral layers should not be excluded so as to approximate coal as mined.

9.6.1.1 Identify and separate all mineral layers or other parts of the seam that are to be excluded from the bulk sample according to the procedure specified in section 7.4.2.2 when sampling.

9.6.1.2 With a rock hammer or chisel, cut out for exclusion all marked material not to be included in the bulk sample.

9.6.1.3 Place all remaining coal core in a plastic bag. Label the outside of the bag with a permanent waterproof marking pen. Seal the bag and attach a properly labelled, waterproof tab. Package in like manner any excluded layers (materials) to be analyzed separately from the coal sample.

9.6.2 *Cores for the Characterization of Strata Within the Seam*—Place the intact core into a split PVC tube or a core box that is lined with polyethylene sheeting. Label top, bottom, parting occurrences, elevations, and drilling depth on the inside of the PVC tube half or core-box lid.

9.6.2.1 For split PVC pipe, place half of the pipe onto the coal core, break the core to the same length as the pipe, roll the core section and PVC pipe over and place the second half of the pipe onto the core. Using fiber reinforced tape, tape the halves of the PVC pipe together so they will not separate, mark the top of the core section on the PVC pipe, either slip the pipe into a polyethylene tube or wrap it in a polyethylene sheet, securely seal the ends of the plastic, and tie a prepared label in a waterproof container to one end of the section. Double-bag the section in plastic and transport.

9.6.2.2 For a core box, break the core into lengths, each of which will fit into one row in the box. Alternatively, wooden boxes can be constructed to match the thickness of the bed. Wrap the core in a polyethylene sheet (0.1-mm minimum thickness), securely double-seal the ends of the core with a twist wire or tape, and properly indicate the direction of the top of the core on the side of the plastic sheet with a waterproof marking pen. Tie a label in a waterproof sleeve to one end of the core to identify the sample, place the core length into the box, and label and seal the box for transporting. For soft or friable coal, it is advisable to extrude the core directly into the core tray as specified in 9.2.

9.6.3 *Bulk Samples for Other Testing*—For samples in which stratigraphic orientation is not necessary and only a bulk sample of all the coal and partings that comprise the bed is required, separate the coal from the roof and floor material, place the coal into polyethylene bags (0.1-mm minimum thickness), seal the bag, such as with a wire tie, attach a labeled tag to the bag, double-bag the sample, and prepare it for transport.

9.7 Moisture determined directly from a core sample shall be considered *questionable* in any core sample because of possible contamination from drilling fluids and groundwater. If a more representative estimate of the inherent moisture content of the core sample (with the exception of certain low-rank coals) is desired, the sample should be analyzed according to Test Method D 1412.

10. Preparation of Samples for Analyses

10.1 *Samples for Washability*—Prepare samples in accordance with Test Method D 4371.

NOTE 3: **Caution**—Crushing of core samples is not likely to simulate the size consist of as-mined or commercially crushed coal.

10.2 *Samples for Testing for Quality*—Prepare samples in accordance with Method D 2013.

11. Keywords

11.1 borehole samples; coal; coal rank; core; core samples; floor; roof

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