COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.1 EXPLORATORY TEST PITS

SECTION 3.1
EXPLORATORY TEST PITS

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3.1 EXPLORATORY TEST PITS

3.1-1 PURPOSE

Test pits and trenches are excavated by backhoe equipment to provide detailed visual examination of near-surface soil, ground water, and bedrock conditions. The depth of excavation depends on site conditions and type of equipment used. The major advantages of test pits over soil borings are as follows:

- The near-surface stratigraphy is exposed, facilitating sample collection and recovery and logging of soil, water level, and bedrock surface.
- Information is provided on the lateral and vertical extent of subsurface features.
- Test pits are usually cost-effective over this depth, and equipment is readily available.

The size of the backhoe equipment and the procedures to be employed are influenced by the type of information to be obtained, anticipated level of contamination (if any), and depth of excavation required. Site-specific safety issues (i.e., test pit stability, contamination potential, and impacts on ground water) should be considered when designing a test pit program. Installation of observation wells in test pits is not recommended; if installed, they should be used for water level data only, not water quality sampling.

3.1-2 METHODOLOGY

The following sections summarize the methodology for test pit explorations, including excavation, hazardous waste protocols, logging and sampling, and backfilling.

3.1-2.1 Excavation

Prior to the start of the test pit program, all potential test pit locations should be laid out to the nearest foot. The presence or absence of underground utilities should be determined before excavation begins. DIG-SAFE should be contacted to clear utilities within a public right-of-way (1-800-DIG-SAFE). All utility companies with potential underground services should be contacted; approval by their representatives should be secured prior to excavation at individual test pit locations. In urban areas, this may require obtaining permits from the city or town of jurisdiction.

The sampler and backhoe operator should plan each test pit excavation. The backhoe operator should excavate the test pit in several increments of depth. After each increment, the operator should wait while the sampler inspects the test pit to decide if conditions are appropriate for sampling. Practical depth increments generally range from 1 to 4 feet. The backhoe operator, who will have the best view of the test pit, should cease digging if any of the following conditions are encountered:

- o Distinct changes in stratigraphy or materials.
- o Odors.
- o Ground water or fluid-phase contaminants.
- o Drums or other potential waste containers.
- o Utility lines not previously identified.

These actions are necessary to permit proper logging and sampling of the test pit, and to prevent a breach in safety protocol. For example, if seepage or fluids are encountered, they could be sampled after suitable screening and monitoring. Waste and sludge deposits could likewise be sampled before proceeding. If uncollapsed drums are encountered, extreme caution must be exercised. The test pit should be terminated, an expert in drum removal should be engaged, and a new test pit should be dug at an adjacent location.

3.1-2.2 Hazardous Waste Protocols and In-pit Safety

To expedite sampling and recordkeeping efforts, and to minimize periods of potential exposure during test pit excavation, the sampling crew should have sufficient tools and equipment to sample each pit thoroughly without requiring decontamination. The backhoe and tools should be decontaminated between excavation of each test pit. Decontamination procedures described in Section 3.3 are appropriate for backhoe equipment. The backhoe bucket and boom should be decontaminated as required before excavation of each test pit at a central staging location. If necessary, decontamination wash water should be collected and stored on-site.

The actual area of each test pit, temporary staging area, and spoils pile will be predicated on site conditions and wind direction at the time the test pit is made. Contaminated spoils should be segregated from clean spoils during stockpiling.

The preselection and use of hand and horn signals is important during completion of test pits due to noise levels around the backhoe. The sampling crew and backhoe operator should rehearse appropriate signals ahead of time and be thoroughly familiar with their meanings. All personnel should be equipped with air-blast horn devices, especially when wearing respiratory safety gear, which hinders communication.

During test pitting, an organic volatile analyzer must continuously monitor for any releases to the environment in the work area and at the facility boundary, as appropriate. Sampling and logging should be done from the ground near the test pit surface unless levels of organics, explosive gases, and oxygen are within acceptable limits. These levels should be measured in the field using field-screening equipment.

Under no circumstances should an individual enter a test pit deeper than 5 feet unless side slopes have been cut back to acceptable Occupational Safety and Health Administration (OSHA) standards, and an experienced geologist or engineer has determined the pit safe to enter. Material excavated from the pit should be piled far enough from the edge of the excavation so that pit stability will not be influenced by the weight of this surcharge.

At potentially hazardous waste sites, the individual entering the test pit should be equipped with safety gear as required by the conditions in the pit, usually Level B. The individual should be affixed to a safety rope and continuously monitored while in the pit by a second individual at ground surface. The second individual should be fully dressed in protective clothing (including a self-contained breathing device) and standing by during all pit entry operations. The individual entering the pit should remain for as brief a period as practical. Further details on this subject are described in Section 2.3, Health and Safety Plans.

Sampling of unopened buried drums is excluded from these exploratory test pit protocols. Such work should be undertaken on a site-specific basis utilizing appropriate safety and sampling protocols for each instance.

3.1-2.3 Logging and Sampling Procedures

3.1-2.3.1 Logging

Features exposed in the test pits should be logged as they are excavated. Records of each test pit should be made on prepared forms or in a field notebook. If the log is made in a fieldbook, it should be transcribed to a prepared form. The records should contain plan and profile sketches of the test pit showing materials encountered, their depth and distribution, and, if necessary, sample locations. Two examples of test pit record forms are shown in Figures 3.1-1 and 3.1-2. These forms provide for entry of necessary sampling, monitoring, and subsurface data for each test pit in a concise and uniform manner, and provide a cross-check with chain-of-custody records and sample label counts. If hazardous materials are anticipated or encountered, the records should also include safety and screening information.

If necessary, a grid system should be used on the face of the test pit to facilitate the measurement and distribution of strata and samples. Soils and rock should be classified in accordance with procedures outlined in Sections 3.5 and 3.7. At a minimum, the test pit log should include the following information:

- Plan and profile sketches of the test pit showing materials encountered, the depth and distribution of these materials in the test pit, and sample location.

- Sketch of the test pit location showing permanent and identifiable location marks.

- Photographs of test pit walls or excavated material.

- The size, quantity, and type of boulders and fill materials excavated from the pit.

- Representative samples, as required.

- The presence or absence of ground water or surface water entering the pit, and a record of the approximate rate of flow.

- The nature and character of bedrock, including attitudes of bedding and discontinuities, as well as relative structural features (a supplemental sketch may be of value).

- A record of voids, stability, and density of the materials encountered, and obstructions to excavation.

- Torvane and/or pocket penetrometer readings, which should be obtained as field measurements of shear strength where cohesive soils are encountered.

- Safety and screening information, if hazardous materials are anticipated or encountered.

- Notation of reason for terminating the test pit.

3.1-2.3.2 Sampling

The actual depth and type of samples to be collected from each test pit should be selected prior to the initiation of the test pit program, if sufficient information exists, or at the time of test pit excavation. Sufficient samples should be obtained to adequately characterize the soil stratigraphy through laboratory index testing (i.e., moisture content, organic content, grain-size distribution, hydrometer analysis, and Atterberg limits). If hazardous materials are anticipated or encountered, the sampling should be sufficient to adequately characterize the contaminant distribution as a function of depth for each test pit. Additional samples of each waste phase and any fluids encountered in each test pit may be collected. Due to uncontrolled exposure to the atmosphere, samples collected from test pits will not be suitable for analysis of volatile organic compounds.

To sample a pit two methods can be used:

- o Samples are withdrawn from the test pit using the backhoe bucket.
- o Samples are obtained from within the test pit.

The method to be used should be selected in the field at the time the test pit is sampled.

(a) Samples of Soil and Fluids Obtained from the Backhoe Bucket The sampler or crew chief should direct the backhoe operator to remove material from the selected depth or location within the test pit. The bucket should be brought to the surface and moved away from the pit edge. If hazardous substances are encountered, the sampler should approach the bucket and monitor its contents with a photoionization meter. If granular or loose soils and/or uniform materials are encountered, a sample can be obtained directly from the bucket. The sample should be collected from the center of the bucket and placed in sample jars using a clean, decontaminated trowel or spatula.

If cohesive or multiphase conditions are encountered (i.e., the bucket contains a mixture of granular soil and cohesive soil or sludge), the sampler should proceed as above, if practical. If not, the sampler should direct the backhoe operator to empty the bucket on the ground. Samples should be obtained from the interior of soil clods or lumps of cohesive soils or sludge using a clean trowel or spatula.

(b) Samples Obtained from Within the Test Pit. Samples can be obtained directly from the test pit providing it is safe to enter. This sample procedure may be necessary when soil conditions preclude obtaining suitable samples from the backhoe bucket (e.g., caving or excessive mixing of soils or wastes within the test pit, or when samples from relatively small discrete zones within the test pit are required). This method may also be required to sample seepage occurring at discrete levels or zones within the test pit. Under these circumstances, samples should be obtained with extendable-handle tools: scrapers, trowels, spoons, or cups. The face of the test pit should be scraped to remove the smeared zone that has contacted the backhoe bucket. The material to be sampled (if a solid) should then be removed from the test pit wall by clean, long-handled scoops or trowels, and placed in sample jars.

If a composite sample is required, several depths or locations within the pit should be selected, and a stainless steel bucket should be filled from each area. A soil sample of known volume should be obtained from each bucket, emptied onto a mixing surface (e.g., stainless steel pan or plastic sheet), and thoroughly mixed before being placed in sample jars. The mixing surface should then be decontaminated or discarded; the spoils should be backfilled in the test pit.

3.1-2.4 Backfilling

A test pit should be backfilled immediately after its completion. The backfilling should be performed in maximum 18-inch lifts, and bucket-tamped or track-rolled by the equipment. No test pit should ever be left open overnight when a site is unattended.

Upon completion of the test pit, the excavated materials should be replaced in more or less the same stratigraphic order. If highly contaminated soil were encountered at or near the surface, they should be replaced near the surface with a clean soil cover. In cases where gross contamination by hazardous materials is encountered at an otherwise uncontaminated location it is safer and more cost-effective to segregate the grossly contaminated soil for off-site disposal and fill the test pit with clean, uncontaminated soil. During sampling and logging of each pit, the backhoe operator and all nearby site personnel should remain upwind or crosswind of the test pit and spoils pile. Wind direction should be monitored by a windsock or other banner located in a prominent position visible to all personnel.

3.1-3 EQUIPMENT NEEDED

- personal protection equipment and clothing
- excavator (size and type dependent on depth and accessibility)
- hand shovel
- 100-foot cloth tape
- 6-foot rule
- pocket penetrometer and torvane
- bags and/or 5-gallon pails with labels
- stakes and flagging
- camera
- indelible pen
- site plans and forms
- pumps (if dewatering is necessary)
- compaction equipment (if required for backfilling purposes)

- decontamination equipment for excavator and sampling equipment (if hazardous materials are anticipated)

- clean backfill if necessary

- PVC sheeting

REFERENCES

Occupational Safety and Health Administration (undated), OSHA manual for soil and foundation engineering firms: Silver Spring, Maryland, Reprinted by Association of Soil and Foundation Engineers, 612 p.

ADDITIONAL REFERENCES

Hvorslev, M.J., 1949, Subsurface exploration and sampling of soils for civil engineering purposes: Vicksburg, Mississippi, U.S. Army Engineer Waterways Experiment Station, 521 p.

U.S. Department of the Army, 1972, Soil sampling: Washington, D.C., Engineer Manual EM 1110-2-1907, various pages.

SECTION 3.1 EXPLORATORY TEST PITS

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TEST PIT RECORD

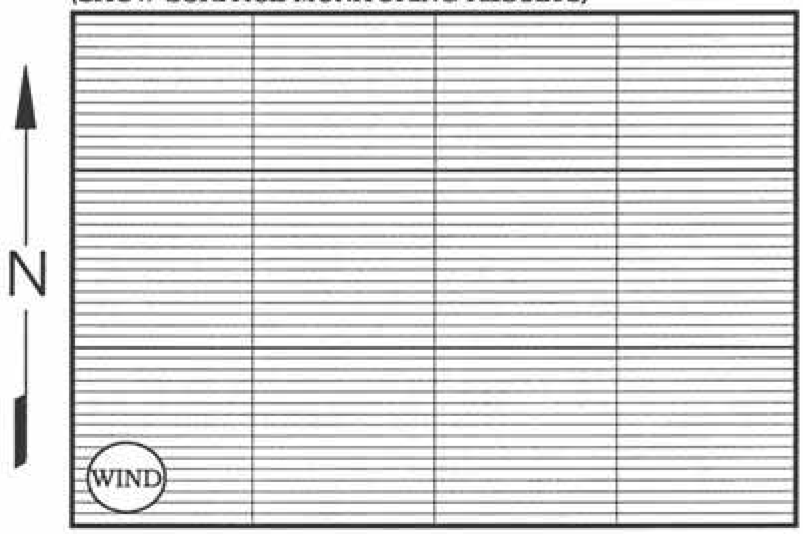
Page 1 of 2

SITE ______________________________

TEST PIT ____________ DATE ____________ TIME ____________ END ____________

COORDINATES ____________ GRID ELEMENT ____________

SKETCH MAP OF TEST PIT SITE
(SHOW SURFACE MONITORING RESULTS)



SCALE 1" = ____________ FT.

NOTES: ______________________________

CREW MEMBERS:

1.

2.

3.

4.

5.

6.

MONITOR EQUIPMENT:

PI Meter	Y	N
Explosive Gas	Y	N
Avail. Oxygen	Y	N
OVA	Y	N

Other ____________

Photographs, Roll ____________

Exposure ____________

Figure 3.1-1

Example of Test Pit Record.

Source: ABB-ES

TEST PIT RECORD

Page 2 of 2

Profile Along Test Pit- ______________________

SITE ______________________

TEST PIT DATE __________ TIME ________ END COORDINATES ________ GRID ELEMENT ________

SKETCH OF TEST PIT CROSS SECTION
(SHOW SURFACE MONITORING RESULTS)

SCALE 1" = __________ FT.
DEPTH (FT.)

NOTES: ______________________

SAMPLES OBTAINED:

No.	Depth (Ft.)	Sample ID	PI Reading
S-1			
S-2			
S-3			
S-4			
S-5			
S-6			
S-7			
S-8			

REFERENCE: Field Book, Pg. __________

Attachments __________

SIGNATURE: ______________________

Figure 3.1-1
(Continued)
Example of Test Pit Record.

Source: ABB-ES

LOG OF TEST PIT No.

January 1991

Test Pit Dimensions:	Face of Test Pit Logged:	Date Excavated	Project No.	Sheet No.

Depth to Water:	Estimated Stripping Depth:	Logged By:

Surface Elevation:	Surface Conditions:		

DEPTH (FEET)	SAMPLE NO.	LAB TEST	WATER CONTENT (%)	SOIL CLASS.	DESCRIPTION	ELEVATION (FEET)	REMARKS
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							

Groundwater		
Date	Time*	Depth/Ft.
Not Encounted		Hrs. after Compl.

_______ X _______ X _______ = _______ Cu. Ft.
(L) (W) (D)

8" to 18" Diam: No._______ "Vol._______ Cu. Ft.
Over 18" Diam: No._______ "Vol._______ Cu. Ft.

Summary
Depth _______
Jar Samples _______
Bag Samples _______
Groundwater _______
Test Pit No.

Figure 3.1-2

Example of Test Pit Report

Source: ABB-ES

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.2 DRILLING TECHNIQUES

SECTION 3.2
DRILLING TECHNIQUES

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Section 3.2 DRILLING TECHNIQUE

3.2-1 PURPOSE

Prior to selecting the drilling technique for a specific project, the objectives of the field investigation program must be established. The program objectives may include any or all of the following:

- Soil or rock evaluation - if undisturbed or representative samples are required, the drilling technique must be able to accommodate the appropriate type of sample collection.

- Characterization of hydrogeologic conditions - the drilling technique should allow for the characterization of each stratigraphic zone, water level measurements, and water sample collection.

- Evaluation of soil or ground water contamination - the drilling technique must provide the appropriate sample collection methods, must not introduce contaminants into the borehole or otherwise alter the existing soil or groundwater chemistry, and should not result in subsurface cross-contamination during or after drilling.

- o Installation of monitoring wells - the drilling method must permit appropriate well construction and minimize the disturbance to both the borehole and the well.

Choice of a specific drilling technique for an investigation will impact the schedule, cost, and technical quality of a field investigation. The quality and representativeness of the soil and ground water samples can be significantly affected by the drilling technique employed. Several items must be taken into consideration to determine the most appropriate drilling method. One of the best resources for selecting an appropriate drilling technique is an experienced drilling contractor. Items that should be considered in the selection process include the following:

o <u>Geologic Conditions</u>:

- unconsolidated or consolidated
- ype of material, including fill material
- presence of boulders or cobbles
- depth to bedrock

o <u>Site Access</u>:

- property ownership
- terrain and vegetative cover
- wet areas
- size of the working area
- weather conditions
- weight and size restrictions

- need for barge equipment
- location of drilling water source

o <u>Seasonal Conditions Affecting Access</u>:

- effect of freezing temperatures, mud, and snow on drilling progress
- use of water
- need to add antifreeze to pumps when not in use under freezing conditions
- antifreeze must be flushed out of hoses and pumps
- high water conditions

o <u>Existence of Contamination</u>:

- utilize decontamination protocols
- minimize disturbance and cross-contamination
- minimize impact on site chemistry
- control drilling discharge
- reduce volume of contaminated spoils
- sampling requirements
- minimize crew's exposure to hazards

- follow appropriate health and safety procedures (See Section 2.3 Health and Safety Plans for more information).

o Required Hole Size and Plumbness:

- single-level or multiple-level well installations (See Section 4.0 Piezometers, Observation Wells and Monitoring Wells)
  - large-diameter wells
  - installation of instruments and downhole equipment
  - availability of drilling equipment
  - adequate annular space for well installation
  - use of packers

o Drilling Rates: DEP projects are almost always conducted on a per diem (time and materials) basis; outside consultants may find it to their advantage to contract the services of a driller on another cost basis (i.e., unit price per foot of soil or rock drilled).

Cost, drilling rates, or availability of equipment should not be the determining factors in choosing a drilling technique. An evaluation should be made of the impact of the drilling method on the integrity of the subsurface soil and ground water samples to be obtained in the investigation. Costs for chemical analyses are high, and money should not be wasted on analysis of unrepresentative samples. Also, analyses and remediation based on faulty data from improperly drilled wells could ultimately be quite costly, greatly exceeding the cost of a well-conceived field investigation program.

Several drilling techniques that are commonly employed in environmental investigations are described in the following subsections. The basic drilling technique is described, along with its advantages and disadvantages, for the following methods:

o Cable Tool
o Drive and Wash
o Spun Casing
o Solid Stem Augers
o Hollow Stem Augers
o Mud Rotary
o Air Rotary/Air Hammer
o ODEX System

Included in Tables 3.2-1 through 3.2-8 and Appendix A is some useful information on standard casing diameters, casing volumes, drill bits and terminology.

3.2-2 CABLE TOOL

3.2-2.1 General Considerations

The cable tool method is a percussion drilling method; it employs a drill bit, attached to a heavy string of drilling tools, that is repeatedly pounded against the bottom of the hole to break up the rock or soil formation into small fragments. Table 3.2-2 shows dimension and weights for standard cable tool drill bits in English and SI units. Water is added to the borehole to form a slurry of the broken rock and soil fragments.

Periodically this slurry is removed from the borehole using a bailer or sand pump. A bail handle at the top of this tool attaches to a cable called the sand line. The sand line is threaded over a separate sheave at the top of the mast and down to the line reel. The diameter of the sand line can vary according to the anticipated loads (Driscoll, 1986).

In unconsolidated or deep borings, the hole is often cased with thick-walled steel casing to prevent collapse of the sidewalls. Casing diameters for the cable tool method generally range from 4 to 24 inches although larger holes can be drilled. Depending on the purpose of the borehole, the drive casing may be removed from the ground or left in place. Figure 3.2-1 is a diagram of a typical cable tool setup. Figure 3.2-2 illustrate equipment used in the cable tool drilling method.

The cable tool method can be used in most soil and rock conditions. In environmental investigations, the cable tool method is generally employed when other methods are undesirable due to their impact on the in-situ chemistry and permeability, or because adequate penetration cannot be achieved with other methods. The cable tool drilling method is suitable for coarse, dense soils such as boulder tills and boulder-cobble-rich, ice-contact deposits. Additionally, the cable tool method is particularly suitable for drilling in highly fractured or cavernous rock formations, and fill debris.

Soil samples can be collected in a variety of ways using the cable tool method. Typically, samples of the bailed slurry are obtained and described. With some minor retrofitting, split-spoon samples can be obtained from the borehole, although this slows the drilling process considerably. Generally, good quality monitoring well installations can be completed in cable tool borings, although, compared with other methods, more time is required to install monitoring wells with the cable tool method.

3.2-2.2 Drilling Methodology

3.2-2.2.1 Drilling Action

The drilling action of the cable tool rig consists of an up-and-down motion of the drilling tools, at a rate controlled by the driller. The vertical stroke of the drill tools can be adjusted by changing the position of the pitman pin [see Figure 3.2-1]. Several factors affect the rate of penetration including the nature of the formation, depth to the water table, and the skill of the driller.

3.2-2.2.2 Driving Casing

When drilling soft or unconsolidated formations, casing must be used to keep the borehole open. A hardened steel drive shoe must be attached to the bottom of the casing to prevent breaking or damage to the casing during penetration. A drive head is placed on top of the casing to protect it from damage. Generally, the casing is driven into the ground with the drill tools. A drive block or clamp is attached to the drill tools and acts as a hammer face. The drill tools are lifted up and down; the pounding of the tools drives the casing into the ground.

Generally, the casing is driven for a distance of 3 to 10 feet without stopping. The disturbed material is then mixed with water, if necessary, to form a slurry; the slurry is bailed out of the casing. The driving, drilling, and bailing operations are repeated until the casing has reached the desired depth. If the subsurface materials are especially dense, the hole may be advanced 2 to 6 feet ahead of the casing to make the casing installation faster and to reduce the chance of casing breakage. The decision to pre-drill in advance of the casing should be based on the driller's judgement.

Depending on the nature of the boring, the casing may or may not be removed from the borehole upon completion. If required, the casing may be pounded back out of the ground by pulling back on the drive head. If the rig is outfitted with hydraulic jacks rather than a cathead arrangement, the casing can be removed more quickly and reliably.

3.2-2.2.3 Removal and Inspection of Cuttings

Formation cuttings are removed from the borehole with either a bailer or a sand pump. A bailer consists of a metal pipe with a check valve in the bottom. The bailer is lowered to the bottom of the borehole, the slurry enters the pipe, and when the bailer is lifted out of the hole, the check valve closes and the slurry is bailed out of the hole.

Alternatively, the cuttings can be removed from the hole with a sand pump or suction bailer. This method is similar to a check-valve bailer except that an internal plunger produces a vacuum that opens the valve when the bailer is lifted from the hole, sucking sand or slurried cuttings into the pipe. Some sand pump bailers have a latch bottom for slurry release. Bailers and sand pumps are generally 10 or 20 feet in length (Driscoll, 1986).

3.2-2.2.4 Telescoping Casing

If the borehole penetration slows considerably due to friction on the casing, it may be advisable to telescope to a smaller diameter casing. A second, smaller diameter casing string is inserted inside the first casing and drilling continues, resulting in a smaller diameter boring. In some cases, the casing size may have to be reduced two or three times in order to complete the boring to the desired depth. If telescoping of casing is expected, the initial casing size must be large enough to allow insertion of additional casings and still maintain the minimum size borehole desired.

3.2-2.3 Field Notes

In addition to the standard field notes such as who, what, when, and where, items that should be noted during the advancement of a cable tool boring include the following:

- total casing in the borehole
- depth of water-bearing horizons
- amount of water added to the borehole
- drilling rate per casing length and/or per foot
- description of formation material

- sample type and depth interval

3.2-2.4 Advantages and Disadvantages

3.2-2.4.1 Advantages

- Often the best method for penetrating dense, coarse soils, cavernous or fractured rock, and thick, permeable, unsaturated zones.
- Rigs are relatively simple to operate and can generally be operated all year round.
- Clean, relatively undisturbed borehole walls are produced.
- Installation of casing assures that the borehole will remain open.
- Excellent for gravel- or filter-packed wells.
- Cased boreholes can be telescoped through contaminated zones to reduce the possibility of cross-contamination down the borehole.
- Relatively small amounts of water that are not under pressure are required, reducing the impact of drilling water on aquifer water quality.
- Suitable for deep boreholes (300 to 500 feet).
- Large-diameter borings are possible (24 inches and greater).

3.2-2.4.2 Disadvantages

- Drilling rate is slow to extremely slow (50 to 10 feet/day).
- Disturbed soil samples are obtained with bailer or sand pump.
- Casing removal may be slow and is not always successful.
- Minimum borehole diameter relatively large (4 inches).
- Difficult to identify the water table.
- Availability of rigs and trained operators is limited.
- Cannot recover intact rock cores.

3.2-2.5 Problems and Possible Solutions

3.2-2.5.1 Casing Broken Off Below Ground

As with any drilling method that uses casing, the potential exists for the casing to break off below the ground surface. Using a steel drive shoe and thick-walled casing will help to prevent this from happening. If the formation is especially dense, it is advisable to pre-drill ahead of the casing several feet to reduce the resistance to the casing. If the casing is broken, it may be possible to continue the boring by installing a smaller diameter casing in the hole. Any change in the original planned drilling method requires approval from DEP. In some instances, the boring may have to be abandoned when the casing is broken.

3.2-3.5.2 Slow Penetration

Although it is simple and reliable, the cable tool drilling method is inherently slow. At sites with substantial thicknesses of unsaturated materials, the frictional resistance on the casing may greatly impede drilling progress. In this situation, it is advisable to telescope to a smaller diameter casing to increase the rate of penetration.

3.2-3 DRIVE AND WASH

3.2-3.1 General Considerations

The drive and wash method (sometimes called wash and drive) requires the use of steel casing to maintain an open hole during drilling and sampling operations. The drive and wash method entails driving a casing into the ground with a 300-pound or heavier hammer dropped a specific distance, then after each interval, washing the soil cuttings out of the casing with a tricone or chopping bit and water. This method requires a nearby source of clean water or a water tank that must be brought to the boring site. Thin-wall, flush-joint casing ranging from 2.5 to 8 inches inside diameter (ID) in 5-foot lengths are typically used with this method. A hardened steel drive shoe is placed on the bottom of the lead casing to aid in penetration and to prevent the casing from splitting and breaking when rocks and cobbles are encountered. Representative soil samples can be collected with standard split-spoon samplers or tube samplers driven ahead of the casing. Figure 3.2-3 is a schematic of a typical drive and wash tool setup.

When conditions are appropriate, the drive and wash method is the preferred drilling method for monitoring well installation. This method is appropriate for many geologic conditions: sandy till and clay deposits; most sand and gravel conditions; organic soils; and fill materials. Because the casing is driven rather than spun, the drive and wash method results in less potential for cross-contamination. Recent studies by the U.S. Geological Survey (USGS) on Cape Cod, Massachusetts, indicate that the drive and wash methods produces a minimum amount of borehole disturbance compared to augers and rotary methods (Morin, 1988).

Also, because the bit is maintained inside the casing throughout the cutting removal process, there is a no jetting of the borehole sidewalls and, generally, the borehole maintains a consistent diameter. Under certain circumstances, such as dense tills, drilling ahead of the casing is permitted. The ease of casing removal and the similarity between the casing ID and the borehole ID allow for good quality and accurately placed well screen, filter pack and seals.

3.2-3.2 Drilling Methodology

3.2-3.2.1 Drilling Operation

A hardened steel drive shoe is typically placed on the bottom of the lead casing. The casing is driven into place using a manually controlled 300-pound or greater hammer or an automatic hammer system. At the discretion of the site geologist or engineer, blows counts may be recorded for discrete intervals of casing penetration. Changes in strata may be detected by changes in number of casing blows per foot, especially in shallow borings.

Once the casing length is driven to the desired depth, the drive head is removed and drill rods with a tricone or rotary bit are placed inside the casing. Table 3.2-3 presents the sizes and weights for standard tricone roller bits. The bit and rods are measured prior to placement in the hole. After the bit is placed inside the casing, the rod stick-up should be measured to determine the depth of the bit. The drill rod should then be marked at the point where the bit will be at the base of the casing. This marking procedure will prevent accidentally drilling below the casing, and disturbing material to be sampled.

3.2-3.2.2 Removal and Inspection of Cuttings

Only uncontaminated water must be used during the washing operation. It is important that this source be identified before the start of drilling and that prior approval be obtained from DEP.
Drill water is forced down through the drill rods to the bit to carry the cuttings up and out of the boring. It is imperative that the water ports in the cutting bit jet water out of the side of the bit and not ahead of the bit as this causes disturbance of the soil below the casing. A minimal amount of water necessary to carry the cuttings up and out of the hole should be used. The water level should be maintained at the top of the casing during the drilling operation, particularly when "running sands" are encountered. Recirculation of drilling water is permitted if the boring is not contaminated. Table 3.2-4 shows water volume for casings and holes of different diameters and depths. Table 3.2-5 presents standard size data for casings and drilling tools. Table 3.2-6 presents recommended rotating speeds and bit size for various formations.

Once the washing procedure is complete, the rods and bit are removed while maintaining the water level at the top of the casing. This should be done slowly to prevent "blowing in" of the formation. If required, a sample can be collected at this point. (See Section 3.4 for proper soil sample collection methods.)

Following sample collection or the washing out of the casing, an additional length of casing is added and the driving process continued.

3.2-3.3 Advantages and Disadvantages

3.2-3.3.1 Advantages

- An open borehole during drilling is assured because of the presence of the casing.
- Clean, relatively undisturbed borehole walls are produced.
- Method allows for inspection of the cuttings throughout the washing process.
- Inspection of cuttings allows for identification of geologic changes.
- Method allows for installation of monitoring wells inside casing.
- In-situ horizontal and vertical hydraulic conductivity measurements can be made.
- Method allows for collection of split-spoon or similar representative samples.
- It is a superior method for monitoring well installation.

3.2-3.3.2 Disadvantages

- A substantial source of water is required and a drilling water discharge is produced when water cannot be recirculated. If the borehole or ground water is contaminated, the discharge may require special treatment or collection procedures.
- The method is relatively slow; footage rates of 30 to 60 feet per day are common in New England soils.
- The water table and water-bearing zones may be difficult to recognize due to the addition of water into the system during drilling.
- Water circulation may be difficult to maintain in highly permeable, unsaturated soils.
- The addition of water to the aquifer system may be undesirable in some situations where contamination is present.
- This method is difficult for very coarse sands and gravels and cobbles and boulders.
- There is a very slight potential for cross-contamination due to flow along the outside of the casing.

3.2-3.4 Problems and Possible Solutions

3.2-3.4.1 Difficulty Removing Cuttings

Large, gravel-size particles may be difficult to wash out of the casing, especially as the borehole becomes deeper. Potential remedies for this problem include the following:

(a) Checking to see if drilling bits are in good condition and working properly.

(b) Using larger diameter drill rods. Small diameter (AW) drill rods in NW- or HW-size casing create a large annular space, decreasing the flow velocity up the annular space. Larger-diameter, heavier, gravel-size particles may not remain in suspension under these conditions. Switching to larger-diameter drill rods may solve this problem.

(c) Checking to see that the water pump on the drill rig is working properly and has sufficient capacity.

(d) In certain cases, the use of drilling mud or other additives to increase the density and viscosity of the drilling fluid will keep larger particles in suspension, carrying them out the hole. Drill-fluid additives should not be used when installing piezometers or monitoring wells where water quality or aquifer test results would be influenced by the additives. The use of drilling mud or other additives must be fully documented by the driller, included on the boring log, and described in the consultant's report.

3.2-3.4.2 Sand or Silt Flowing Up Inside the Casing -"Running Sands"

Sands or silts are often found to flow up inside the casing during the sampling or clean-out process. Unless true artesian ground water conditions are encountered within a stratum, this situation is usually the result of an unbalanced hydrostatic head between the borehole and the equivalent hydrostatic head in the formation at the elevation of the bottom of the casing. The imbalance occurs when drill rods are removed from the borehole, lowering the water level in the casing. This condition is usually associated with sand and/or silty soils where the unbalanced head creates a "quick" condition in the soil. If this condition, called "running sand," is encountered, it should be noted on the boring log because significant sample disturbance below the borehole often occurs. One possible way to minimize this problem is to remove the drill rods very slowly while concurrently adding water to the casing, thus maintaining the water volume displaced by the drill rods. This procedure maintains the water volume displaced by the drill rods. If this does not work, one may consider driving the casing past the zone of loose material into a more stable formation. The addition of non-aquifer water to minimize soil instability at the bottom of the casing should be fully documented by the drillers, included on the boring logs and described in the consultant's report. Furthermore, they must be able to document the fact that all non-aquifer water was removed during well development prior to collecting a sample for water quality analysis.

3.2-3.4.3 Loss of Drilling Fluid

Circulation return through the top of the borehole may cease if highly permeable formations are encountered at depth. In this situation the loss of fluid through the bottom of the casing is greater than the drill rig pumping rate. Three potential means are available to overcome this problem:

(a) Increasing the viscosity and weight of the drilling fluid with additives, as long as these additives will not influence the results of analytical testing of monitoring wells or the natural permeability in the vicinity of wells. Prior approval from DEP is required before using additives in the drilling operation.

(b) Cleaning out the casing without circulation return: this process involves breaking down the larger-size soil particles into sands and silt-size particles. The formation may have large enough voids to allow passage of the smaller-size particles out the bottom of the casing. This method should be used with caution because it is possible to jam the cutting tools in the casing with drill cuttings. It can be argued that sample recovery in zones of high hydraulic conductivity would be difficult due to the probable size of the soil particles or size limitations of the sampling tools.

(c) Driving past the sample interval to the next interval which may have a lower hydraulic conductivity. When this is done, it should be fully documented by the driller and included as a statement in the consultant's report.

3.2-4 SPUN CASING

3.2-4.1 General Considerations

Spinning casing is used as an alternative to typical drive and wash methods in conditions where a driven cased hole is unsuitable. This method is suitable for drilling soils and seating casing into bedrock. It is typically used in dense or boulder-rich strata such as lodgement till. In the spun casing method, a diamond spinning shoe or bit is attached to the bottom of the casing. The casing is attached to the drill head and advanced by a rotation and cutting action similar to coring. Water is forced down through the center of the casing and flows out and up the sides of the borehole, carrying cuttings to the surface. Residual soil material may remain inside the casing and must be cleaned out periodically with a rotary bit during advancement of the boring.

Two and a half- to eight-inch diameter, flush-joint casing in 5-foot lengths are typically used with this method. As with drive and wash methods, good-quality, representative tube and split-spoon samples can be obtained. Drill rigs capable of spinning casing include truck- and track-mounted types; both types are able to access most terrains. In general, good-quality well installations can be completed in spun cased holes, although large voids may develop along the borehole walls where the fines have been washed away by the water. The principal disadvantage of the spun casing method is that substantial amounts of drilling water may be lost into highly permeable formations during drilling. Thus a high potential for cross-contamination exists.

3.2-4.2 Drilling Methodology

3.2-4.2.1 Drilling Operation

A diamond spinning shoe or bit is placed on the bottom of the lead casing. The casing is attached to the drill head with a threaded adaptor. As the casing is spun and advanced, a slight downward pressure is applied. At the same time, water is pumped down through the rods, out the end of the bit, and up the annular space between the casing and the boring (Figure 3.2-4). If recirculation or collection of the drill water is necessary a larger diameter casing can be placed around the spun casing.

3.2-4.2.2 Removal and Inspection of Cuttings

Once the casing has reached the required depth, the distance to the bottom of the casing should be measured to determine if any cuttings remain inside the bottom of the casing. If there is material inside the casing, it should be removed by washing out prior to sampling. The drill rod attached to the bit should be marked where the bit reaches the bottom of the casing. This marking procedure will prevent accidentally washing beyond the bottom of the casing and disturbing the material to be sampled. Soil cuttings are carried to the surface with the water and this drill water is discharged at the top of casing, preferably to a recirculation tank equipped with a baffle to enhance settling of solids. When the boring is free of cuttings to the bottom of the casing, a sample may be collected.

Once the soil sampling process is completed, an additional length of casing is added, and drilling can continue.

3.2-4.3 Advantages and Disadvantages

3.2-4.3.1 Advantages

- Casing can be advanced through large-diameter cobbles and boulders.
- Drilling method is relatively rapid through large-diameter cobbles typical of many New England glacial tills.
- Representative samples can be obtained.
- Angle hole drilling is possible.
- Able to seat casing into bedrock to accommodate rock coring.
- Method allows for installation of monitoring wells inside the casing.

3.2-4.3.2 Disadvantages

- A continuous water source is required for drilling.
- Changes in strata are difficult to recognize between sample intervals.

- o Cross-contamination may occur due to the circulation of water between the casing and borehole wall.
- o Large quantities of water can be introduced into permeable formations.
- o Difficult to control release of drilling fluid at surface.

3.2-4.4 Problems and Possible Solutions

3.2-4.4.1 Lost Circulation

In highly permeable, unsaturated formations (e.g., sand and gravel deposits), fluid circulation may be lost into the formation during drilling because the rate of fluid loss through the bottom of the casing is greater than the pumping rate that can be maintain. As a result, the loss of the lubricating action of the water may destroy the shoe and cause the casing to "bind up." There are two options that can be used to overcome this problem:

(a) Increase the viscosity of the drilling fluid by the addition of additives as long as these additives will not influence the results of analytical testing of samples from the monitoring wells. Prior approval must be obtained from DEP before using any additives.

(b) Consider changing to another drilling method, such as cable tool. This may require a different drilling contractor.

3.2-4.4.2 Eroding a Large Hole

With this method it is possible to erode a large hole in the borehole wall, especially if an obstruction is encountered. A minimum amount of water should be used during drilling to help control this problem.

3.2-5 SOLID-STEM AUGER

3.2-5.1 General Considerations

Solid-stem auger drilling utilizes spiral, solid-center auger flights. The augers are screwed into the soil by a combination of downward pressure and rotating action. This method is not recommended for environmental studies. It is not recommended by DEP for determining soil characteristics or monitoring well installations unless the soil has been characterized previously by another drilling and sampling technique.

There is no provision for obtaining soil samples unless the auger is removed from the borehole. If soil sampling with a split-spoon is attempted, there is always the potential for caving of the borehole when the augers are removed, which would influence the quality of the sample recovered. Auger cuttings that come to the surface can be examined and a general stratigraphy described. Soil samples taken from the flights may misrepresent the actual formation material at the bottom depth of the augers.

The solid-stem auger method is more commonly used for probing to refusal or bedrock. See Figure 3.2-5 for an illustration of an auger drilling setup using a solid-stem auger.

Although the information obtained from solid-stem auger borings is limited, this method can be useful as a reconnaissance technique and for drilling pilot holes in fill and debris. Solid-stem augers should only be used under special conditions when it has been determined that plugging of the borehole will not be required. As with hollow-stem augers, the rigs are quite mobile and can access almost any site. Because no samples are collected, drilling is quite rapid and setups are minimal. The diameter of the drilled hole ranges from 4 to 20 inches.

3.2-5.2 Drilling Methodology

3.2-5.2.1 Drilling Operation

The lead auger is placed on the drill head, and the boring is advanced by a combination of rotation and downward pressure. Once the bottom of the auger reaches the desired depth, an additional auger may be added. If pins or bolts are used to attach the augers to each other, these should be secure before drilling continues.

Drilling can proceed quite rapidly with the addition of more augers. Drilling should continue until the boring has reached the desired depth or until refusal. Refusal means that the auger encounters substantial resistance and penetration is slowed or stopped. This may be caused by a boulder or by the auger encountering the bedrock surface. The distinction between the top of bedrock and a boulder is extremely difficult to determine. Bedrock can only be verified by rock coring methods.

3.2-5.2.2 Removal and Inspection of Cuttings

As drilling proceeds, the cuttings will travel up the outside of the augers to the ground surface. General soil characteristics can be described by examining the cuttings, although no information on soil structure can be obtained with this method. Generally, the best way to obtain a sample for inspection is to place a shovel at the top of hole and to collect a sample of the cuttings.

3.2-5.3 Advantages and Disadvantages

3.2-5.3.1 Advantages

- Especially suitable for cohesive, moderately dense soils which will remain open, uncased.
- Quick method for probing with generalized stratigraphic description possible.
- Rigs are able to access most terrains.

3.2-5.3.2 Disadvantages.

- Not generally suitable for monitoring well installation and for determining soil conditions.
- If the subsurface materials are contaminated, this method can result in cross-contamination, potentially affecting future subsurface investigations.
- Soil cuttings return is poor to non-existent below the water table.
- Refusal data is not always reliable for determining the top of bedrock, particularly in glacial till.
- Not suitable for sampling soft, unstable soils which will not remain open, if uncased.

3.2-6 HOLLOW-STEM AUGER

3.2-6.1 General Considerations

This method is suitable for unconsolidated deposits that do not have large cobbles or boulders. Hollow-stem augers are continuous augers equipped with a hollow core that serves as casing. Representative soil samples may be obtained by passing a sampling tool through the bottom of the lead hollow-stem auger. Monitoring wells can also be installed through the center of the augers. Figures 3.2-6 and 3.2-7 are examples of typical hollow-stem auger equipment.

Commonly, the inside diameter of the hollow-stem is 4 to 6 inches, and the augers produce a borehole 8 to 12 inches in diameter. Auger rigs are skid-, truck-, or track-mounted, giving them excellent mobility. This drilling method is relatively fast, depending on soil sampling requirements.

Hollow-stem auger methods have significant limitations in investigations in contaminated areas due to the potential for cross-contamination in the borehole. Contaminated cuttings moving up an auger flight may contaminate overlying clean zones. In other cases, contaminated auger flights penetrating to greater depths may carry contamination down with them.

Additionally, the rotating action of the augers causes a smearing in fine-grained soils. This smearing may significantly reduce the permeability in the vicinity of the borehole, resulting in erroneous estimates of in-situ permeability from field tests. Furthermore, this smearing may effectively seal off a zone opposite the proposed screened interval of a monitoring well, and well development may not be adequate to overcome this effect.

3.2-6.2 Drilling Methodology

3.2-6.2.1 Drilling Operation

The lead auger should be attached to the drill head. In order to assist in cutting the borehole, auger teeth (i.e., sharp, protruding, carbide-capped metal tabs) are located at the tip of the lead auger. This auger is drilled or "screwed" into the ground by a combination of rotation and downward pressure. If obstructions are encountered, the auger may "walk," causing the borehole to become crooked or deflected from vertical. If this occurs at a shallow depth, it is advisable to move the boring location slightly and start the hole again.

During advancement, a removable center plug (pilot bit) or split-spoon sampler is attached to the drill rods and placed in the bottom of the lead auger to prevent soil materials from entering the hollow stem. When a required depth is reached, the center plug can be removed and representative samples obtained by passing a sampling tool through the hollow stem of the auger and out the bottom.

Once the augers have reached the desired depth and a sample has been collected, drilling can continue. The center plug is replaced in the bottom of the lead auger and an additional auger flight is attached. If the augers are attached to each other with bolts or pins, it is important that they be secured before drilling proceeds. Failure to do this can result in detachment of the augers below the ground surface.

3.2-6.2.2 Removal and Inspection of Cuttings

During drilling, the cuttings from the borehole are carried upward to the ground surface along the outside of the augers on the screw-shaped auger flights. These cuttings are usually shoveled to the side, where they can be inspected. In some cases, stratigraphic changes can be observed due to significant changes in the cuttings or the drilling action of the auger. In some soil conditions, such as fine sands, once the augers are below the top of the saturated zone the cuttings may not travel to the surface along the outside of the auger flights. When this happens, standard split-spoon samples may be the only way to collect and determine the soil characteristics.

Once the auger flight has reached the required depth, soil samples can be collected. A sampling tool can then be lowered down through the hollow center of the auger and a sample can be obtained.

Recently, a new method of obtaining soil samples with hollow stem augers has been developed which uses an inner tube sampler. This sampler consists of an inner split-barrel tube, typically 4-inches in diameter, that is placed inside the lead auger. As the borehole is advanced, the soil material enters the tube for the length of the drilling interval, similar to the way rock core enters a core barrel. Once the interval is completed the augers are detached from the drive head and the tube is removed with the drill rods. The split-barrel tube is removed and opened in a manner similar to a split-spoon. This sampling method allows rapid, continuous sampling in hollow-stem auger holes and is best suited for fine-grained soils such as silts and clays.

3.2-6.3 Advantages and Disadvantages

3.2-6.3.1 Advantages

- Water is usually not required.
- Fast drilling technique in soft and fine-grained soils.
- Quick set-ups possible.
- Can install well casing inside hollow-stem auger.
- Representative samples can be obtained.

3.2-6.3.2 Disadvantages

- Difficult to use in very dense or boulder-rich soils.
- Monitoring well installation quality may vary from good to poor due to small diameter opening in the augers, a disturbed interface with formation soils, and the fact that the augers are generally rotated out of the hole.
- Can be difficult to obtain samples of silts and sands beneath the water table as "quick" (i.e., running sand) conditions may be present.
- Frictional resistance from fine sand or nested boulders may tend to lock the augers in the ground.
- Due to the constant rotation of the augers, smearing of fine-grained soil material may occur on the sidewalls of the borehole.
- Potential for cross-contamination within the borehole at contaminated sites.
- Good seals around the top of the sand packs may be difficult to achieve due to the large annular space and the presence of a zone of disturbed soil materials in the annular space, once the augers are removed.

3.2-6.4 Problems and Possible Solutions

3.2-6.4.1 Sand or Silt Flowing Up Inside the Auger; "Running Sands"

When drilling below the water table, sands may run up into the center of the augers when the center plug is removed. An unbalanced hydrostatic head is created if water is not added to the augers during the advancement of the borehole. Unbalanced heads can also occur during the sampling as discussed in the subsection on the drive and wash method (see Section 3.2-3.4.2). These problems may be overcome by removing all downhole tools (including the center plug) very slowly or by introducing water into the auger or both simultaneously.

3.2-6.4.2 Health and Safety Problems

Health and safety problems generally involve the increased volume of potentially contaminated soils produced by this method. When required, special drill-through containers can be used to catch and hold the auger cuttings to minimize potential spread of hazardous materials and contact with workers.

3.2-7 MUD ROTARY

3.2-7.1 General Considerations

Mud rotary drilling methods should not be employed for environmental investigations at either state or privately funded sites except with the specific, prior approval of DEP. The use of mud rotary techniques should be fully documented by the driller and described by the consultant in his report. Although mud rotary is a popular exploration drilling method, it has limited application in hydrogeologic investigations since use of drilling mud results in many problems from a hydrogeologic and chemical standpoint. For example, drilling mud may significantly lower the permeability in the adjacent formation. Also, mud residues are difficult to remove with standard well development techniques. Because of the potential for cross-contamination in the borehole, recirculation of the drilling mud is a concern where contaminated zones are encountered. Also, mud residues may alter the groundwater chemistry by binding metals, adsorbing organics, altering the pH, or changing COD conditions.

In mud rotary drilling a bit, usually a tricone, is placed on the bottom of the drill stem, and the rotating action of the bit crushes and grinds the subsurface materials into small pieces. Simultaneously, drilling fluid (usually a bentonite drilling mud) is pumped down through the center of the drill pipe and circulates up the borehole, carrying the cuttings up and out of the hole. The "dirty" drilling mud is directed to a mud pit or baffled tank where the cuttings are allowed to settle. Once the drilling mud is relatively clean, it is recirculated down the borehole. Efficient mud rotary operation requires an experienced driller who is familiar with the proper drilling and mud mixing techniques for various geologic conditions. Figures 3.2-8 through 3.2-10 illustrate typical set-ups for mud rotary drilling and equipment.

In mud rotary drilling, the drilling fluid stabilizes the borehole sidewalls, cools the bit, and brings the cuttings up out of the borehole. One significant advantage of mud rotary over many other drilling techniques is that in most applications, casing is not required to stabilize the borehole sidewalls, resulting in much faster drilling. The hydrostatic pressure of the column of drilling fluid in the borehole prevents caving of the sidewalls. As drilling proceeds, a film of clay particles builds up on the borehole walls to form a filter cake lining the sidewalls. This "clay casing" prevents erosion of the walls by the circulating drilling fluid and reduces or prevents fluid loss into the formation.

Mud rotary holes vary from 3- to 28-inches in diameter, with 6- to 8-inch holes being the most common. Mud rotary methods can be used to drill to depths of 500 feet and greater.

3.2-7.2 Drilling Methodology

3.2-7.2.1 Drilling Operation

Mud rotary drilling requires a substantial setup and a fairly large working area. Prior to drilling, adequate water and mud (usually bentonite) should be prepared in advance so that the drilling process need not be interrupted. The water should be clean, as the quality of the mud can be seriously affected by contaminants or water with a high mineral content. Prior to drilling, a quantity of drilling mud is mixed either in mud pits, tubs, or tanks. The viscosity and quantity of the mud will be dependent on the anticipated geologic conditions and the depth and diameter of the borehole.
Typically, mud rotary borings are advanced in intervals equal to the length of a drill rod. As the boring is advanced by a combination of rotation and downward pressure, additional mud may be mixed and added due to the increased volume of the hole and losses due to infiltration in very coarse material. If the formation conditions change, the mix may have to be modified.

It is important that a drill collar (sometimes referred to as a stabilizer), a larger diameter, heavier length of drill pipe, be placed on the drill stem immediately above the bit. The drill collar helps to maintain a straight hole during drilling.

If the boring is penetrating very soft or caving formations, a surface casing may be set to keep the borehole walls from collapsing. The surface casing usually has a discharge pipe connected to the top to direct the drilling mud into the settling tank.

3.2-7.2.2 Removal and Inspection of Cuttings

Generally, mud rotary samples consist only of samples of the cuttings that come up out of the borehole. A strainer can be used to collect the cuttings and, after rinsing them with clear water, they can be described. Mud rotary methods can be modified to obtain representative geologic samples, such as split-spoon samples, although this slows down the drilling progress significantly.

3.2-7.3 Advantages and Disadvantages

3.2-7.3.1 Advantages

- Rapid drilling method in most geologic conditions.

- Generally no casing is required during drilling.

- Can drill deep borings, 500 ft. or greater, under most conditions.

3.2-7.3.2 Disadvantages

- Drilling mud may adversely affect water-quality, permeability, and well development parameters. During drilling, mud may mask geologic details and water-bearing zones.

- Cross-contamination potential is high.

- Cold weather drilling is difficult due to mud mixing requirements.

3.2-7.4 Problems and Possible Solutions

3.2-7.4.1 Lost Circulation

Lost circulation occurs in porous, granular, or jointed formations when the drilling fluid cannot be maintained in the hole. Lost circulation can lead to caving of the borehole and loss of the drilling tools. Three methods are used to remedy lost circulation problems:

- Increase the viscosity of the drilling fluid.

- Case off the permeable zone.

- Add wash circulation material (i.e., mica flakes, peanut hulls) to increase viscosity of the drilling fluid; this method is only appropriate for explorations when contamination is not present or anticipated.

Once a lost circulation problem occurs, efforts should be taken immediately to avoid losing excessive amounts of drilling fluid into the formation.

3.2-7.4.2 Crooked Holes

A straight hole is essential for drilling, particularly for deep borings. Crooked holes are most likely to occur in hard formations, especially those with large boulders, dipping structures, or numerous fractures. Proper selection of bits and stabilizers will help to avoid the development of crooked holes. Generally, the best method to straighten a crooked hole is to ream or enlarge the hole size. If this does not work effectively, it may be best to abandon the hole and start a new one.

A crooked hole may be difficult to detect. One indication of a crooked hole is excessive wear on the drill string. The wear occurs where the hole orientation is deflected and results in abrasion of the drill stem.

3.2-7.4.3 Stuck Bits and Rods

In any rotary method, drill rods and bits will occasionally become "grouted" in the hole due to the settlement of cuttings around the bit. Shaking the rods and circulating drilling fluid may help to loosen the drill stem. If excessive amounts of sand remain in suspension in the drilling fluid, it may be necessary to send the fluid through a de-sander prior to recirculation down the drill hole. The de-sander uses centrifugal motion to separate the sand from the fluid, reducing the amount of suspended sand.

3.2-8 AIR ROTARY/AIR HAMMER

3.2-8.1 Drilling Methodology

The procedure is similar to mud rotary, except that air rather than mud is used as a drilling fluid to cool the bit and bring the cuttings out of the hole. A guide for the use of bit types with air drilling systems is presented in Table 3.2-7. The primary reason for using air hammer or rotary techniques is that it is a cost-effective method to rapidly advance a deep hole in dense, unconsolidated and consolidated material for monitoring well installation.

3.2-8.1.1 Drilling Operation

A large compressor on the drill rig provides air for the drilling operation. Occasionally, a small amount of water is added to the air system to reduce the air-borne dust and to cool the bit. Similar to mud rotary, a rotating tricone at the bottom of drill stem chips and cuts the formation. At the same time, air is forced down the inside of the drill stem to blow the cuttings up and out of the hole.

Air rotary rigs are generally used in dense, unconsolidated and hard rock formations. This drilling method is unsuitable for loose, unconsolidated formations because the installation of casing is required. Often, air rotary rigs are equipped with both fluid- and air-based equipment, allowing the overburden to be drilled with fluid rotary techniques, casing to be installed, and bedrock to be drilled using air techniques. Figures 3.2-11 and 3.2-12 depict the equipment and typical set-up for air rotary drilling.

Air hammer or "down-the-hole hammer" drilling methods use a pneumatic hammer to break up the rock into fine particles. Air is used to remove the cuttings from the borehole and from the cutting surface on the rock. Air hammer holes are typically 6- to 9-inches in diameter, although holes as large as 18 inches have been drilled successfully. Air hammer techniques are used in hard, consolidated formations, such as the bedrock typical of New England, where other drilling methods are slow or unsuitable.

3.2-8.1.2 Removal and Inspection of Cuttings

Sample collection is limited to obtaining a portion of the borehole cuttings. Generally, the cuttings are quite fine-grained and provide only extremely limited information on the rock characteristics.

3.2-8.2 Advantages and Disadvantages

3.2-8.2.1 Advantages

- Drilling is very rapid compared to other drilling techniques, especially for very hard rock formations.
- Drilling can be done year round.
- Little or no water is necessary to complete boring.

3.2-8.2.2 Disadvantages

- Rigs are generally quite large and cannot access wet or sloping sites without the construction of a road.
- Undisturbed or representative samples are not practical.
- Not generally suitable for drilling in loose, unconsolidated deposits; casing must be used in soft or caving formations; only suitable for dense, unconsolidated or consolidated formations.

- Cross-contamination can occur in the borehole due to circulation up and down an open, uncased hole; therefore, may be unsuitable for use at contaminated sites.
- Minimum borehole diameter is six inches.
- Difficult to identify potentiometric surface.
- At a contaminated site, air emissions may be a significant health and safety concern.
- Potential for contamination from compressor oil.

3.2-8.3 Problems and Possible Solutions

3.2-8.3.1 Contaminated Air Injected Into Boring

Air rotary rigs use lubricants and oils in the compressor. Filters should be used to minimize contamination from oils and lubricants. Filters will remove particulate and droplets of oil but not 100 percent of hydrocarbon vapors. It should be noted that the quality of the ambient air may be impacted from drill rig exhaust; this cannot be avoided. If the hydrogeologic objective(s) include a contamination assessment, care must be taken to ensure that an effective filter is used and that the air injected into the hole is uncontaminated.

3.2-8.3.2 Air Emission Hazards

The air-borne emissions resulting from air drilling methods may be difficult to control during drilling. If hazardous contaminants are encountered in the borehole, they may be blown to the surface with the cuttings, posing a potential hazard to the drill crew and inspector. Air drilling methods are generally unsuitable for highly contaminated, subsurface conditions due to the potential for personal exposure and cross-contamination.

3.2-9 ODEX SYSTEM

3.2-9.1 General Considerations

The ODEX drilling method has been adapted from an air percussion drilling method used in the construction industry to install earth anchors and tie-backs. The standard percussion drilling equipment has been modified to allow for the installation of a heavy-duty temporary casing. The ODEX method is capable of drilling 3- to 6-inch diameter holes in unconsolidated materials and bedrock. Conventional sampling is possible with a slight modification of the drilling method. Figures 3.2-13 and 3.2-14 are schematics of the drilling equipment used in the ODEX system.

The ODEX method is suitable for unconsolidated materials, or down-hole hammer drilling in bedrock, although conventional rock coring can be accomplished through the use of temporary casing. The ODEX drilling system is suitable for most soil conditions, although the bit has a tendency to plug in cohesive, granular soils with fines.

3.2-9.2 Drilling Methodology

The boring is advanced to the required depth by a combination of pilot and reamer bits. This drilling method incorporates simultaneous advancement of the boring with the pilot bit and enlargement with the eccentric reamer bit to the desired depth. When the drilling is completed, the pilot bit is rotated in the opposite direction, aligning the bit with the eccentric reamer. Once they are re-aligned, the drill tools can be withdrawn from the borehole (Figure 3.2-13) and a sampling device can be used to collect a representative sample.

During the advancement of the boring, temporary steel casing is installed directly behind the reamer bits. The casing is driven into place by a percussion motion without rotation (Figure 3.2-14). Following completion of the boring, the casing can be removed. If a permanent casing is desired, the steel casing can be replaced with a less expensive, smaller-diameter casing. The permanent casing is installed inside the temporary steel casing, and the steel casing is withdrawn.

3.2-9.3 Advantages and Disadvantages

3.2-9.3.1 Advantages.

- Drilling method is extremely fast and cost-effective.
- Provides for the installation of temporary and/or permanent casing.
- Limited use of water to cool the cutting bit is necessary in the drilling method.
- Small rigs can be used on most terrains and under most weather conditions.
- Borings can be used to install monitoring wells or instrumentation.
- Standard soil samples can be obtained.

3.2-9.3.2 Disadvantages

- o Soil sampling may result in a significant reduction in drilling rate.
- o Requires an air compressor; air must be filtered to minimize volatile contamination.
- o Specialized equipment not readily available in all parts of Massachusetts; requires experienced operator.
- o Not suitable for fine-grained soils due to problems with the bit plugging.
- o Air emissions may be a problem at contaminated sites due to volatile and aerosol material discharged to the work environment.

3.2-10 DRILLING FLUIDS

Several types of drilling fluids, including water, air, mud, polymers, and surfactants, are used in the completion of borings. In environmental investigations, clean water is the most commonly used fluid. Mud is used occasionally. Surfactants and polymers are rarely used in environmental investigations and, consequently, will not be discussed here. The use of any drilling fluid, other than air and potable water, requires prior approval by DEP. At other sites the use of drilling fluids other than air or potable water should be fully documented by the driller and described in the consultant's report.

3.2-10.1 Functions of Drilling Fluids

The selection of a specific drilling fluid will depend on the drilling equipment to be used, the nature of the soil and rock materials, and the constraints of the investigation. The primary functions of drilling fluids are, as follows:

- o To remove cuttings from the borehole.
- o To stabilize the borehole.
- o To cool and lubricate the drill bit.
- o To control fluid loss in highly permeable formations.

In addition, drilling fluids provide information, in the form of cuttings, about the generalized borehole stratigraphy.

3.2-10.2 Factors Affecting Performance

The ability of a drilling fluid to perform these functions is related to the following factors:

- o Viscosity - The resistance of liquids, semi-solids, and gases to movement or flow; a liquid having a high viscosity rating will resist flow more than a liquid having a low viscosity.

- o Density - The mass of a substance per unit volume; the ratio of the mass of any volume of a substance to the mass of an equal volume of a standard substance. For example, water is used as the standard substance to which the ratio of a quantity of a drill mud is compared. Density is expressed in units of pounds per gallon, pounds per cubic ft, and kilograms per cubic meter.

- o Discharge - Outflow from a pump, drill hole, piping system, or other mechanism.

- o Drill Fluid - Usually water or mud-laden water (sometimes applied to compressed air, natural gas, or oil) circulated through a drill string to keep the bit cool and to wash produced cuttings away from the bit face; also called circulation fluid.

- o Gel - A form of matter in a colloidal state that does not dissolve but remains suspended in a solvent from which it fails to precipitate without the intervention of heat or an electrolyte. A colloidal suspension exists in such a state that shearing stresses below a certain finite value fails to produce permanent deformation. The minimum shearing stress which will produce permanent deformation is known as the shear or gel strength of the gel. Gels commonly occur with bentonite in water.

- o Yield Point (yield value) - Stress needed to deform a plastic system sufficiently to initiate flow.

3.2-10.3 Types of Drilling Fluids

3.2-10.3.1 Water

In environmental investigations, water is the most commonly used and preferred drilling fluid. In small-diameter borings, 4-inches or less, water is quite effective in removing soil and rock cuttings during drilling. In most cases the cuttings drop out of the water quite easily when discharged into a settling tank. In certain materials, especially clays and rock, the cuttings may remain in suspension for long periods of time and, when recirculated, result in clogging of the drill rods and drill stem. The easiest remedy is to replace the drilling water with fresh, clean water when it becomes too thick or dirty.

In both rotary and bedrock coring drilling methods, water is used to cool and lubricate the bit. Loss of circulation, due to blockage or formation conditions, can quickly destroy drilling tools. Water flow may be monitored by observing flow meters generally located on the rig and by monitoring the volume of wash water discharge. Even small quantities of water lost into the formation can be detected by a gradual lowering of the water level in the discharge tank.

Water is not capable of performing all the functions desired in a drilling fluid. Water does not have the proper viscosity and density to stabilize and support the wall in uncased borings. Water is lost into permeable formations. This may be undesirable due to the addition of non-representative fluids to the aquifer and due to the drilling difficulties encountered when circulation is lost. Except for very fine-grained materials, water is not capable of suspending cuttings in a borehole for extended periods of time. Because of this, boreholes should be thoroughly flushed if drilling is interrupted. Bits should be left a short distance off the bottom of the hole to avoid trapping the bit in the settled soil and rock cuttings.

Water has the significant advantage that, in small quantities, it will have a minimal impact on the existing aquifer chemistry. In all drilling applications, only clean, potable water should be used. In contamination investigations, the drilling water should be tested prior to and periodically during drilling to assure that it is of suitable quality. In contamination investigations, only clean water is an acceptable drilling fluid.

3.2-10.3.2 Drilling Mud

Drilling mud is a general term applied to several types of bentonite-based drilling fluids. As previously described, these fluids consist of a mixture of bentonite and water. Bentonite, a naturally occurring sodium montmorillonite clay, is added to water to increase its viscosity, density, gel strength, and lubrication capacity. The plate-shaped clay particles expand in water and remain in colloidal suspension. Properly mixed drilling fluid is capable of removing the cuttings, stabilizing the hole, and permitting the cuttings to settle out before recirculating. Drilling muds have been developed primarily for large-diameter rotary holes where the annular space and size of the suspended particles are too large for water to be an effective drilling fluid. A significant advantage of drilling mud is that it eliminates the need for the use of casing. The use of drilling mud substantially speeds up a drilling program but is not acceptable in most environmental investigations due to the effects of the mud on the borehole permeability and chemistry. Experience has shown that drilling muds are very difficult to remove even after vigorous well development and purging. Appropriate applications of bentonite-based drilling fluids in environmentally sensitive investigations might include:

- Drilling pilot holes through thick, unsaturated, coarse-grained deposits where other techniques are ineffective.

- Drilling fast reconnaissance borings as part of a preliminary investigation.

- Completing borings for specific geotechnical or geophysical assessments.

- Under some conditions the use of mud may minimize the potential for cross-contamination during drilling.

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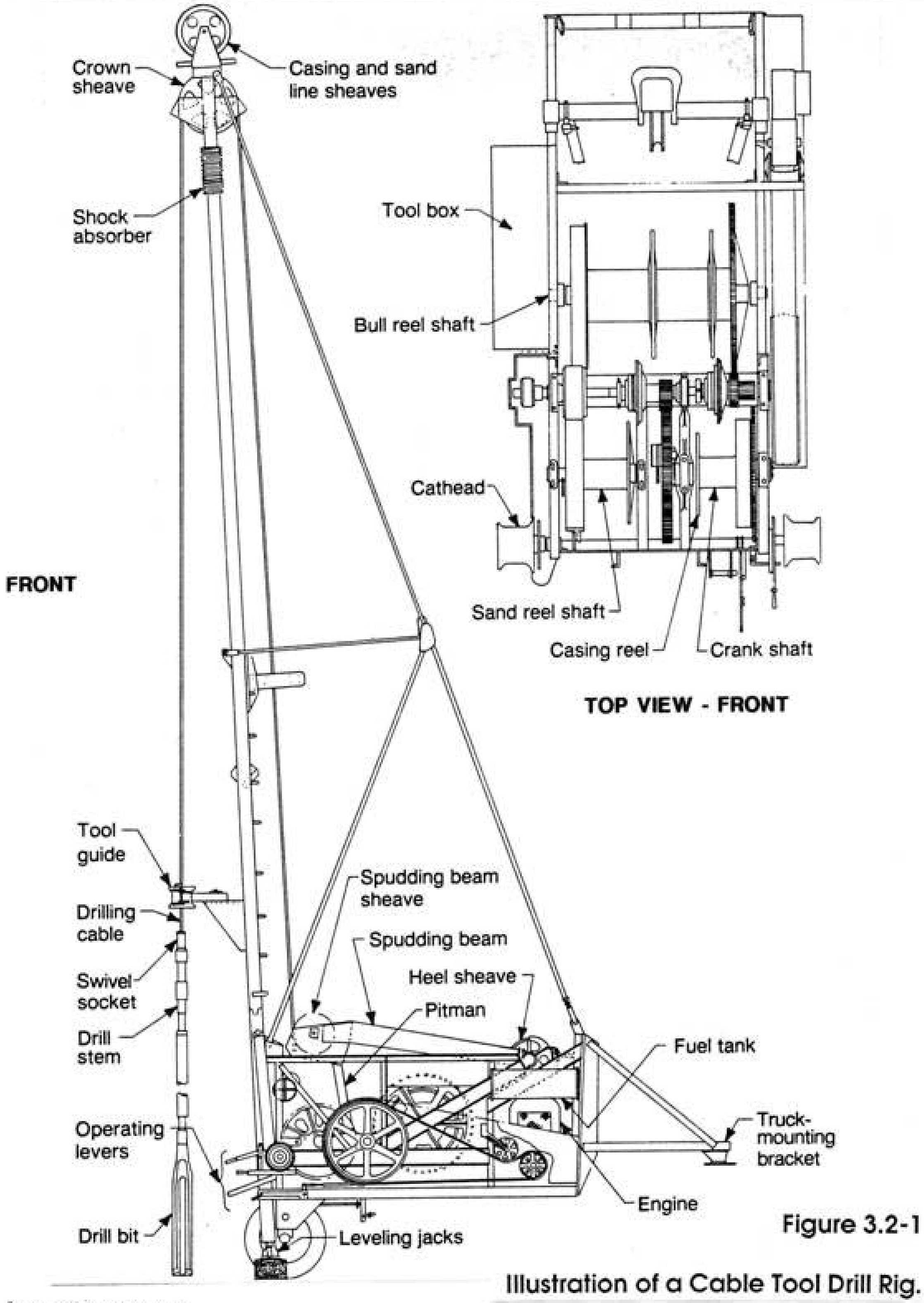


Figure 3.2-1

Illustration of a Cable Tool Drill Rig.

Source: Driscoll (1986)

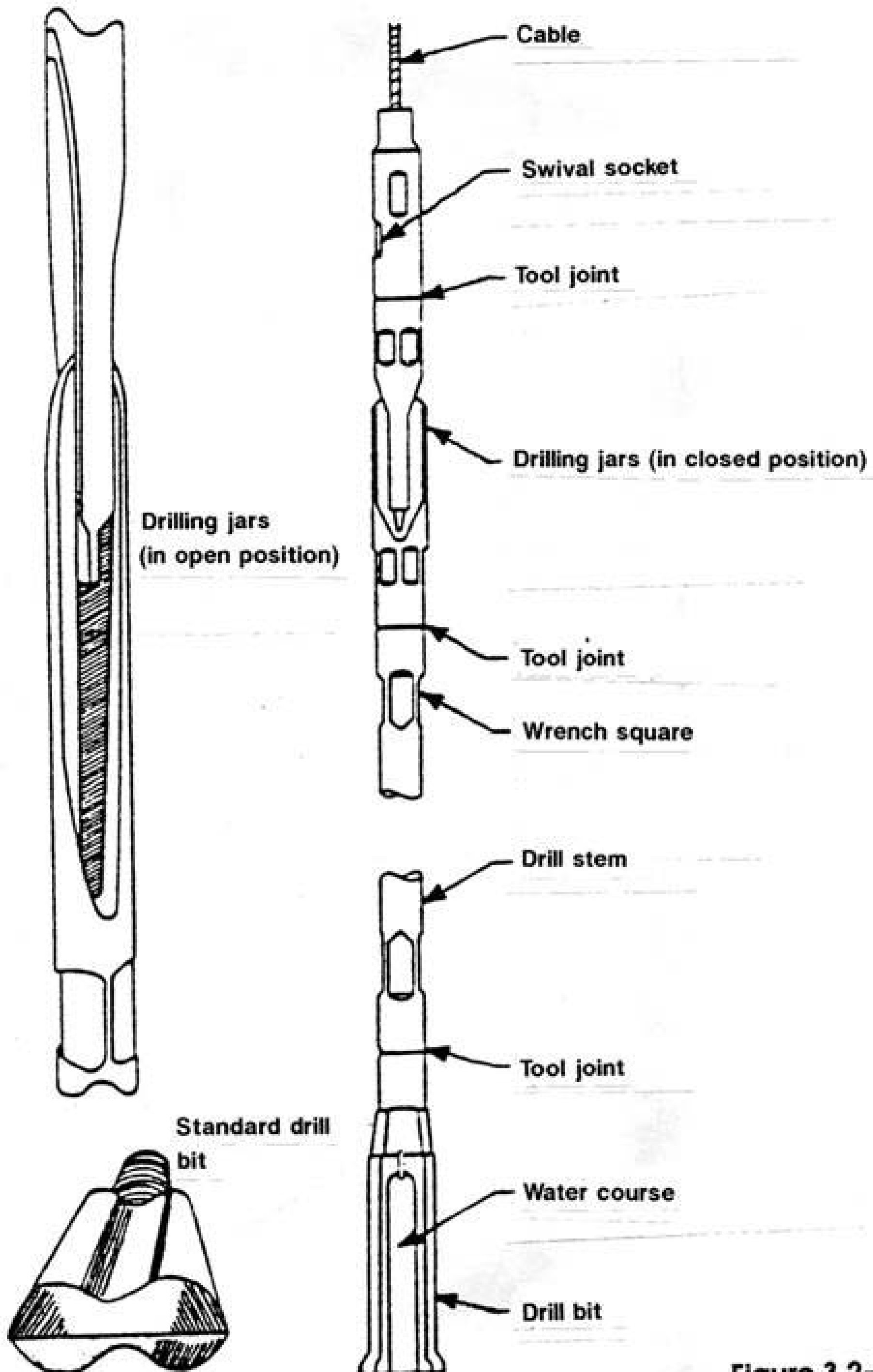


Figure 3.2-2

Source: Driscoll (1986)

Cable Rig Drilling Tools.

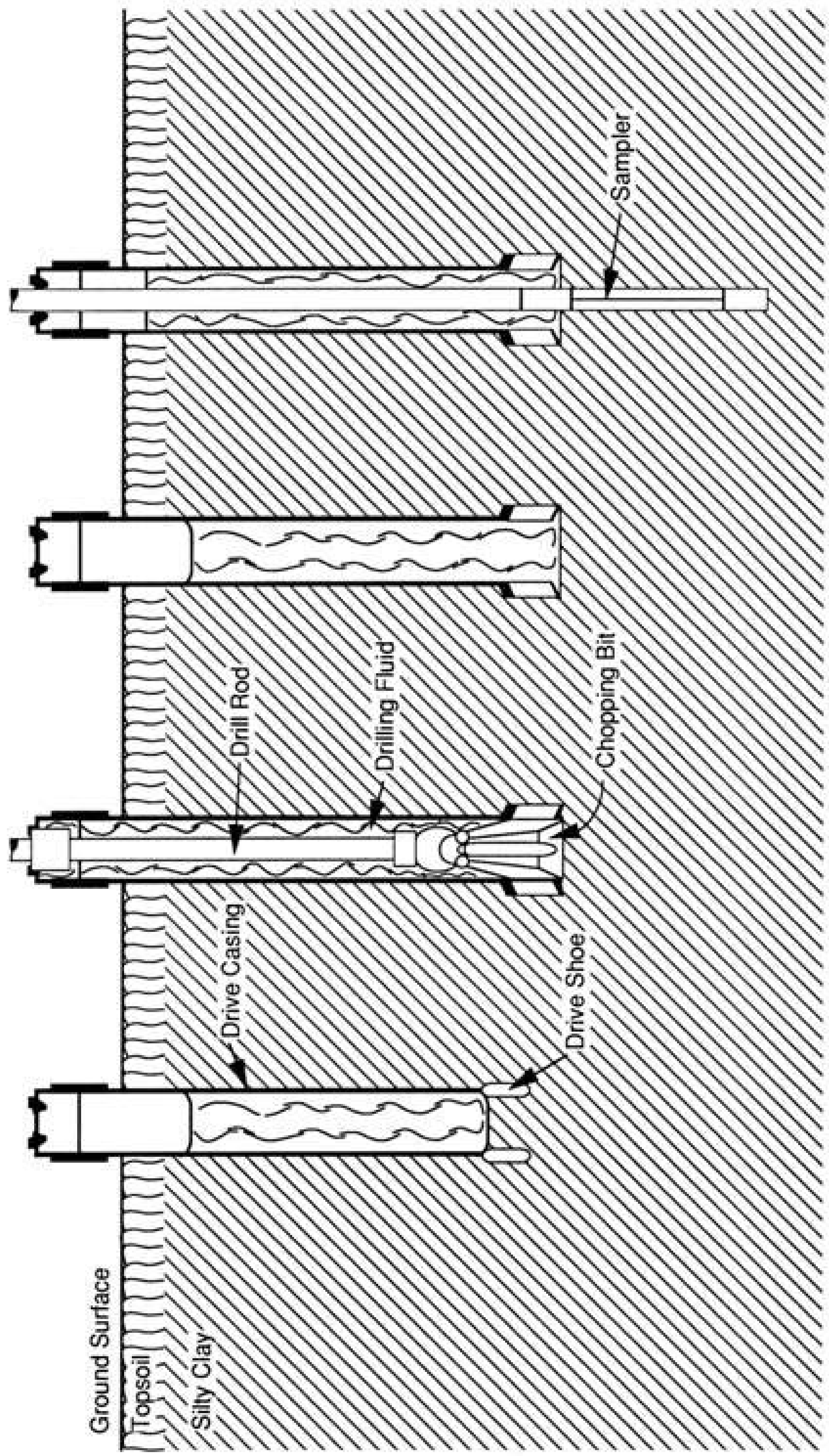
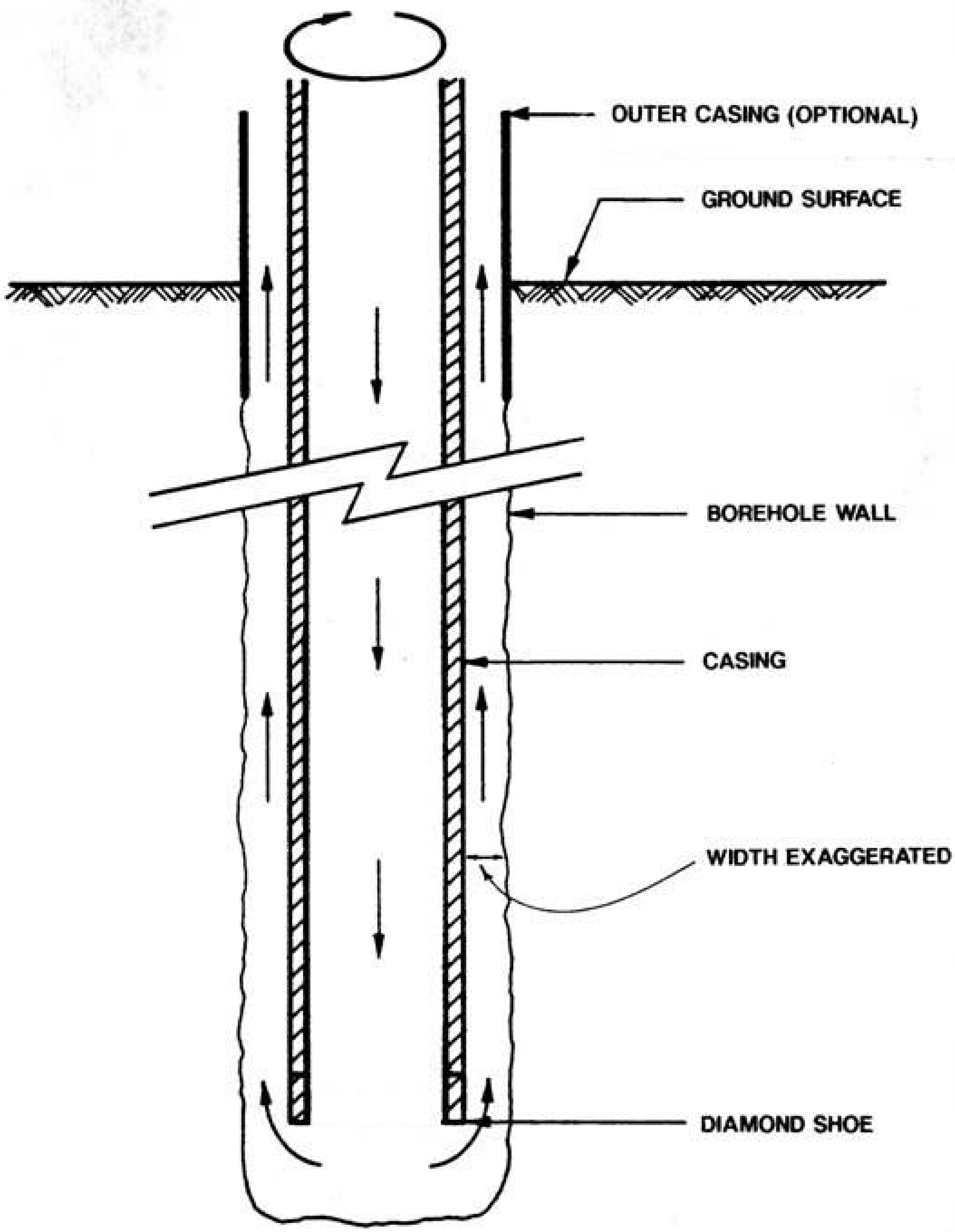


Figure 3.2-3

Schematic of Drive and Wash Drilling Method.

Source: MADEP



NOT TO SCALE

Source: MADEP

Figure 3.2-4

Schematic of Spun Casing Drilling Method.

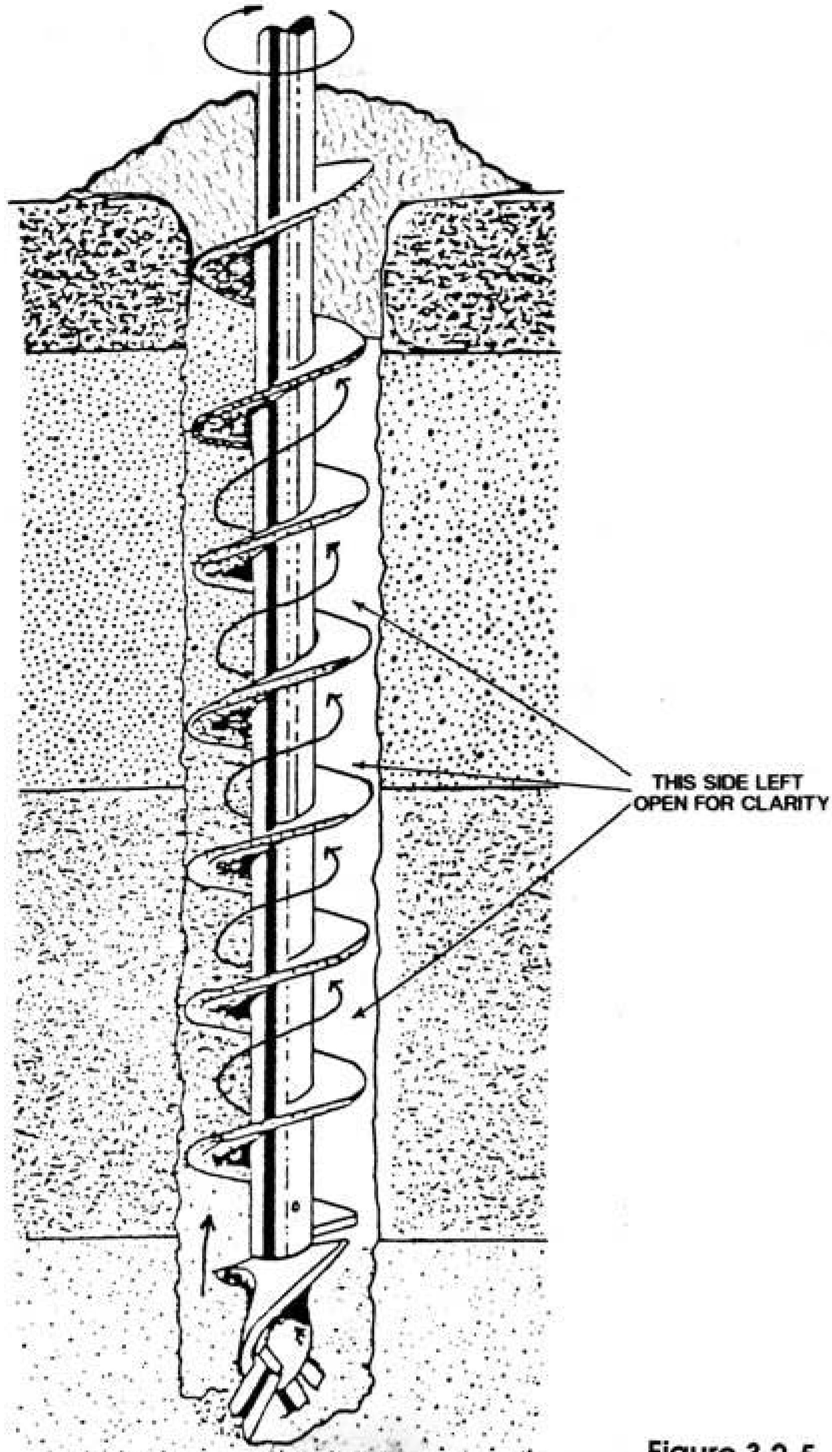


Figure 3.2-5

Source: After Scalf et al. (1981)

Schematic of Auger Drilling Method.

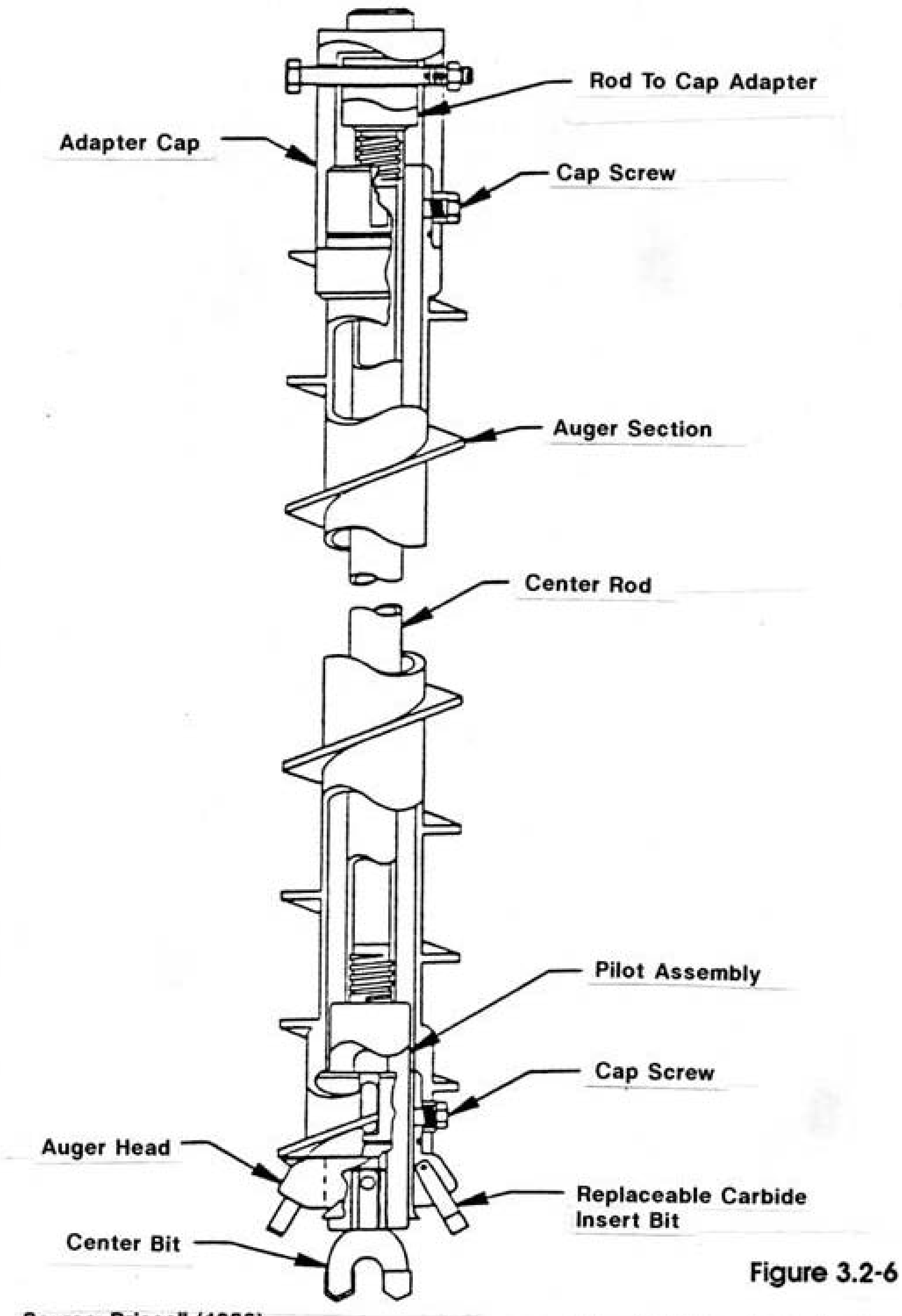


Figure 3.2-6

Source: Driscoll (1986)

Components of Hollow-stem Auger.

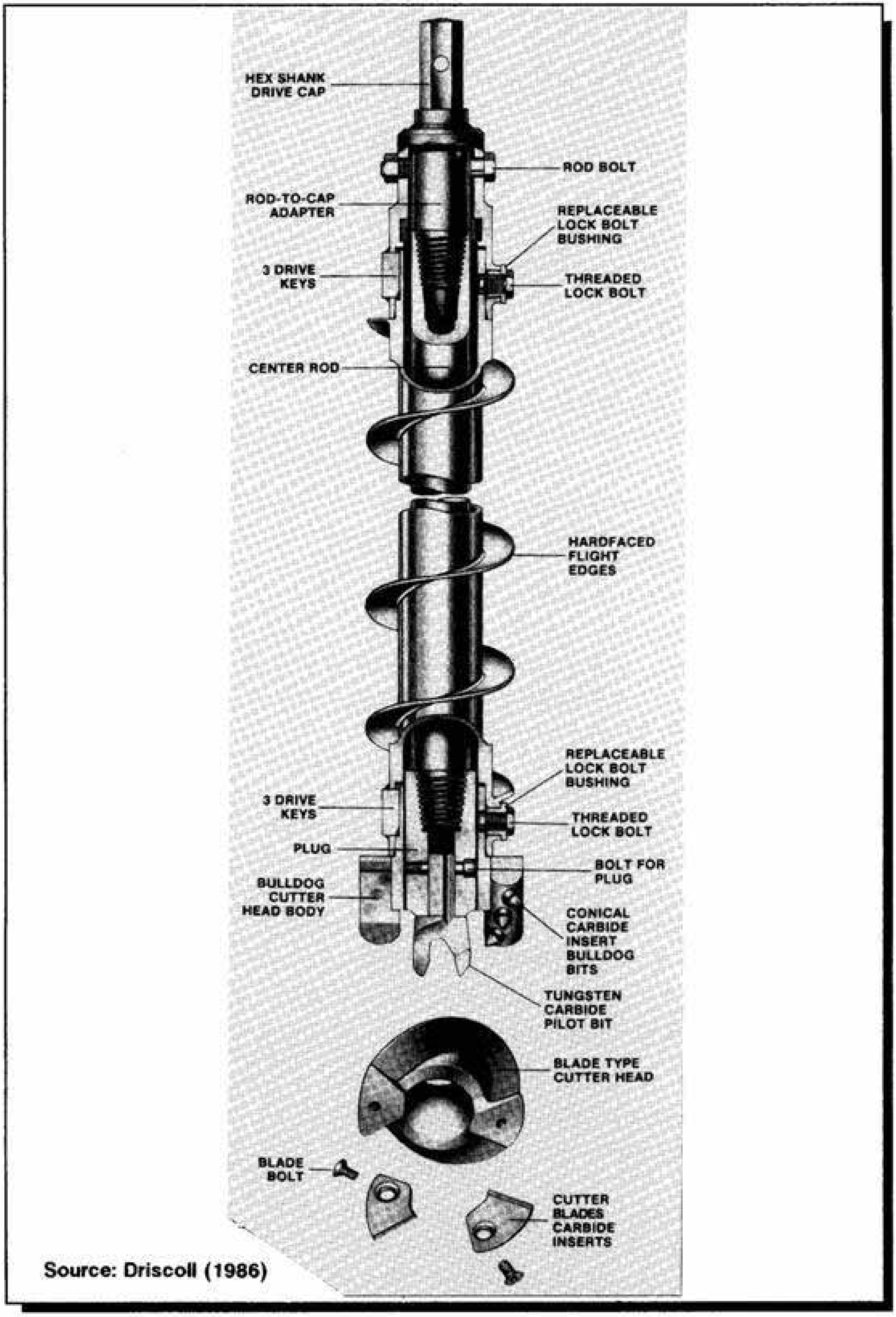


Figure 3.2-7

Detail of Lead Hollow-stem Auger.

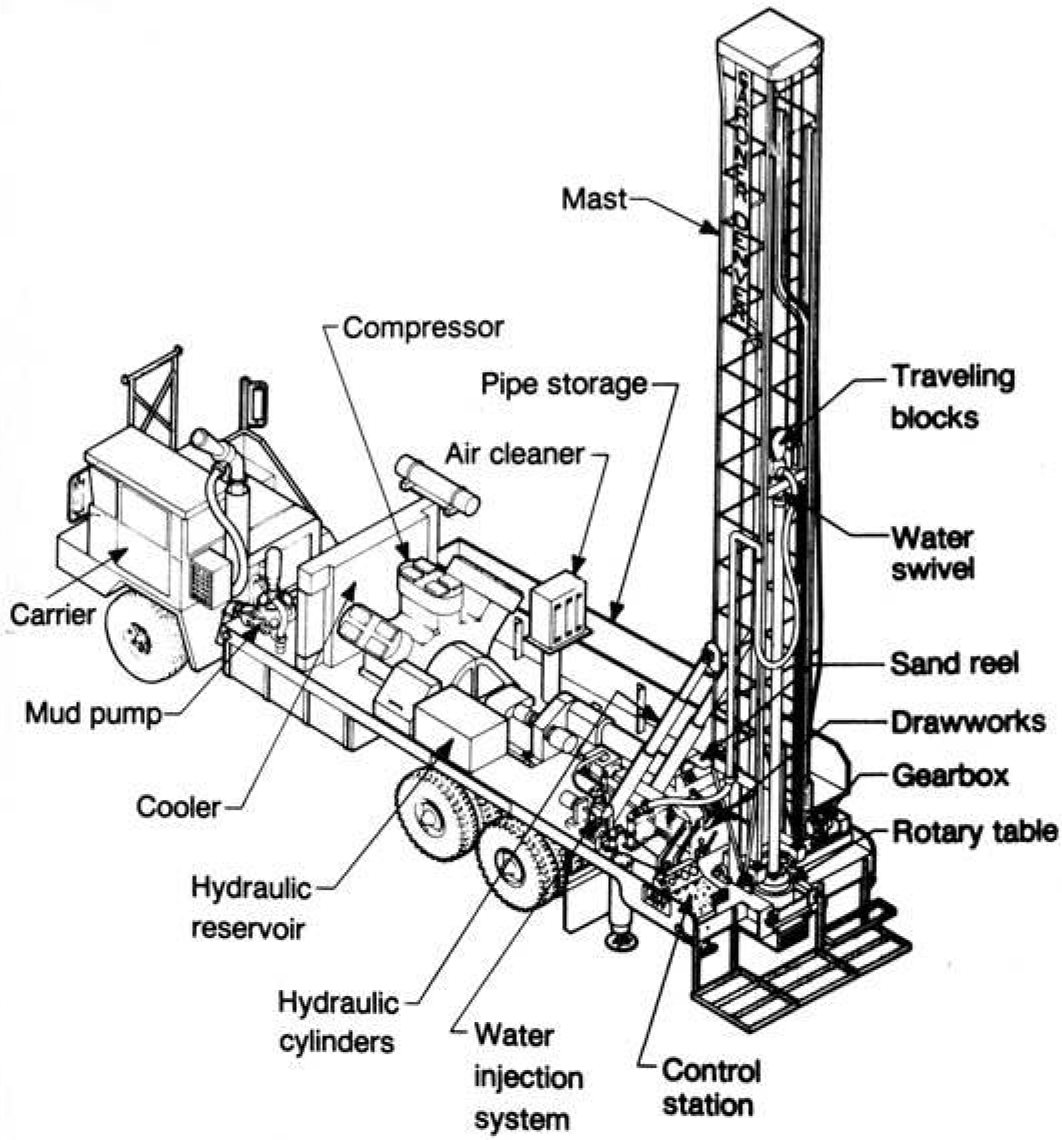
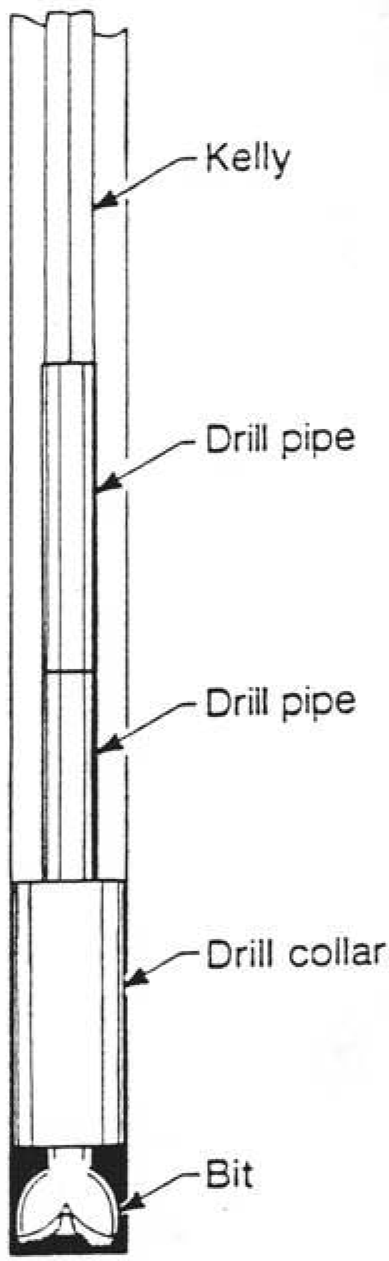


Figure 3.2-8

Source: Driscoll (1986)

Schematic of Rotary Drill Rig.



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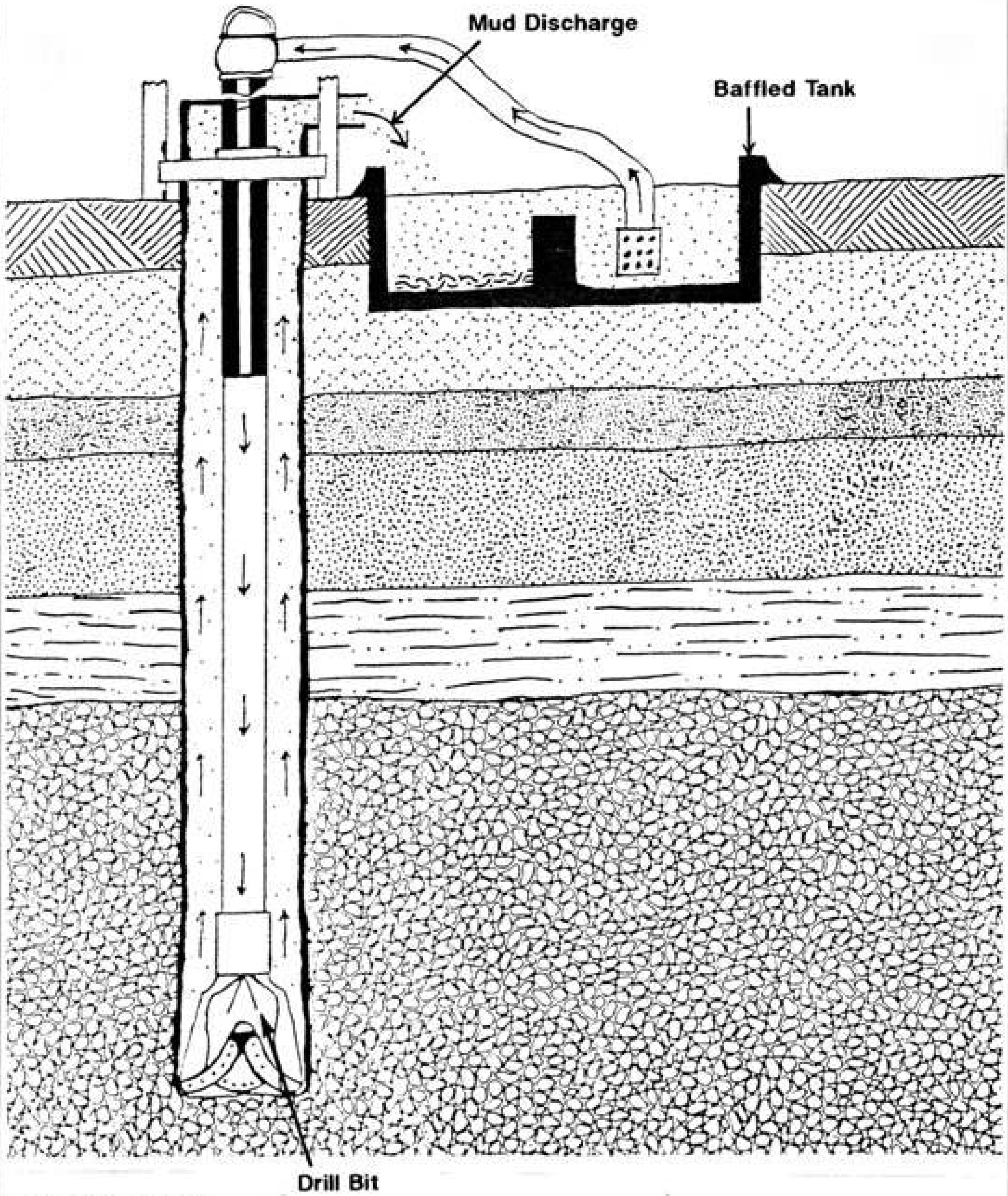
Source: Driscoll (1986)

Figure 3.2-9

Drill String for Mud Rotary Drilling Method.



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Source: After Scalf et al. (1981)

Figure 3.2-10

Schematic of Mud Rotary Drilling Method.

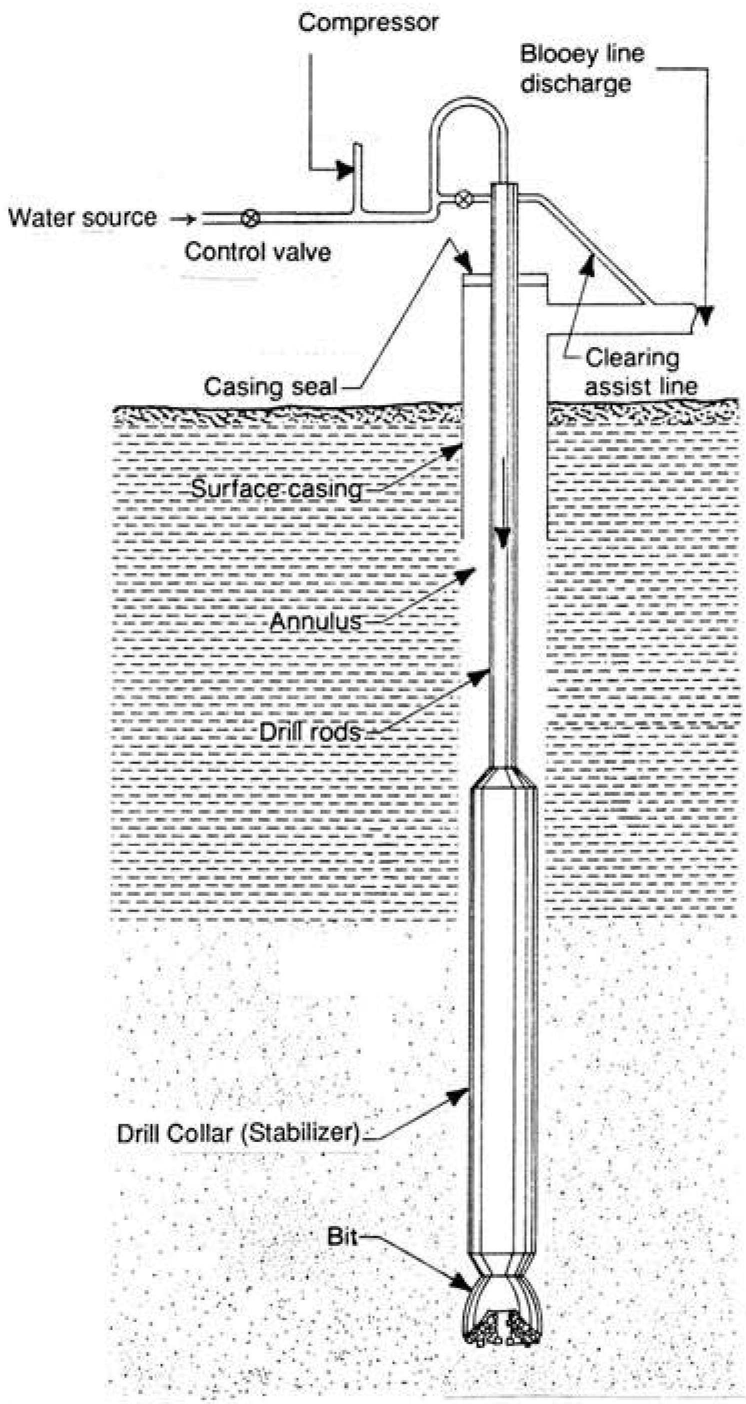

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Figure 3.2-11

Source: Driscoll (1986)

Schematic of Air Rotary Drilling Method.

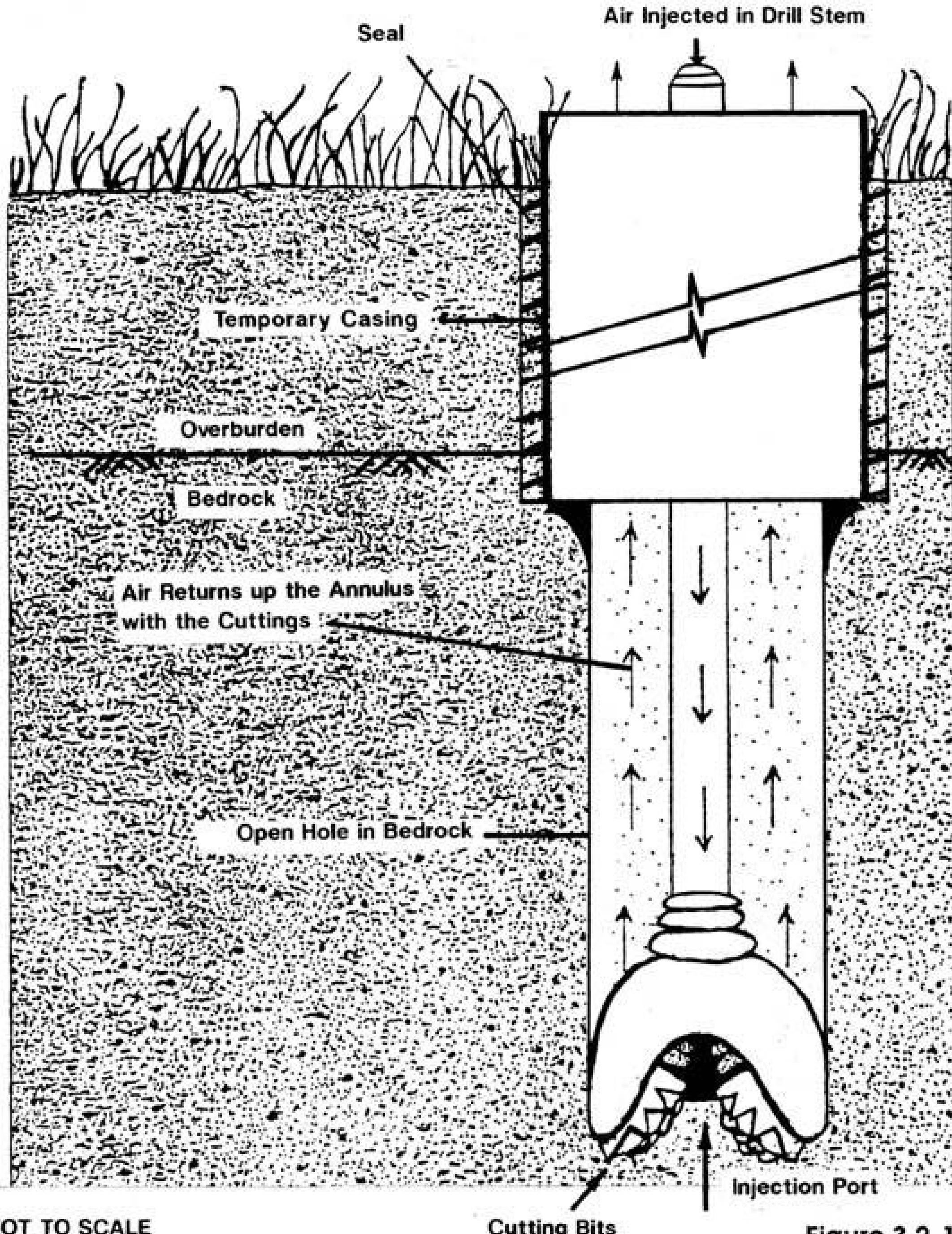
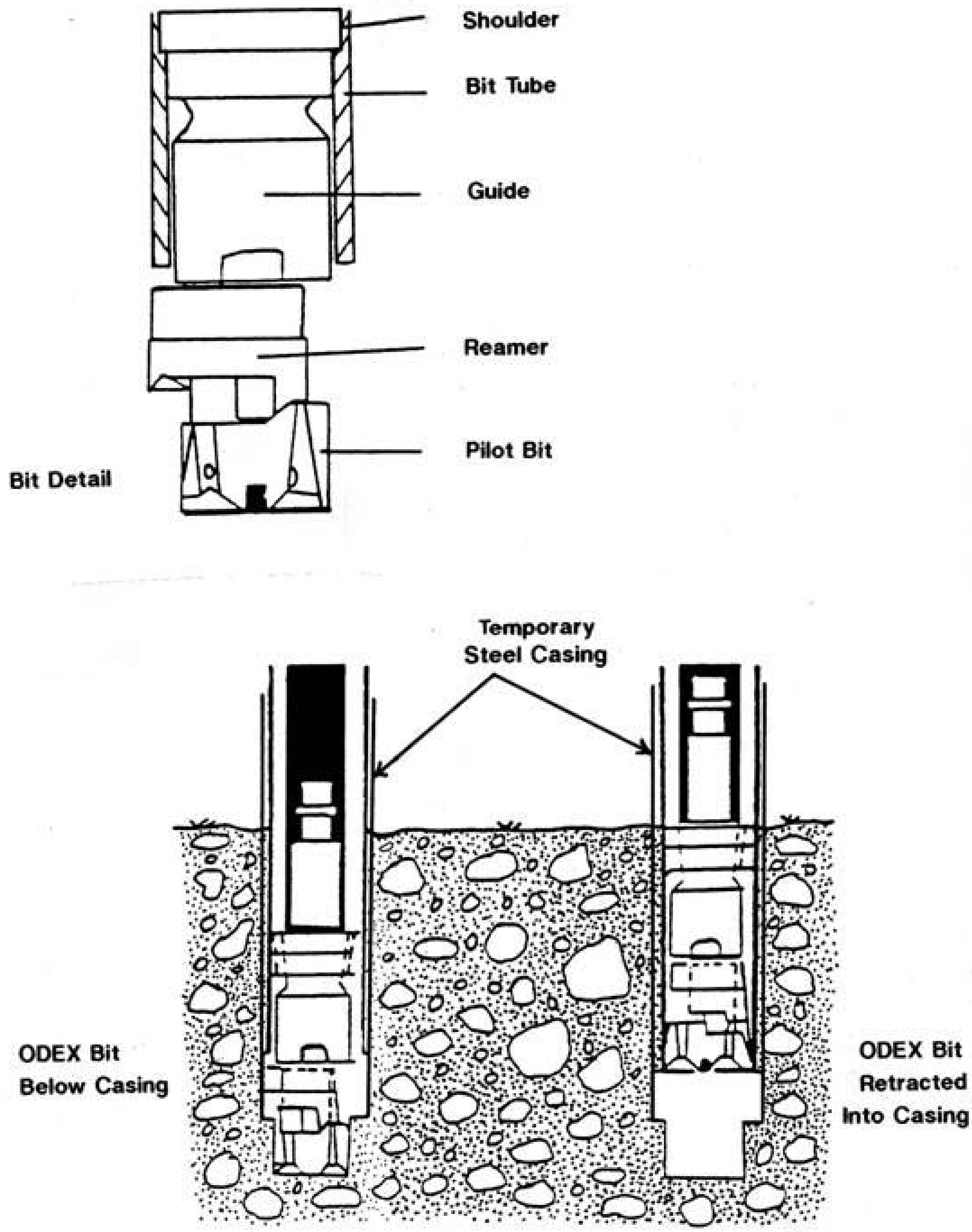


Figure 3.2-12

Schematic of Air Circulation.

Source: After Keely and Boateng (1987)

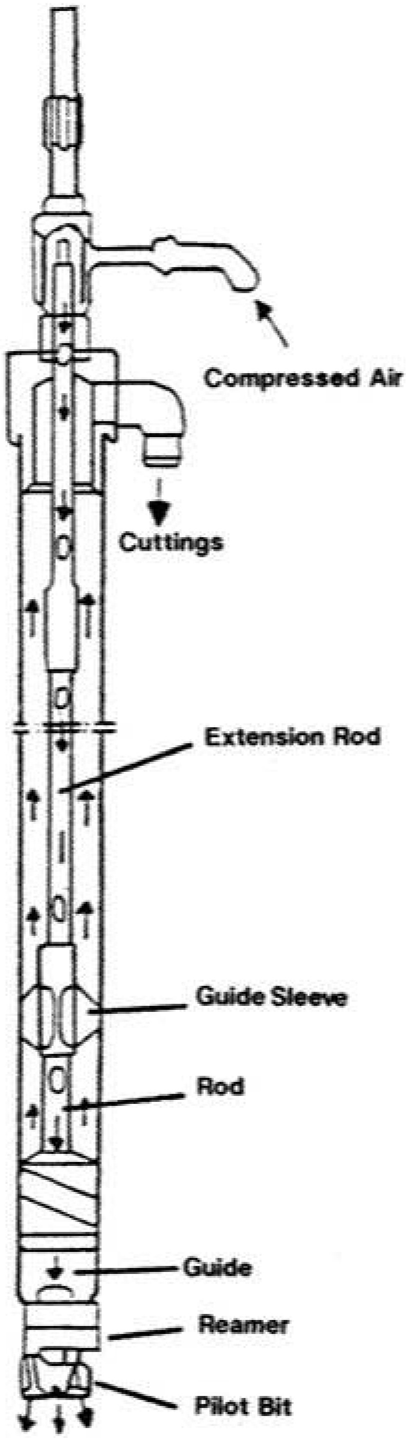


Source: Atlas Copco-Sandrik
Rock Tools (Catalog)

NOT TO SCALE

Figure 3.2-13

Schematic of ODEX Bit.



Source: Atlas Copco-Sandrik
Rock Tools (Catalog)

NOT TO SCALE

Figure 3.2-14

Major Elements of ODEX Drilling System.

Type of Formation	Cable Tool	Direct Rotary (with fluids)	Direct Rotary (with air)	Direct Rotary (Down-the-hole air hammer)	Direct Rotary (Drill-through casing hammer)	Reverse Rotary (with fluids)	Reverse Rotary (Dual Wall)	Hydraulic Percussion	Jetting	Driven	Auger
Dune sand	2	5	Not recommended	Not recommended	6	5*	6	5	5	3	1
Loose sand and gravel	2	5	Not recommended	Not recommended	6	5*	6	5	5	3	1
Quicksand	2	5	Not recommended	Not recommended	6	5*	6	5	5	Not recommended	1
Loose boulders in alluvial fans or glacial drift	3-2	2-1	Not recommended	Not recommended	5	2-1	4	1	1	Not recommended	1
Clay and silt	3	5	Not recommended	Not recommended	5	5	5	3	3	Not recommended	3
Firm shale	5	5	Not recommended	Not recommended	5	5	5	3	Not recommended	Not recommended	2
Sticky shale	3	5	Not recommended	Not recommended	5	3	5	3	Not recommended	Not recommended	2
Brittle shale	5	5	Not recommended	Not recommended	5	5	5	3	Not recommended	Not recommended	Not applicable
Sandstone—poorly cemented	3	4	Not recommended	Not recommended	Not applicable	4	5	4	Not recommended	Not recommended	Not applicable
Sandstone—well cemented	3	3	5	Not recommended	Not applicable	3	5	3	Not recommended	Not recommended	Not applicable
Chert nodules	5	3	3	Not recommended	Not applicable	3	3	5	Not recommended	Not recommended	Not applicable
Limestone	5	5	5	6	Not applicable	5	5	5	Not recommended	Not recommended	Not applicable
Limestone with chert nodules	5	3	5	6	Not applicable	3	3	5	Not recommended	Not recommended	Not applicable
Limestone with small cracks or fractures	5	3	5	6	Not applicable	2	5	5	Not recommended	Not recommended	Not applicable
Limestone, cavernous	5	3-1	2	5	Not applicable	1	5	1	Not recommended	Not recommended	Not applicable
Dolomite	5	5	5	6	Not applicable	5	5	5	Not recommended	Not recommended	Not applicable
Basalts, thin layers in sedimentary rocks	5	3	5	6	Not applicable	3	5	5	Not recommended	Not recommended	Not applicable
Basalts—thick layers	3	3	4	5	Not applicable	3	4	3	Not recommended	Not recommended	Not applicable
Basalts—highly fractured (lost circulation zones)	3	1	3	3	Not applicable	1	4	1	Not recommended	Not recommended	Not applicable
Metamorphic rocks	3	3	4	5	Not applicable	3	4	3	Not recommended	Not recommended	Not applicable
Granite	3	3	5	5	Not applicable	3	4	3	Not recommended	Not recommended	Not applicable

*Assuming sufficient hydrostatic pressure is available to contain active sand (under high confining pressures)

Rate of Penetration:
1 Impossible
2 Difficult
3 Slow
4 Medium
5 Rapid
6 Very rapid

Source: Driscoll (1986)

Table 3.2-1

Relative Performance of Different Drilling Methods in Various Types of Geologic Formations

Hole Size (in)	Approx. Weight (lb)	Approx. Length	Size Pin (in)	Hole Size (in)	Approx. Weight (lb)	Approx. Length	Size Pin (in)
3	50	4′5″	1¾	8	600	6′6″	4¼ or 4½
3½	75	4′6″	1¾	8	650	7′	4¼ or 4½
4	100	4′10″	2¼ or 2⅝	8	700	7′6″	4¼ or 4½
4½	100	4′	2¼ or 2⅝	8	750	8′	4¼ or 4½
4½	125	5′	2¼ or 2⅝	9	550	6′	3¾ or 4¼
4½	150	6′	2¼ or 2⅝	9	600	6′6″	3¾ or 4¼
5	135	4′	2¼ or 2⅝	9	650	7′	3¾ or 4¼
5	165	5′	2¼ or 2⅝	10	400	4′	3 or 3¼
5	190	5′	2⅝ or 3	10	500	5′	3 or 3¼
5	220	6′	2⅝ or 3	10	450	4′	3½ or 3¾
5	250	7′	2⅝ or 3	10	500	4′5″	3½ or 3¾
5⅝	180	4′	2¼ or 2⅝	10	575	5′	3½ or 3¾
5⅝	200	4′6″	3 or 3¼	10	500	4′	4¼ or 4½
5⅝	220	5′	3 or 3¼	10	625	5′	4¼ or 4½
5⅝	260	6′	3 or 3¼	10	750	6′	4¼ or 4½
6	150	3′4″	2¼ or 2⅝	10	875	7′	4½ or 5
6	175	4′	2¼ or 2⅝	10	950	7′6″	4½ or 5
6	200	4′	3 or 3¼	10	1000	8′	4½ or 5
6	250	5′	3 or 3¼	12	500	3′6″	3½ or 3¾
6	300	6′	3 or 3¼	12	700	4′6″	3½ or 3¾
6¼	270	5′	3 or 3¼	12	800	5′	3½ or 3¾
6¼	320	6′	3 or 3¼	12	600	3′6″	4¼ or 4½
6⅝ – 6¼	300	5′	3½ or 3¾	12	800	4′6″	4¼ or 4½
6⅝ – 6¼	350	6′	3½ or 3¾	12	1000	5′6″	4¼ or 4½
6⅝ – 6¼	400	7′	3½ or 3¾	12½	1100	6′	4½ or 5
6⅝ – 6¼	425	7′6″	3½ or 3¾	12½	1200	6′6″	4½ or 5
6⅝ – 6¼	450	8′	3½ or 3¾	12½	1350	7′	4½ or 5
8	250	3′6″	3 or 3¼	12½	1450	7′6″	4½ or 5
8	300	4′	3 or 3¼	14	800	4′6″	4¼ or 5
8	350	4′6″	3 or 3¼	14	1000	5′	4¼ or 5
8	400	5′	3 or 3¼	15½	1550	6′	4½ or 5
8	400	5′	3½ or 3¾	15½	1700	6′6″	4½ or 5
8	450	5′6″	3½ or 3¾	15½	1850	7′	4½ or 5
8	500	6′	3½ or 3¾	15½	2000	7′6″	4½ or 5
8	600	7′	3½ or 3¾	16	1000	3′6″	4¼ or 5
8	400	4′6″	4¼ or 4½	16	1200	4′6″	4¼ or 5
8	450	5′	4¼ or 4½	16	1700	6′	4¼ or 5
8	500	5′6″	4¼ or 4½	16	2000	7′	4¼ or 5
8	550	6′	4¼ or 4½				

Table 3.2-2

Dimensions and Weights for Standard Cable Tool Drill Bits (English Units)

Source: Driscoll (1986)

Hole Size (mm)	Approx. Weight (kg)	Approx. Length (m)	Size Pin (inches)	Hole Size (mm)	Approx. Weight (kg)	Approx. Length (m)	Size Pin (inches)
76.2	22.7	1.35	1¾	203	272	1.98	4¼ or 4½
88.9	34.0	1.37	1¾	203	295	2.14	4¼ or 4½
102	45.4	1.48	2¼ or 2⅝	203	318	2.29	4¼ or 4½
114	45.4	1.22	2¼ or 2⅝	203	340	2.44	4¼ or 4½
114	56.7	1.52	2¼ or 2⅝	229	250	1.83	3¾ or 4¼
114	68.0	1.83	2¼ or 2⅝	229	272	1.98	3¾ or 4¼
127	61.2	1.22	2¼ or 2⅝	229	295	2.58	3¾ or 4¼
127	74.8	1.52	2¼ or 2⅝	254	181	1.22	3 or 3¼
127	86.2	1.52	2⅝ or 3	254	227	1.52	3 or 3¼
127	99.8	1.83	2⅝ or 3	254	204	1.22	3½ or 3¾
127	113	2.14	2⅝ or 3	254	227	1.35	3½ or 3¾
143	81.6	1.22	2¼ or 2⅝	254	261	1.52	3½ or 3¾
143	90.7	1.37	3 or 3¼	254	227	1.22	4¼ or 4½
143	99.8	1.52	3 or 3¼	254	284	1.52	4¼ or 4½
143	118	1.83	3 or 3¼	254	340	1.83	4¼ or 4½
152	68.0	1.01	2¼ or 2⅝	254	397	2.14	4½ or 5
152	79.4	1.22	2¼ or 2⅝	254	431	2.29	4½ or 5
152	90.7	1.22	3 or 3¼	254	454	2.44	4½ or 5
152	113	1.52	3 or 3¼	305	227	1.07	3½ or 3¾
152	136	1.83	3 or 3¼	305	318	1.37	3½ or 3¾
159	113	1.52	3 or 3¼	305	363	1.52	3½ or 3¾
159	145	1.83	3 or 3¼	305	272	1.07	4¼ or 4½
168 – 159	136	1.52	3½ or 3¾	305	363	1.37	4¼ or 4½
168 – 159	159	1.83	3½ or 3¾	305	454	1.68	4¼ or 4½
168 – 159	181	2.14	3½ or 3¾	318	499	1.83	4½ or 5
168 – 159	193	2.29	3½ or 3¾	318	544	1.98	4½ or 5
168 – 159	204	2.44	3½ or 3¾	318	612	2.14	4½ or 5
203	113	1.07	3 or 3¼	318	494	2.29	4½ or 5
203	136	1.22	3 or 3¼	356	363	1.37	4¼ or 5
203	159	1.37	3 or 3¼	356	454	1.52	4¼ or 5
203	181	1.52	3 or 3¼	394	703	1.83	4½ or 5
203	181	1.52	3½ or 3¾	394	771	1.98	4½ or 5
203	204	1.68	3½ or 3¾	394	839	2.14	4½ or 5
203	227	1.83	3½ or 3¾	394	907	2.29	4½ or 5
203	272	2.14	3½ or 3¾	406	454	1.07	4¼ or 5
203	181	1.37	4¼ or 4½	406	544	1.37	4¼ or 5
203	204	1.52	4¼ or 4½	406	771	1.83	4¼ or 5
203	227	1.68	4¼ or 4½	406	907	2.14	4¼ or 5
203	250	1.83	4¼ or 4½				

Table 3.2-2
(Continued)
Dimensions and Weight for Standard Cable Tool Drill Bits (SI Units)

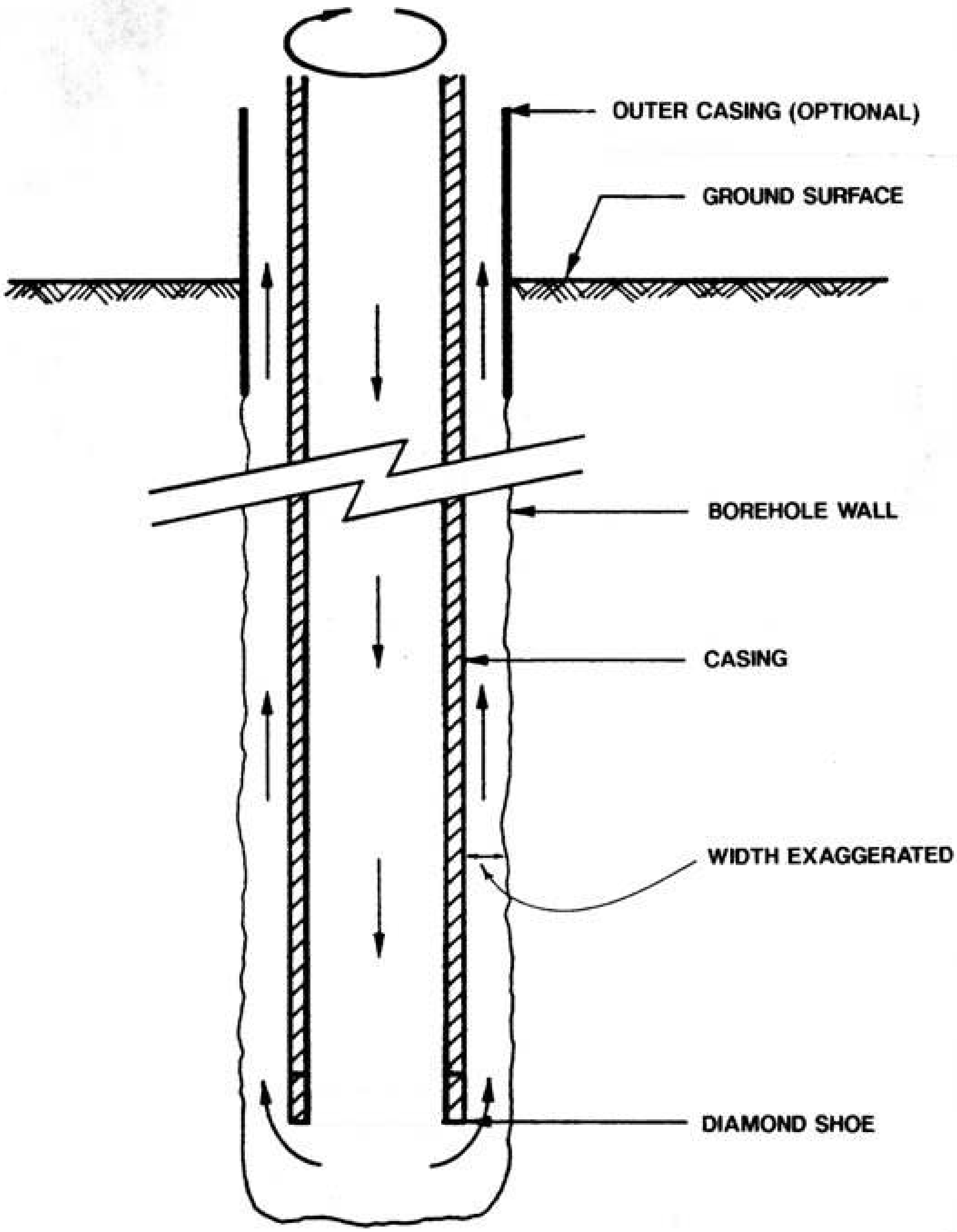
Source: Driscoll (1986)

Diameter in	Diameter mm	Approximate Weight lb	Approximate Weight kg	API Pin Size
2⅞	73.0	4	1.8	N Rod
2 15/16	74.6	4¼	1.9	N Rod
3⅛	79.4	4¼	1.9	N Rod
3½	88.9	7	3.2	2⅜ N Rod
3¾	95.3	7½	3.4	2⅜
3⅞	98.4	7½	3.4	2⅜
4¼	108	10	4.5	2⅜
4½	114	11	5.0	2⅜
4¾	121	13	5.9	2⅞
5	127	17	7.7	2⅞
5⅛	130	19	8.6	2⅞
5⅝	143	22	10.0	3½
6	152	27	12.2	3½
6¼	159	30	13.6	3½
6¾	171	33	15.0	3½
7⅜	187	42	19.1	3½
7⅝ – 7⅞	200	52	23.6	4½
8½	216	75	34.0	4½
8¾	222	75	34.0	4½
9	229	75	34.0	4½
9⅝	244	105	47.6	6⅝
9⅞	251	115	52.2	6⅝
10⅝	270	120	54.4	6⅝
11	279	145	65.8	6⅝
12¼	311	175	79.4	6⅝
13¾	349	219	99.3	6⅝
14¾	375	360	163.3	6⅝
15	381	375	170.1	6⅝ or 7⅝
16	406	450	204.1	6⅝ or 7⅝
17½	445	575	260.8	6⅝ or 7⅝
18½	470	625	283.5	6⅝ or 7⅝
20	508	665	301.6	6⅝ or 7⅝
22	559	810	367.4	6⅝ or 7⅝
24	610	1,014	460.0	6⅝ or 7⅝
26	660	1,217	552.0	6⅝ or 7⅝
30	762	2,320	1,052.35	7⅝ or 8⅝

Table 3.2-3

Source: Driscoll (1986)

Sizes and Weights for Tricone Roller Bits



NOT TO SCALE

Source: MADEP

Figure 3.2-4

Schematic of Spun Casing Drilling Method.

Size	OD in	OD mm	ID in	ID mm	Weight lb/ft	Weight kg/m	Coupling OD in	Coupling OD mm
			DRILL RODS—FLUSH COUPLED					
E†	1 5/16	33.3	7/8	22.2	2.7	4.0	7/16	11.1
A†	1 5/8	41.3	1 1/8	28.5	3.7	5.7	9/16	14.3
B†	1 7/8	47.6	1 1/4	31.7	5.0	7.0	5/8	15.9
N†	2 3/8	60.3	2	50.8	5.2	7.5	1	29.4
EW‡	1 3/8	34.9	15/16	23.8	3.1	4.7	7/16	11.1
AW‡	1 3/4	44.4	1 1/4	31.8	4.2	6.5	5/8	15.9
BW‡	2 1/8	54.0	1 3/4	44.5	4.3	6.7	3/4	19.3
NW‡	2 5/8	66.7	2 1/4	57.1	5.5	8.4	1 3/8	34.9
HW‡	3 1/2	88.9	3 1/16	77.8	7.7	11.5	2 3/8	60.3
			CASING—FLUSH JOINTED					
EW	1 13/16	43.0	1 1/2	38.1	2.76	4.2		
AW	2 1/4	57.2	1 29/32	48.4	3.80	5.8		
BW	2 7/8	73.9	2 3/8	60.3	7.00	10.6		
NW	3 1/2	88.9	3	76.2	8.69	13.2		
HW	4 1/2	114.3	4	101.6	11.35	16.9		
PW	5 1/2	139.7	4 7/8	127.0	15.35	22.8		
SW	6 5/8	168.3	6 1/32	152.4	19.49	29.0		
UW	7 5/8	193.7	7	177.8	23.47	34.9		
ZW	8 5/8	219.1	8 3/32	203.2	27.80	41.4		
			CASING—FLUSH COUPLED					
EX	1 13/16	46.0	1 5/8	41.3	1.80	2.7	1 1/2	33.1
AX	2 1/4	57.2	2	50.8	2.90	4.4	1 29/32	48.4
BX	2 7/8	73.0	2 9/16	65.1	5.90	8.8	2 3/4	69.3
NX	3 1/2	83.9	5 3/16	81.0	7.80	11.8	3	76.2
HX	4 1/2	114.3	4 1/8	104.8	8.65	13.6	3 15/16	100.0
			CASING—STANDARD DRIVE PIPE					
Size in.	**OD in**	**OD mm**	**ID in**	**ID mm**	**Weight lb/ft**	**Weight kg/m**	**Coupling OD in**	**Coupling OD mm**
2	2 3/8	60.3	2 1/16	52.4	5.5	8.3	2 7/8	73.0
2 1/2	2 7/8	73.0	2 15/32	62.7	9.0	13.6	3 3/8	85.7
3	3 1/2	88.9	3 1/16	77.8	11.5	17.4	4	101.6
3 1/2	4	101.6	3 9/16	90.5	15.5	23.4	4 5/8	117.3
4	4 1/2	114.3	4 1/32	102.4	18.0	27.2	5 3/16	131.8
			CASING—EXTRA HEAVY DRIVE PIPE					
2	2 3/8	60.3	1 15/16	49.2	5.0	7.6	2 7/32	56.4
2 1/2	2 7/8	73.0	2 21/64	59.1	7.7	11.6	2 5/8	66.7
3	3 1/2	88.9	2 29/32	73.8	10.2	15.4	3 1/4	82.5
3 1/2	4	101.6	3 23/64	85.3	12.5	18.9	3 3/4	95.3
4	4 1/2	114.3	3 53/64	97.2	15.0	22.7	4 1/4	107.8

*From Diamond Core Drill Manufacturers Association (DCDMA).

†Original diamond core drill tool designations.

‡Current DCDMA standards.

Table 3.2-5

Source: Hunt (1984)

Standard Sizes of Casing and Tools

(a) Recommended Rotating Speeds for all Sizes and Types of Bits in Various Formations

Bit Sizes and Types	Sticky Shales or Gumbos	Soft Unconsolidated Shales, Silts, Sandy Shales, etc.	Medium Hard Shales, Sandy Shales, Soft Chalk	Medium Hard Sandstones Hard Very Sandy Shale	Very Hard Sandstones, Quartzite, Angular Limestones, Anhydrite	Hard Brittle Shale and Limestone Conchoidal Fracture
13 to 20 Inch						
Drag	100 – 130	100 – 130				
Zublin	100 – 160	100 – 150	100 – 175	125 – 175		
Rock (Rolling Cutter)		125 – 200	100 – 200	60 – 125	40 – 60	40 – 150
10 to 13 Inch						
Drag	100 – 175	100 – 300				
Disc		110 – 180				
Zublin	125 – 175	125 – 200	125 – 200	125 – 200		
Rock (Rolling Cutter)		150 – 300	100 – 250	80 – 120	40 – 80	60 – 150
6 to 10 Inch						
Drag	125 – 200	100 – 200				
Zublin	150 – 200	100 – 150	150 – 225	150 – 200		
Rock (Rolling Cutter)		150 – 300	100 – 250	80 – 125	40 – 100	60 – 200

The minimum speeds given are for flat lying strata and certain type bits. The maximum speeds are for flat or inclined formations. The maximum allowable weight may be carried in flat beds and the minimum in steeply dipping strata. Slower and faster speeds than these recommended are useful in specific and more or less unusual cases.

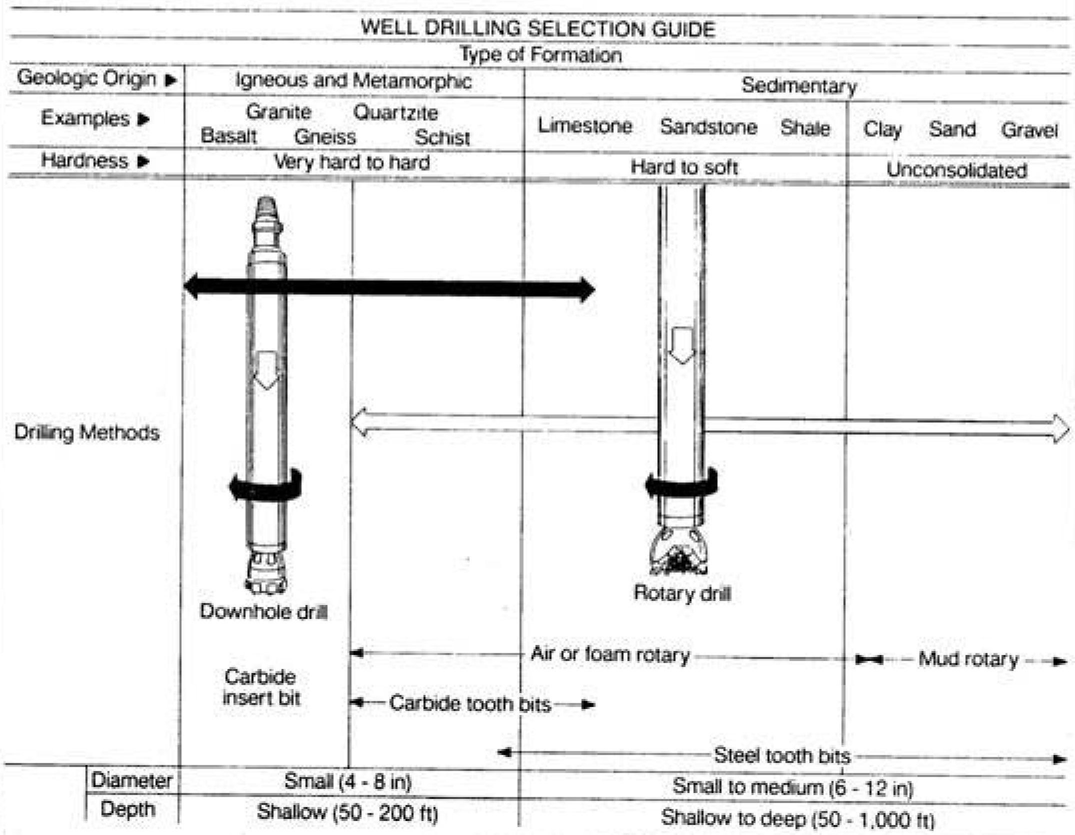
(b) Weight on Bit and Rotary Speed in Various Formations

Bit Classification	Weight per in (2.54 cm) of Bit Diameter lb/in	Weight per in (2.54 cm) of Bit Diameter kg/cm	Rotary Speed rpm
Soft formation	3,400 to 6,750 4,050 to 7,800	609 to 1,210 725 to 1,400	250 to 100 180 to 60
Medium formation	4,500 to 9,000	806 to 1,610	120 to 40
Hard milled tooth bit	5,600 to 11,250	1,000 to 2,010	70 to 35
Hard insert bit	2,250 to 5,600 4,500 to 9,000	403 to 1,000 806 to 1,610	70 to 35 65 to 35
Hard friction bearing bit	4,500 to 6,750	806 to 1,210	60 to 35

Table 3.2-6

Rotary Bits

Source: Driscoll (1986)



Source: Driscoll (1986)

Table 3.2-7

Guide for the Use of Bit Types in Air Drilling Systems

APPENDICES

Appendix	Title	Page No.
A-1	Example # 1 of a Boring Log	55
A-2	Example # 2 of a Boring Log	56
A-3	Example # 3 of a Boring Log	57

Note: These are variations of the same theme. Each one has certain advantages which are not related to a specific drilling technique.

A-1: This log visually shows blows/6-in and is particularly useful if extensive sampling for analysis will take place.

A-2: This log is useful if comments are important and Lower Explosive Limit (LEL) readings will be taken.

A-3: This log is preferred if multiple changes in geology are expected as there is plenty of room for descriptions.

			Boring no:
Client			**Project no:**
Contractor		**Date started**	**Completed**
Method	**Casing size**	**PID**	**Protect'n level**
Ground el.	**Soil drilled**	**Rock drilled**	▽ **Below grnd**
Logged by	**Ch'd by**	**Date**	**Site**

Depth (ft)	PID ambient air	Sample no. and type[1]	Sample	Pen Rec	CLP	GC	PID sample (ppm)	Soil/rock description	Lithologic symbol	Well data	Soil class	Blows/6-in. or RQD % 0 20 40 60 80 100	Elevation (ft)

[1] U = Thin wall tube S = Split spoon R = Rock

Source: ABB-ES

Figure A-1

Example No. 1 Boring Log.

			Boring no:
Project no.	Project name		Page of
Contractor	Driller	Date started	Completed
Method	Casing size	PID	Protect'n level
Ground el.	Soil drilled	Rock Drilled	Total depth
Logged by	Ch'd by	Date	Below grnd

Sample No.	Depth in feet	Blows per 6 inches	Pen/Rec	Description	HNU JAR	Comments on Advance of Boring	Monit'g HNU	Monit'g LEL

Source: ABB-ES

Figure A-2

Example No. 2 Boring Log.

Date
Started ________
Finished ________
Sheet ______ of ____

Hole No. ____________
Surf. Elev. ____________
G. W. Depth ____________

Project ______________________________
____

Location ______________________________
Method of Investigation ____________

Depth (ft)	Samples	Sample No.	Blows on Sampler 0/6	6/12	12/18	N	Blow on Casing C	Soil or Rock Classification	Notes

N = No. blows to drive ______ "spoon ______ "with ______ lb. pin wt. falling ______ "per blow.
C = No blows to drive ______ "casing ______ "with ______ lb. weight falling ______ "per blow.

Classification ____________
____

Source: ABB-ES

Figure A-3

Example No. 3 Boring Log.

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STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.3 BORINGS IN CONTAMINATED AREAS

SECTION 3.3
BORINGS IN CONTAMINATED AREAS

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3.3-3	Contaminated Borings - Drilling with Hollow-stem Augers/Flush-joint Casing	10

3.3 SECTION
BORINGS IN CONTAMINATED AREAS

3.3-1 PURPOSE

A fundamental aspect of most contamination investigations is the delineation of the extent of contamination in soil materials and ground water. Typically, both the horizontal (areal) extent and vertical distribution of the contamination must be defined. Geologic heterogeneities, variations in hydraulic conductivity, and contaminant characteristics will significantly influence the subsurface distribution of the contaminants. Accurate evaluation of contaminant migration and distribution requires the isolation and sampling of specific zones within an aquifer. To ensure the collection of representative samples and to prevent cross-contamination of soils and ground water, special drilling techniques may be required. In some cases, additional precautions must be taken during drilling to prevent contamination of nearby existing or potential water supplies. Protection of the health and safety of workers at contaminated waste sites is discussed in Section 2.3 Health and Safety Plans.

For the purpose of this discussion, "contaminated areas" are defined as highly contaminated source areas (i.e., oil and hazardous materials spills, landfills, waste lagoons, or zones of highly contaminated ground water). The contamination may occur in either the saturated or unsaturated zones or both, depending on the location of the source and length of time the leakage has been taking place. In these areas drilling may alter or mask the existing distribution of contaminants by bridging contamination between aquifers. Some drilling techniques are better suited than others for investigations in contaminated areas. Generally, mud-rotary and air-rotary techniques are undesirable drilling methods in contaminated areas, due to the problem of inadequate control of fluids and cuttings in the borehole and at the surface (see Section 3.2). The most suitable drilling methods for contaminated areas employ casing, either single or multiple, to seal off the overlying strata during drilling. The basic considerations for selecting an appropriate drilling method at contaminated sites are, as follows:

- To prevent cross-contamination or migration of contaminants in the borehole.

- To obtain accurate and representative samples of formation materials and contaminants.

- To introduce a minimum amount of water or fluid into the aquifer, preferably none at all.

- To produce a borehole that does not pose a potential contamination migration pathway when a monitoring well is installed.

- To minimize the safety hazards to the drilling crew, field personnel, workers at and residents of abutting properties.

3.3-2 RECOMMENDED DRILLING METHODS

Because each site is unique in terms of geologic material, ground water characteristics, and types and properties of potential contaminants, the development of the subsurface exploration program may require modification of standard, generally accepted, drilling methods. It is always advisable to plan a drilling program, so that the drilling sequence progresses from the cleaner areas to the more contaminated areas. The drilling methods most generally recommended for application in contaminated subsurface conditions are briefly described in the following subsections.

3.3-2.1 Telescoping Casing

Perhaps the most common method used to prevent cross-contamination in a borehole during drilling is telescoping a smaller casing inside a larger one that has been terminated at some distance below a contaminated zone or at an impervious stratum. Several drilling methods can be used to complete telescoped, multi-cased wells. These methods include cable tool, hollow-stem augers, drive-and-wash, and spun casing. In some situations, where the sampling of overlying contamination is not of interest, mud or air-rotary techniques might be used with prior approval from DEP.

Telescoping methods may use either a temporary or permanent casing. The telescoped casing method requires drilling a relatively large-diameter borehole, installing a temporary casing, and sealing that casing with a bentonite cement mixture. Once the temporary casing is installed and sealed, a second, smaller-diameter casing is set inside the first casing and drilling proceeds from the bottom of the temporary casing through the seal to the desired depth. Casing may be "telescoped" two or three times depending on the number of contaminated zones encountered and the size of the casings. When the boring has been completed to the desired depth, drilling stops. Depending on the site-specific project specifications, the borehole may either be plugged and the casing removed from the hole, or the borehole may be used for the installation of a monitoring well before the casing is pulled. Plugging of boreholes is described in Section 3.9 of these Standard References; well installation is addressed in Section 4.3.

In some applications (e.g., highly contaminated zones above an aquifer that serves as a water supply), initial installation of a permanent casing is preferable. This is a more expensive method, due to the cost of the permanent casing and the time required for installation. As shown in Figure 3.3-1, this method requires a series of steps. First, a pilot hole is drilled to the desired depth, filled with grout, and a permanent casing is installed, as shown in Step 1. In this technique, the pilot hole has a diameter larger than the permanent casing. Once the grout has set up, a second casing is advanced by drilling through the grout plug on the inside of the permanent casing and continuing with the drilling as shown in Step 2 (Figure 3.3-1). As the second casing is removed, the well riser is sealed with grout to the surface. This method produces a double seal through the highly contaminated zone at the surface and into the impervious stratum.

Advantages

- o It is the best technique for minimizing cross contamination.
- o Method is the least expensive technique as the casing is pulled.
- o Multiple casings can be utilized in difficult geological settings.
- o Multiple casings combined with seals provide the best protection against cross contamination.

Disadvantages

- o Method can be expensive if permanent casing into bedrock is left in the ground.
- o Inner casing may jam or bridge inside of outer casing.
- o Casings can be difficult to pull if set at a depth.
- o Casings can be difficult to separate from each other.

3.3-2.2 Hollow-stem Auger/Flush-joint Casing

A combination of hollow-stem augers and flush-joint casing can also be used to complete a boring where the contaminated sources occur above the water table. Large-diameter (i.e., 6- to 8-inch ID) hollow-stem augers can be used to advance the borehole to the top of the water table, or the boundary between the contaminated/clean horizon (as determined by field screening), or to the top of an impervious stratum above the water table.

The borehole would then be advanced beyond this depth with flush-joint casing (i.e., 4-, 5-, or 6-inch OD) that is placed inside the hollow-stem augers. The flush-joint casing can be advanced with standard drive-and-wash techniques. Standard soil samples can be obtained with either method. A schematic of this drilling method is presented in Figure 3.3-3. It is recommended that (1) all casing be flush-joint, threaded steel; and (2) that the flush-joint casing should be driven through the remaining portion of the impervious strata to minimize the potential for cross-contamination. If spun technique is required, a second telescope can be placed inside the driven casing.

In this drilling method, the augers would not penetrate below the contaminated zone, except to reach the top of an impervious stratum above the water table. Therefore (1) the contaminants would not be smeared or dragged down or up by the augers, and (2) monitoring well installations would not be compromised by the auger methodology. Installation of telescoped casing inside a hollow-stem auger has the following advantages and disadvantages:

Advantages

- o Water would not be required near highly contaminated surface zones.
- o Casing can be spun into bedrock, if desired.
- o Contaminated zones at greater depths can be isolated by additional telescoping of flush-joint casing.
- o Standard soil samples can be collected.

Disadvantages

- o Inner casing may jam or bridge inside augers.
- o Introduction of water during drilling is required when using inner casings.

3.3-3 DISPOSAL OF DRILLING SPOILS

Another significant consideration when drilling in contaminated areas is the disposal of drilling spoils that may include water as well as soil. Efforts should be made to minimize the amount of material that is removed from the contaminated area and the amount of equipment or water that comes in contact with the contaminants. If a site is highly contaminated, drill cuttings and fluids must be containerized, screened for chemical contaminants, and, in some cases, manifested as hazardous waste. In designing a drilling program for a suspected or known oil or hazardous material disposal site, consideration should always be given to minimizing the amount of waste material produced, as its disposal can result in logistical problems during drilling and substantial costs for disposal. For these reasons, auger or casing techniques are often preferred over drive-and-wash techniques because liquid drilling spoils are more difficult to contain.

3.3-4 DECONTAMINATION OF EQUIPMENT

Decontamination of equipment used to collect samples is essential in order to maintain the integrity of the chemical data from different sampling locations. In general, decontamination should provide for adequate cleaning of the drilling and sampling tools for the particular contaminants found at a specific site. Different chemicals or mixtures of chemicals will require the use of different cleaning methods or compounds.

The method or compounds selected for decontamination should fully remove site contaminants from the sampling equipment without interfering with the specific chemical analysis for that site. The method of choice should also consider the site and weather constraints.

In general, decontamination usually is a sequential procedure beginning with a water rinse, detergent wash/steam cleaning, solvent and/or acid/base wash and final deionized or potable water rinse. If wash/rinse steps are conducted in containers (i.e., buckets, drums, etc.), the solutions should be changed between each boring or sample location to prevent cross-contamination. Based on the anticipated contaminants at a specific site, the choice of decontamination methods and compounds may consist of the following:

- o Potable water rinse.
- o Detergent (i.e., liqui-nox which is biodegradable or Alconox which is biodegradable and phosphate-free) wash followed by potable or distilled water rinse.
- o Steam cleaning.
- o Low strength organic solvent (i.e., methanol/ethanol/alcohol) wash followed by water rinse.
- o High strength organic solvent (i.e., hexane/freon) wash followed by water rinse.*
- o Common petroleum product (i.e., fuel oils, kerosene, gasoline) wash followed by detergent wash and water rinse.*
- o Acid/base wash followed by water rinse.

*Decontamination solutions require special handling.

More than one method or compound may be used in series for a particular site. Section 6.5 of the Standard References describes the choice of decontamination methods in terms of the required test parameters. In extreme cases, disposable equipment is recommended over decontamination because the level of effort and costs required to adequately clean the equipment and dispose of the decontamination solutions may not be warranted.

3.3-4.1 Cleaning the Drill Rig

All drilling equipment should be decontaminated prior to arriving at the site. An inspection of the equipment should be made prior to moving onto the site. It is essential that all parts of the drill pipe, drive head, tracks, or wheels be thoroughly cleaned at the site before starting work. The drill rig and attached equipment should be thoroughly steam-cleaned between contaminated borings. If necessary, the equipment should be scrubbed to loosen packed-on materials. Those parts of the drill rig that do not come in contact with the well installation or sampling equipment should be cleaned as necessary between borings. Vehicle wheels and tracks should be checked and cleaned between borings to prevent the spreading of contaminated soil and liquid around the site. At the completion of the exploration program, the drill rig and attached equipment should be decontaminated prior to leaving the site.

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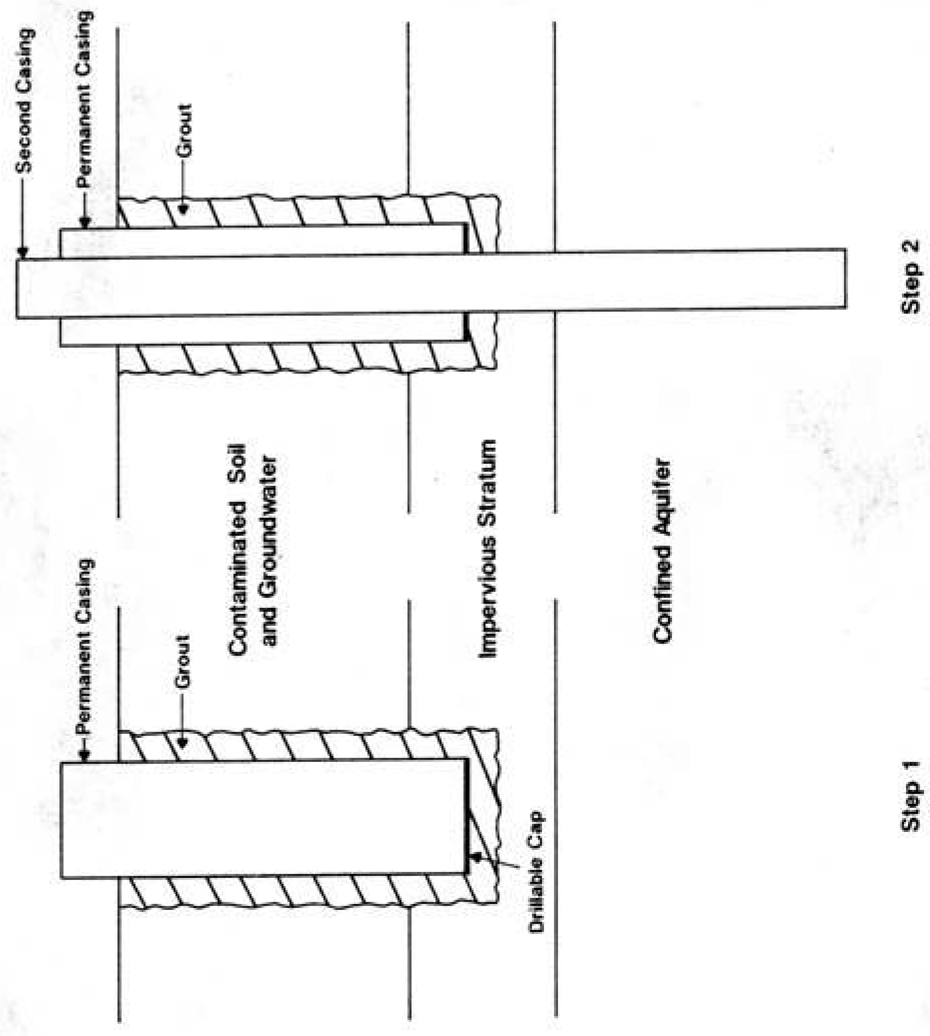

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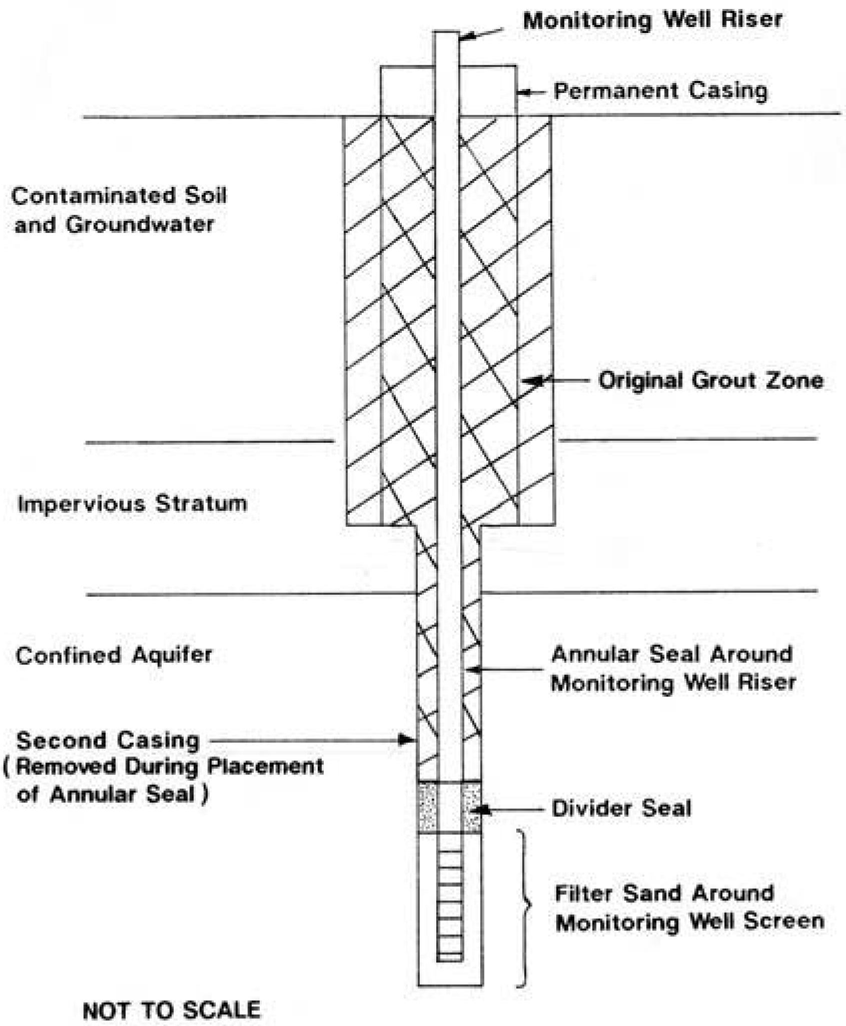
Source: MADEP

Figure 3.3-1. Telescoped Casing Method.



Source: MADEP

Figure 3.3-2

Monitoring Well Installed with Telescoped Casing Method.

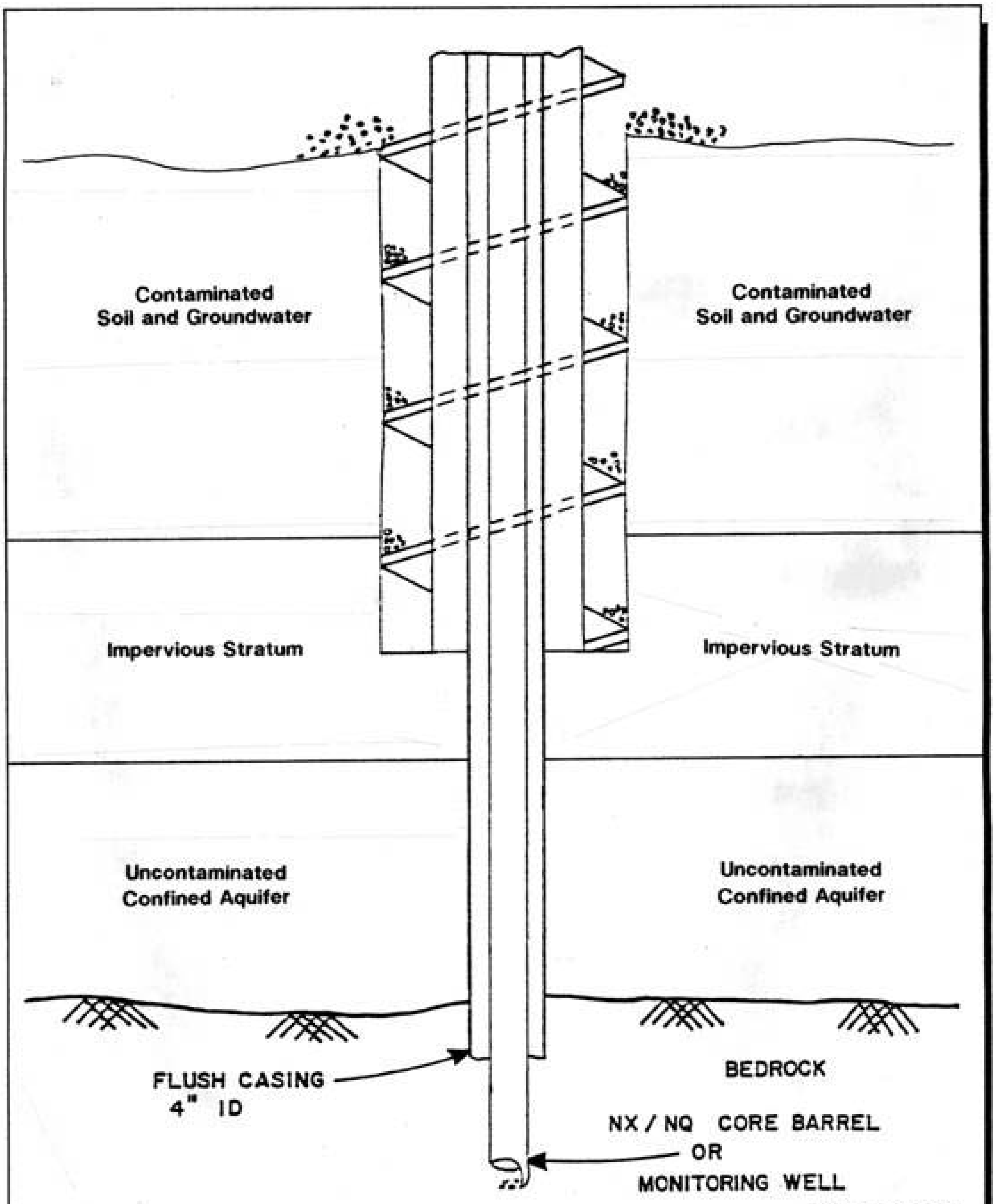


Figure 3.3-3

Source: MADEP

Contaminated Borings - Drilling with Hollow-stem Augers/Flush-joint Casing.

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STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.4 IN-SITU SAMPLING OF SOIL

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3.4 IN SITU SAMPLING OF SOIL

3.4-1 PURPOSE

Considerable variability exists in methods used to obtain soil samples by both different individuals and by a single individual, particularly when an established procedure is not available for reference. The purpose of this Standard Reference (SR) is to provide methods and procedures for the collection of soil samples that will reduce variability and encourage continuity in sample collection protocols by samplers.

Soil is a natural unconsolidated aggregate of mineral grains that is formed as the result of chemical and physical weathering of consolidated rock formations. It is sampled to obtain a specimen (disturbed or undisturbed) that is representative of a particular subsurface stratum. It can be sampled for chemical analysis, geotechnical analyses, and geologic classification. Selection of a specific sampling technique is dependent on the objectives of the environmental assessment. For example, while some projects may require a detailed sampling program to quantify a deep source of contamination, other projects may require characterization of only the uppermost surficial soils for clean-up of a recent spill. Characterization of extensive contamination may require collection of samples from multiple depths. The selection of site-specific soil sampling techniques may be influenced by one or more of the following factors:

- Purpose of exploration.
- Depth of soil to be sampled.
- Anticipated subsurface soil types and conditions.
- Engineering properties to be determined.
- Depth to the water table.
- Degree and types of contamination anticipated, if any.

Once the method of exploration (e.g., test pit, boring, or hand auger) has been determined, the sampling methodology required to provide appropriate specimens for analyses should be selected. Soil sample methodologies fall in to two broad categories:

- Disturbed Samples
- Undisturbed Samples

This SR describes sampling devices and procedures for the collection of both disturbed and undisturbed samples at sites that are presumed to be either uncontaminated or contaminated. It has become an increasingly accepted field procedure at contaminated sites to screen soil samples with a photoionization detector (PID) to check for the presence of volatile organics. While many sampling devices are available to collect soil samples, this section provides SRs only for those devices most commonly used in environmental assessment work. Other devices, traditionally used for geotechnical engineering studies, are only listed here. SRs for engineering studies are outside the scope of this section and are not included.

For the purpose of conducting environmental testing, the following factors should be considered in selecting the sampling method:

- Representativeness
- Sample suitability for selected analysis
- Ease of operations
- Flexibility
- Practicality
- Safety
- Budget
- Requirement for decontamination

The significance of these factors will be determined by the purpose and objective(s) of the sampling plan and the type of environmental assessment to be conducted.

The following sections describe various methods and equipment used to obtain representative samples and some of the constraints upon their use. Decontamination of sampling equipment is not included in this section; it is discussed in Section 2.3 and 6.0.

3.4-2 DISTURBED SAMPLES

A disturbed sample is a representative sample of a selected geologic unit that has undergone structural alteration as a result of the sampling operation. These types of samples can be used for soil classification, soil index testing, and analytical testing purposes. Disturbed samples obtained from borehole cuttings may not be representative of in-place strata and, therefore, are only suitable for general lithologic identification.

Soil samples may be either discrete or composite. A discrete sample represents a single location within the soil column; it must be used for all volatile organic analyses. A composite sample represents a mixture of soil from more than one discrete location. If a composite sample is to be obtained, it can be mixed in a shallow high density polyethylene pan, lined with aluminum foil, or in a stainless steel pan. Stainless steel sieves may be used to remove larger rock fragments (see Figure 3.4-1). Such compositing procedures are not appropriate for samples obtained for analysis for volatile organic compounds because the agitation of the sample results in a loss of volatiles from the sample.

Soil sampling devices used to collect disturbed samples are separated into two groups, differentiated by the depth of sampling:

- Surface and shallow subsurface soil sampling
- Borehole soil sampling

3.4-2.1 Surface and Shallow Subsurface Soil Sampling

Surface and shallow subsurface soil sampling is generally done using manually operated sampling equipment. Depending on the subsurface conditions, this method is limited to approximately 20 feet of the soil. In some cases backhoes can be used to make excavations to depths of more than 20 feet. Soil sampling devices and equipment that can be used to obtain surface and shallow subsurface soil samples include:

- Cleaned or disposable scoops, hand trowels, and shovels
- Slotted sampling trier
- Hand auger
- Backhoe buckets
- Plastic syringes

3.4-2.1.1 Scoops, Hand Trowels, and Shovels

The practical sample depth of scoops, hand trowels and shovels ranges from the surface to about two feet.

(a) Advantages

- Ease of use.
- Easy to decontaminate.
- An inexpensive method to collect samples at or near the ground surface.

(b) Disadvantages

- Limited depth of sampling.
- Difficult or impossible to use in frozen ground.
- Difficult in gravelly soil.

(c) Procedures for Use

(1) Carefully remove the top layer of soil to the desired sample depth with a clean tool.

(2) If applicable, screen the area to be sampled using a organic vapor analyzer and record readings in the field log. The PID screen is used as a field safety procedure as well as for selecting potentially contaminated soil samples.

The soil readings should be compared to action levels presented in the project Health and Safety Plan (see Section 2.3). The operator of the PID must be experienced in its use and aware of the effect of factors such as temperature, humidity, or methane affecting the instrument readings.

(3) Using a clean tool, remove and discard a thin layer of soil from the area that came in contact with the shovel.

(4) Obtain a discrete soil sample using a stainless steel lab spoon or its equivalent. Place the sample into a sterile wide-mouth glass soil sample jar with screw on cap. In addition to analytical samples, a reference sample considered representative of the soil may also be collected and stored in a glass jar for future use.

(5) Check that a teflon liner is present in the cap of all analytical sample jars, if required. Secure the cap tightly. Although chemical preservation of solids is generally not required, the samples should be refrigerated and analyzed within specified holding times.

(6) Label the sample bottle with the appropriate sample tag. Be sure to label the tag carefully and clearly using indelible ink. Complete all chain-of-custody documents and record in the field log book. Use of pre-labelled bottles aids greatly, particularly if gloves are being worn or weather conditions are adverse.

(7) Decontaminate equipment after use and between sample locations. Also decontaminate sample containers and/or isolate them (such as sealing in Ziploc bags).

3.4-2.1.2 Soil Sampling Tube

This sampler is useful within a depth range of two and one-half to three feet, depending upon soil conditions. Samplers range in diameter from one to two inches. A soil sampling tube allows for visual inspection of the specimen or screening with a PID before it is placed into a sample container. An example of a soil sampling tube is shown on Figure 3.4-2.

(a) Advantages

- Ease of use.
- Limited disturbance of ground surface.
- Inexpensive method for collecting shallow soil samples.

(b) Disadvantages

- Limited depth of sampling.
- Difficult to use in hard or frozen ground.

- o Difficult to use in gravelly or filled soils.

- o Lack of sample retention with dry, clean sandy soils.

(c) <u>Procedures for Use</u>

(1) Make certain that the soil sampling tube has been decontaminated in accordance with project-specific requirements.

(2) Align the sampler in the desired orientation and advance into the soil using a constant pressure until the desired depth is achieved and/or an obstruction is encountered.

(3) Rotate the sampler 360 degrees by turning the handle and then slowly withdraw the sampler.

(4) If applicable, immediately screen the sample for volatile organic compounds using a PID after the sampler is removed from the ground. The most effective way to screen the sample is to place it in a soil sample jar, leaving one to two inches of clearance in the jar. Place the lid on the jar, shake the sample, carefully remove the lid, and test the headspace for VOCs.

(5) Compare PID readings to action levels presented in the project Health and Safety Plan. The operator of the PID must be experienced in its use and aware that factors such as temperature, humidity, and methane may affect the readings.

(6) Obtain samples (discrete or composite) and place in appropriate containers.

3.4-2.1.3 Hand Auger: Solid-stem Auger

Hand augers are effective in obtaining soil samples to depths of about five feet. The auger diameter ranges from 1.5 inches for a solid-stem auger to 8 inches for a hollow or bucket auger (see Figure 3.4-3).

Exploration with solid stem augers precludes the use of a separate soil sampling device. Soil samples are obtained either from cuttings brought to the ground surface by auger flights or directly from the auger after it has been withdrawn from the borehole. This sampling technique does not provide discrete samples.

(a) Advantages.

- o Ease of use.
- o Inexpensive method to obtain shallow soil samples.
- o Minor disturbance of ground surface.

(b) Disadvantages.

- o Does not yield a representative sample from discrete depth; sample obtained from auger flights.
- o Difficult to penetrate coarse, granular soils.
- o Rotation of auger up and down hole may result in cross-contamination of soils.
- o VOCs are not representative as volatilization may take place.

(c) Procedures for Use

The general procedure for advancing a hand auger exploration is discussed below.

(1) Decontaminate all hand auger equipment in accordance with project requirements.

(2) To make a hand auger borehole, attach the auger bit to a drill rod extension, and attach a "T" handle to the drill rod.

(3) Clear the area to be sampled of any surface debris (twigs, rocks, of litter). It may be necessary to remove the first three to six inches of surface soil for an area approximately six inches in radius around the auger location.

(4) Begin augering by pressing down on the handle while manually rotating the auger stem. Periodically remove soil

cuttings that accumulate on the ground around the auger stem. This will prevent loose material from falling back down into the borehole when removing the auger or adding drill rods. If necessary, cuttings should be screened for volatile compounds (VOCs) with a photoionization meter (PID) or for other parameters, as appropriate.

(5) Compare PID readings to action levels presented in the project Health and Safety Plan. The operator of the PID must be experienced in its use and aware of such factors as temperature, humidity, and methane on the readings provided by the PID.

(6) After reaching the desired depth, carefully remove the auger from the hole.

(7) To obtain a soil sample, remove the tip from the auger and replace it with a decontaminated sampler. (Note: When sampling directly from the auger, collect the sample after the auger is removed from the boring and proceed to Step 10).

(8) Carefully lower the sampler down the hole. Gradually force the sampler into the soil. Care should be taken to avoid smearing the borehole sides. Hammering of the drill stem to facilitate sampling should be avoided as the vibrations may cause the walls to collapse.

(9) Remove the sampler and unscrew the rods, if necessary.

(10) Place the soil sample in a decontaminated stainless steel tray and screen with a PID for VOCs. Place the soil to be analyzed into an appropriate container.

(11) Decontaminate sampling equipment after use and between sampling locations, as necessary.

3.4-2.1.4 Hand Augers: Hollow-stem Auger

Exploration using a hollow-stem auger is similar to that for a solid stem auger except that the bottom section of the auger is designed to retain a sample of soil as the auger is advanced. As a result, the borehole is advanced in intervals equal to the length of the hollow-stem auger section.

(a) Advantages

- Ease of use.
- Inexpensive method to obtain shallow soil samples.
- Minor disturbance of ground surface.

(b) Disadvantages

- o Difficult to penetrate coarse, granular soils.
- o Sampler section needs to be decontaminated between sample collection.
- o Potential for contaminated soils to fall from the walls of the hole as the augers are removed or reinserted into the hole.
- o Lack of sample retention in saturated sands and other loose soil materials.
- o Not good for discrete depth samples.

(c) Procedures for Use

See Solid Stem Auger section on procedures (3.4-2.1.3)

3.4-2.1.5 Hand Augers: Bucket Auger

The bucket auger is advanced in the same way as the hollow-stem auger. The bucket auger makes a larger diameter hole (e.g., 3- to 4-inch diameter) than the hollow-stem hand auger. It can be advanced to depths of 10 feet.

(a) Advantages

- o Ease of use.
- o Inexpensive method to obtain shallow soil samples.
- o Minor disturbance of ground surface.
- o Can be used to sample discrete depth intervals.

(b) Disadvantages

- o Difficult to penetrate coarse, granular soils.
- o Sampler section needs to be decontaminated between sample collection in contaminated areas.
- o Potential for contaminated soils to fall from the walls of the hole as the augers are removed or inserted in the hole.

(C) Procedures for Use

See Solid Stem Auger section for procedures (3.4-2.1.3)

3.4-2.1.6 Backhoes

The standard procedure for making test pits or trenches with a backhoe and the collection of soil samples from them is presented in detail in Section 3.1 Exploratory Test Pits.

3.4-2.2 Borehole Sampling

Boreholes are used when it is necessary to obtain representative soil samples at depths greater than 15 to 20 feet (beyond small to medium-sized backhoe reach) or when soil conditions or subsurface contamination suggests the use of a more discrete technique. Boreholes can be advanced using several different techniques, with casing or hollow-stem augers being the most commonly employed techniques. Section 3.2 Drilling Techniques presents a detailed discussion of the various techniques used to drill a borehole. Disturbed soil samples obtained from boreholes are most commonly collected using the following techniques and devices:

- o Split-spoon and Split-tube Samplers
- o Cuttings Sampling

3.4-2.2.1 Driven Split-spoon and Split-tube Samplers

The primary device for obtaining a disturbed soil sample, considered representative of the material from which it is obtained, is the split-spoon sampler. Samples obtained using this device are suitable for physical and environmental laboratory analyses. Further, when the split-spoon sampler is driven in accordance with the Annual Book of ASTM Standards, Standard Penetration Test (D 1586-84), blow count data may be used as an index of soil density or consistency.

The split-spoon sampler consists of a steel tube split longitudinally, equipped with a ball check valve in the head for venting, and a hardened steel shoe for driving, see Figure 3.4-4. When the head and shoe are removed, the split-barrel opens into two halves exposing the entire sample. The split-spoon is driven into the soil at the bottom of the borehole. The recovered sample is then described, and removed for classification and preservation. The split-spoon sampler is available with inside diameters ranging from 1.5 to 4.5 inches in 0.5-inch increments. It is also available in barrel lengths of 18 inches to 60 inches. The most commonly used split-spoons are 1.5 inches inside diameter with barrels that are 18- or 24-inches in length. The ASTM Standard Penetration Test requires the use of the 1.5-inch inside diameter spoon. Various baskets, sleeves or "trap doors" can be added to the sampler to assist in the retention of the sample during the recovery process.

(a) Advantages.

- o Readily available.
- o Easy to decontaminate.
- o Used to sample to depths exceeding 100 feet.
- o When driven in accordance with ASTM D 1586-84, the data can be used to establish geotechnical engineering parameters such as soil density or consistency.
- o Better soil recovery than hand methods.

(b) Disadvantages.

- o Lack of sample recovery in very dense or coarse gravel material.
- o Limited soil volume from discrete depth intervals.

(c) Sampling Intervals

Split-spoon samples are generally collected continuously or at every change of stratum or at 5-foot intervals. The sampling frequency should be designed to meet the required sampling objectives.

The sampling interval shall be determined on a project-by-project basis. A sufficient number of split spoons must be available at the borehole so that necessary decontamination of spoons does not excessively delay drilling. On the other hand, since obtaining the soil samples is the purpose of the exploration, drilling rates should never hurry soil logging or sample collection to the point where data quality is compromised. The drill inspector/geologist must control the situation.

(1) Continuous Sampling

Advantages

- o Allows the complete soil interval to be observed and/or screened.
- o Provides a near continuous vertical sample of the soil column sampled.
- o Can detect soil or contaminant variations that might be missed by less frequent sampling intervals.

o

Disadvantages

- o Slower rate of sampling with depth.
- o Increasing cost per sample with increasing depth.

(2) 5-foot Intervals

Advantages

- o Less expensive than continuous sampling.
- o Appropriate for relatively homogeneous soil conditions.

Disadvantages

- o May not yield enough detailed geologic information in complex deposits.
- o May miss important stratigraphic or contaminant variations.
- o Poor recovery from successive samples may yield insufficient data to characterize large vertical intervals of soil.

(d) Procedures For Use

(1) Advance the casing/augers to the required sample depth using one of the techniques described in Section 3.2 Drilling Techniques.

(2) Decontaminate all split-spoon sampling equipment in accordance with the project-specific quality assurance plan (see Section 6.1).

(3) After the borehole has been advanced to the desired sampling depth, assemble the sampler and lower it carefully to the bottom of the hole.

(4) With the split-spoon sampler set at the bottom of the hole, mark the drill rod at consecutive six-inch intervals for measuring the blows per six inches of driving. The drill rods are marked with reference to a common datum. Be certain that the bottom of the hole is at the bottom of the casing. If the sampler is not at the bottom of the casing, it should be withdrawn and the hole cleaned out again.

(5) Obtain samples by using the standard penetration test (SPT) which determines the driving resistance within the zone sampled. Drive the sampler using a 140-pound hammer with a vertical free drop of 30 inches.

Check that the vertical free drop is 30 inches by marking the drive head. The driller should use no more than two wraps of the rope around the cathead. (A cathead is a rotating horizontal drum with flanged edges. When tension is put on a rope around the cathead, the rope tightens on the drum and can be used to lift a 140 or 300 lb weight.) Be certain that the rope is fully released to permit completely free fall of the hammer. The number of blows to drive each six-inch interval should be recorded. Drive the sampler at least 18 inches, unless refusal as defined in the project specifications, is met. Samples up to 24 inches in length may be collected with appropriate sampling equipment.

(6) After driving the sampler, the drill rods may have to be turned clockwise to free them from the soil and to permit retrieval. Carefully retrieve the sampler to avoid unnecessary banging or vibration of the drill rods as these actions may cause soil to fall out of the sampler. Avoid bumping up the rods with the hammer. As an alternative to bumping the sampler free from very dense soils it is sometimes necessary to use the drill rig's hydraulic capability to pull the rods. Where washed borings are being used, the casing must be kept full of clean water at all times. This will require adding water while the rods are being withdrawn prior to sampling and when the sampler is withdrawn. The addition of water to hollow-stem augers may also be required. Where soil samples for chemical analysis are to be obtained, the water supply should be uncontaminated and verified by a sample of the field screening with a PID periodically and collecting at least one sample for chemical analyses as identified in the project work plan. (This subject is more fully discussed in Section 6.0.)

(7) When the sampler is brought to the ground surface, open it immediately, scan for VOCs using a PID, measure the length of recovery and enter significant sample data in the field book and on the boring log (see Figure 3.4-5). Loose wash at the top of the sample should not be counted as part of the recovery.

(8) Adequate recovery will be defined by the site-specific sampling plan or by the project geologist/engineer. If recovery is determined by the geologist/engineer to be insufficient, place the sampler back down the hole and advanced as follows: if the original depth is reached, drive the sampler an additional 18 inches and record the blows as a new sample; if the original depth is not reached, redrive the sampler to recover disturbed material. Record only the original blow count and note that the sample was redriven.

3.4-2.2.2 Auger-advanced Split-tube Sampler

In recent years, a split-tube sampler has been developed that fits into the bottom 5-foot section of a hollow-stem auger drill string. With this method, as the augers are advanced, the split-tube "cores" the soil for each 5-foot run. Assuming 100% recovery, this device will yield a 2½ to 3½-inch diameter by 5-foot long slightly disturbed soil sample; this is about 1-inch less than the hollow-stem auger I.D. The sampling procedure is shown on Figure 3.4-6. The procedures to be used to collect split-spoon samples by this technique follow.

(a) Advantages

- o Less expensive since sampling occurs simultaneous with drilling.
- o Very efficient in relatively homogeneous soil conditions.
- o Can chemically screen five-foot wide samples.

(b) Disadvantages

- o Sample can become disturbed during augering making geological interpretation difficult.
- o May not yield detailed geological information in complex deposits.
- o Poor recovery from successive samples may yield insufficient data to characterize large vertical intervals of soil.

(c) Procedures for Use

The procedure for use of the auger-advanced split-tube sampler is the same as for the driven split-spoon sampler described above in Section 3.4-2.2.1(d) except for four steps (i.e., where the sampler is placed in the borehole and advanced). Follow the steps described in the previous subsection for (1) and (2).

(3) After the augers have been advanced to the sample depth, remove the auger plug and lower the decontaminated 5-foot long split tube and lock it into the bottom 5-foot section of the auger.

(4) Place a 5-foot section of augers on the top of the drill stem and secure it to the drill head. A stroke of 5-feet is then marked on the drill head guide bars.

(5) Advance the auger at a slow, smooth rate until the 5-foot stroke is complete or an obstruction is encountered.

(6) After the advance of the auger is complete, release the drill head from the augers and retrieve the split-tube sampler from the borehole.

(7), (8), (9), (10), (11), (12), (13), and (14) follow the steps described in the previous subsection (3.4-2.2.1(d) 1 through 8).

3.4-2.2.3 Sampling Borehole Cuttings

An alternate, through less desirable method of obtaining a soil sample during drilling is from cuttings generated by wash water used to remove soil from inside a casing or from cuttings brought to the ground surface on auger flights. Samples collected in this manner are not suitable for physical or environmental analysis because of their non-representative nature. Information from cutting samples should only be used to supplement information between the intervals where representative samples are collected. Although samples collected from cuttings are not acceptable for physical or environmental analysis, a discussion of two methodologies is included for reference purposes.

(a) Wash Sampling

The term "wash boring" refers to the technique of advancing a hole by using a stream of water under pressure to remove the cuttings produced by the rotation or chopping action of the drill string. As the hole is advanced, the soil is washed to the surface where it can be caught, decanted, and saved as "wash samples" or "wet samples". Borehole cuttings of this type will give a very general picture of the subsurface conditions, but intermixing of the various strata may lead to erroneous interpretations. An estimate of the depth (or range of depth) from which the sample was obtained can be recorded on the log sheet. Much of the finer fraction will not settle out. The resulting sample will have a coarser gradation than this in-situ soil.

(b) Auger Cuttings

Auger cuttings are produced as the borehole is advanced and the auger flights transport material upward to the ground surface. Auger cuttings are reworked and the depth from which cuttings observed on the ground surface originated cannot be accurately determined. Obvious changes in auger torque or vibration may indicate changes in strata. Where geology is complex and/or critical for site characterization, this information should only be used to supplement other direct determinations of geologic characteristics.

3.4-3 STORAGE OF DISTURBED SOIL SAMPLES

When taking soil samples for environmental analyses, remove the disturbed soil samples from the sampler and place in appropriate containers. Trim the soil core after sampling so that samples can be taken from the bulk of the core rather than the surface. A single split-spoon core may provide for more than one individual sample depending on conditions encountered and lithologic changes.

3.4-3.1 Containers for Soil Samples

Representative samples to be used for physical laboratory testing and/or soil description purposes shall be placed in large mouth, round, screwed top, air-tight, clear glass jars. Typically, the size of the jars should be 8 ounces for 1-3/8-inch diameter samples and 12 ounces for 2-1/2-inch diameter samples. After environmental samples have been obtained, place the remaining specimens in air-tight jars so that the original moisture content may be preserved. The jars should be tightly capped, waxed, and suitably boxed, marked, and identified with legible labels, as directed by the geologist/engineer.

3.4-3.2 Data for Labels and Field Book

The label information should be placed on a gummed printed label that can be affixed to the jar not to the cap. Use of clear acetate tape over the label is recommended to doubly secure the label and protect the information thereon. In addition, label the jar lid with the project number, boring number, number of sample, and depths at top and bottom of the sampling interval. A labeled jar often is prepared for every sample attempted, even if there is no recovery. Place jar samples should into containers, such as cardboard boxes, with dividers to prevent movement and breakage of the jars. Label the boxes on the top and four sides to show the project number and name, the identification of the samples contained in the box, and the depth from which the samples were taken.

If all of the soil recovered is to be collected and saved, place samples into jars in six-inch increments or, where lenses or layers are clearly evident, separate the material types into different jars. Each six-inch increment or individual layer of a sample should be assigned a letter suffix, beginning with "A" at the bottom of the sample. Figure 3.4-7 shows sample selection based on individual layers while Figure 3.4-8 is based on 6-inch increments in a uniform material. If only six inches of a sample is recovered, this would be given the suffix "A". This information should also be noted on the boring log.

Sample information to be included on sample labels and in boring logs and field books should include the following information:

- Project name and number.
- Boring number.
- Depths at top and bottom of sample interval.
- Number of sample.
- Number of blows for each six inches of penetration (blow counts).

- Organic vapor analyzer results.
- Date of sampling.
- Other project-specific information (field book only).
- Recovery in inches (field book only).

3.4-3.3 Storage and Shipment

Protect representative jar samples from the weather, including excessive heat and freezing temperatures. If the representative samples are contaminated, evidence tape or custody seals should be placed across the jar lids. For commercial shipment of contaminated samples see Section 6.3.

Initiate proper procedures for delivery to the designated laboratory when all samples have been collected. This includes packaging, shipping with sample logs, analysis request forms, and chain-of-custody forms.

Indicate the type of material on the boring log and described in accordance with the Annual Book of ASTM Standards using the Modified Burmister classification, Unified Soil Classification System (D 2487-66 and D 2488-69), or DEP approved-equivalent.

3.4-4 REPRESENTATIVE "UNDISTURBED" SOIL SAMPLES

Relatively "undisturbed" samples have traditionally been collected for the purpose of determining specific geotechnical engineering properties of soils through special laboratory tests. Relatively undisturbed samples of soil can be obtained using samplers equipped with thin-walled tubing or by block samples. Thin-wall tube samples are obtained from boreholes and, as a result, can be collected at various depths. Block samples are commonly collected from test pits or trenches and, as a result, are generally shallow, less than 20 feet. A description of appropriate procedures for each method of collection follows.

3.4-4.1 Thin-Wall Tube Samples

This collection technique consists of pressing thin, seamless tubing into cohesive soils of soft consistency for observation and laboratory testing. Although loose, fine-grained granular soils may be sampled with this method, sample retention is a problem even if the sampler device is equipped with a piston that creates a vacuum to help retain the sample in the tube. It is more easily used in non-granular, fine-grained material, such as silt or clay.

The thin-walled tubing, more commonly referred to as Shelby tubes, may be any thin-wall tubing with a tapered cutting edge. The sides of the tube are drawn in slightly to reduce sample friction against the wall of tube during penetration (See Figure 3.4-9). The tubes are usually cut in 2- to 3-foot lengths and coated with a lacquer or other rust-preventative solution. Uncoated tubes made of stainless steel or brass are also available, if desired. Tube materials and coatings compatible with project testing requirements should be selected.

Standard dimensions for thin-wall tubing are summarized in Table 3.4-1.

The thin-wall tubing may be used with a variety of sampling devices to obtain representative and relatively undisturbed samples. As with any sampling device or method, variations in design, operation, and ability to recover the sample is dependent upon the characteristics of the materials being sampled. Standard guidelines for thin-wall sampling (D 1587-83) have been established in the Annual Book of ASTM Standards, 1988. Detailed procedures are also included in the U.S. Bureau of Reclamation "Earth Manual".

Numerous thin-wall tube samplers are available, including:

- Open-drive sampler
- Piston sampler
- Stationary fixed piston sampler
- Floating piston sampler
- Retractable piston sampler
- Hydraulic (Osterberg) piston sampler
- Bishop sand sampler
- Swedish foil sampler
- Hvorslev sampler

The samplers most commonly used in Massachusetts to obtain tube samples of cohesive and/or fine-grained soils are:

- Open drive sampler
- Stationary fixed piston sampler
- Hydraulic (Osterberg) sampler

The other samplers noted are not recommended at this time because of the potential for excessive sample disturbance and/or lack of experience and familiarity in Massachusetts.

3.4-4.1.1 Open-drive Sampler

This device consists of a sampler head to which a thin-wall tube is fastened. The sample is obtained by pressing the open tube into the desired stratum at the bottom of the borehole. This sampler does not use any sample retention devices, although the sampler head is equipped with a ball check valve and vents that relieve air and water pressure buildup within the tube as it is pressed into the soil, they also prevent water pressure buildup when the sampler is pulled to the surface. (See Figure 3.4-9). Excessive penetration of the sampler under the weight of the rods may occur in very soft or loose materials, preventing accurate measurements of depth of penetration and causing disturbance of the material.

(a) Advantages

- o Simple to use.
- o Commonly available.
- o Easy to decontaminate sampler head.
- o Short amount of time required for sampling.

(b) Disadvantages

- o Disturbed and intermixed soil materials from the bottom and sides of the borehole may enter the tube as it is lowered into position, if the borehole is not cased.

- o Total or partial sample recovery is difficult without a supplemental retention system.

- o Hydrostatic pressures may disturb the sample during penetration or totally prevent the sample from entering the tube.

(c) Procedures for Use

See Procedures used to collect Thin-Wall Tube samples (3.4-4.1.4)

3.4-4.1.2 Stationary Fixed Piston (SFP) Sampler

This sampler employs the use of a sealed piston to reduce sample disturbance. Sample recovery is improved compared to the open-drive sampler (see Figure 3.4-10). The piston is prevented from moving downward by a locking cone in the head assembly. The piston can be locked and fully sealed at the bottom of the thin-wall tube so that it can be lowered into the borehole without collecting unwanted soil material.

Once the sampler is in position, the piston, through a series of small-diameter, inner actuating rods, is locked to the drill rig or the casing. Pressure is applied to the outer drill rods, forcing the thin-wall tube down from the "stationary" piston. When the full press is completed (24 inches), any pressure buildup is released through a small hole in the actuating rods. The tight seal of the piston also creates a vacuum on the sample that aids in sample retention.

(a) Advantages.

- o Reduced potential for sample disturbance.
- o Improved sample recovery.
- o Commonly available with considerable local experience in its use.

(b) Disadvantages.

- o More complex than open-drive sampler.
- o Requires more time to sample.
- o More parts to decontaminate at contaminated sites.

(c) Procedures for Use

See procedures used to collect Thin-Walled Tube samples (3.4-4.1.4)

3.4-4.1.3 Hydraulic (Osterberg) Piston Sampler

The hydraulic piston sampler is designed to obtain undisturbed samples of soft soils and soils that experience significant loss of strength as a result of disturbance. The design of the movable piston sampler varies considerably from the stationary piston sampler, the movable piston sampler consists of an inner thin-wall sampler tube and outer pressure cylinder, (See Figure 3.4-11). In the sampling position, a movable piston is attached to the top of the sampling tube and a stationary piston rests on the soil to be sampled. The sampler is activated by pumping fluids or gas through the pressure cylinder, which drives the upper piston and sampling tube down over the lower piston into the soil for a fixed distance. The piston is then withdrawn from the borehole with the sample. This frequently consists of a blade type drill bit with fluid deflectors.

(a) Advantages.

- o Easier to use than the stationary fixed piston (SFP) sampler.
- o Improved sample recovery.
- o Available, with considerable local experience.
- o Less time required than the SFP to obtain a sample.

(b) Disadvantages.

- o More time to decontaminate than for other samplers.

(c) Procedures for Use

See procedures to collect Thin-Walled Tube samples (3.4-4.1.4)

3.4-4.1.4 Procedures Used to Collect Thin-wall Tube Samples

The following steps are applicable to all thin-wall tube sampling:

(1) Advance the casing/augers to the required sample depth using the procedures described in Section 3.2, Drilling Techniques.

(2) Decontaminate all sampling equipment in accordance with the project-specific quality assurance plan.

(3) After the borehole has been advanced to the required sample depth, lower a "clean-out" auger into the borehole to remove loose, disturbed soils present at the bottom of the borehole.

(4) Assemble the thin-wall tube sampler and lower to the bottom of the borehole. The depth to the bottom of the borehole must be carefully measured to ensure the sampler is not "resting" on the soils at the bottom of the hole.

(5) Advance the sampler as noted below:

Open-Drive Sampler. Advance the sampler by pushing the drill rods downward in a continuous steady motion at a rate of about 0.5 feet to 1.0 foot per second.

Fixed Piston Sampler. Lock off the actuating rods so the piston will remain fixed on the soil surface. Advance the sampler by pushing downward on the drill rods at a rate of about 0.5 feet to 1 foot per second.

Hydraulic (Osterberg) Piston Sampler. Secure the drill rods at the ground surface so that the bottom piston is at the soil interface. Advance the sampler by pumping clean water down the drill rods. Continue pumping water until return of water is observed coming up the inside of the casing.

(6) Once the advance of the sampler is complete, wait 10 minutes or more before sample withdrawal.

(7) Rotate the drill rods by hand two revolutions clockwise to shear off the end of the sample.

(8) Remove the sampler from the borehole with extreme care to minimize sample disturbance.

(9) Scan the sampler with a PID to determine whether detectable levels of VOCs are present. Carefully remove the sampler head from the sample tube and remove soft disturbed material from the top of the sample. The sample tube must be kept in an upright vertical orientation at all times. Measure the length of sample recovered and record on the boring log.

(10) Remove about 1/2-inch of undisturbed soil from each end to allow room for the placement of seals. The soil cleaned from each end of the tube can be used for visual classification of the sample and head space analysis.

(11) The space at each end of the tube is sealed using flexible microcrystalline wax such as Socony Vacuum Product 2300 or equivalent, or with expandable packers. Paraffin is not acceptable. Fill empty portions of the tube filled with clean inert sand.

(12) Close the ends of the tube with tight-fitting metal or plastic caps, and wrap the seam between the cap and tube with tape. Finally, dip the ends repeatedly in hot wax, completely covering the tape, to ensure a good seal.

(13) Label the sample container and the top cap by writing on them with an indelible marker or by affixing a label. Locate all labeling on the top one foot of the tube. Include the following information on the tube: the project number, project name, date of sampling, boring number, sample number, zone of sampling, and any other information the field engineer/geologist feels is pertinent. Detailed information must also be permanently recorded in a field log. In addition, the tube shall be marked TOP and BOTTOM so that the orientation of the soil sample is known.

(14) Vertically place the tube samples in a container designed to relieve shock, vibration, and disturbance during storage and shipment.

3.4-4.2 Rotary Core Soil Samples

A variety of core barrels that were originally developed for drilling and sampling bedrock have been modified or adapted to obtain "undisturbed" overburden samples in very dense or partially cemented soils. These core barrels are used when the more conventional thin-wall samplers cannot penetrate the selected geological unit.

There are many variations in the type and mechanics of these core barrels, which are commercially available under a variety of trade names.

Single-wall or single-tube core barrels equipped with saw-tooth cutter bits have been used to a limited extent in sampling soils. However, the samples are usually disturbed by intermixing, swelling, or contamination with drilling fluid. Core barrels equipped with non-rotating inner liners are more suitable for overburden sampling.

Two of the more commonly used samplers for traditional geotechnical engineering studies are the Denison and Pitcher samplers. However, because of the potential for introduction of drilling fluids into the sample as the sampler is advanced, their use is not recommended for collection of environmental samples. A contractor proposing the collection of environmental samples using either of these devices should submit a detailed protocol for sample collection to DEP for review and approval. A brief description of each sampler and its sampling technique is presented below.

3.4-4.2.1 Denison Sampler

The Denison sampler is designed to recover relatively undisturbed thin-wall samples in dense sand/gravel soils, hard clays, partially cemented soils, or soft and weathered rock. The sampler consists of a double-tube, swivel-type core barrel with a non-rotating inner thin-wall steel or brass liner designed to retain the sample during penetration and subsequent transportation to the laboratory (see Figure 3.4-12).

The inner liner tube of the Denison sampler has a sharp cutting edge, which can be varied to extend from zero to about three inches beyond the outer rotating cutter bit. The amount of extension can be varied by means of interchangeable saw-tooth cutter bits that are preselected depending on the anticipated formation to be sampled. The maximum extension is used in relatively soft or loose soils and a cutting edge flush with the coring bit is used in hard or cemented formations. This sampler is generally effective in homogeneous soils. An important feature of the Denison sampler is a system of check valves and release vents which relieve the hydrostatic pressure buildup within the inner sampling tube, improving sample recovery, and minimizing pressure disturbance of the sample.

The Denison sampler is rotated into a formation in the same manner as conventional rock coring procedures. It is designed for use with water, mud, or air and is available in five sizes, ranging from 2.94 inches to 7.75 inches O.D. A schematic drawing of the Acker-type Denison rotary core barrel sampler is shown on Figure 3.4-12.

The Denison sampler is not a practical tool for sampling loose sands or soft clays, as the sample retention devices are usually inadequate for these materials. The presence of cobbles and boulders also will present major difficulties for penetration and recovery. The saw-tooth bit, with which the Denison is usually equipped, is not capable of coring hard boulders, which may cause collapse of the inner sampling tube if it is in an extended position.

3.4-4.2.2 Pitcher Sampler

The Pitcher sampler also was developed to recover relatively undisturbed thin-wall samples in formations that are too dense for conventional thin-wall sampler penetration. The Pitcher sampler consists of a single-tube, swivel-type core barrel with a self-adjusting, spring-loaded inner thin-wall sample tube which telescopes in and out of the cutter bit as the hardness of the material varies, see Figure 3.4-13. This telescoping aspect eliminates the need to pre-select a fixed inner barrel shoe length as is necessary with the Denison sampler.

The inner steel or brass thin-wall liner tube has a sharp cutting edge which projects a maximum of 0.5 feet beyond the saw-tooth cutter bit in its normal assembled position. As the sampler enters the borehole, a sliding valve directs the drilling fluid through the thin-wall sample tube for a thorough pre-flushing of the borehole. When the sample tube comes in contact with the bottom of the borehole, it telescopes into the cutter barrel and closes the sliding valve, which diverts the drilling fluid to an annular space between the sample tube and the cutter barrel. This sliding valve arrangement allows the circulation of drilling fluid to remove the borehole cuttings during sampling and prevents disturbance of the recovered sample by the drilling fluid.

The spring-loaded inner sample tube automatically adjusts to the density of the formation being penetrated. In very soft materials, it will extend as much as 0.5 feet beyond the cutter bit; as the formation density increases, the sample tube telescopes into the outer core barrel and compresses the control spring, which in turn exerts a greater force on the tube to insure adequate penetration. In extremely dense formations or obstructions, the sample tube will retract completely into the outer core barrel to allow the cutter bit to penetrate the obstruction. The Pitcher sampler is rotated into the unconsolidated formation in the same manner as conventional rock coring techniques. The sampler is designed for use with either water or mud and has been available in four sizes, ranging from 3.0 inches to 5.0 inches O.D. Reportedly, only the 5.0-inch O.D. sampler, which utilizes 3-inch O.D. thin wall sampling tube is presently on the market.

In highly variable formations, a major advantage of the Pitcher sampler is its telescoping sample tube, which prevents collapse of the sample tube and prevents fluid erosion of softer layers. However, the Pitcher sampler, like the Denison, is not capable of coring very large and intact cobbles and boulders.

3.4-4.3 Block Samples

One of the oldest, and considered by many as the most reliable, methods of obtaining undisturbed samples for laboratory testing consists of cutting large blocks of soil from natural, in-situ formations. Block samples should be obtained in accordance with procedure described in the Annual Book of ASTM Standards Volume 4.08, Soil and Rock (ASTM 1988).

3.4-5 PROBLEMS AND SUGGESTED SOLUTIONS

Particular advantages and disadvantages of the various subsurface sampling techniques and equipment have been discussed within the preceding sections. However, limitations and difficulties may be encountered during the exploration program that are common to all soil sampling techniques. These are usually the result of site-specific geological conditions and not necessarily a function of the equipment or procedure.

3.4-5.1 Inadequate Sample Recovery

Inadequate sample recovery can be influenced by such factors as:

- Residual cuttings in the casing prior to driving the sampler.
- Loss of sample.
- Blockage of sampler.
- Densification or frictional resistance.

3.4-5.1.1 Residual Cuttings

As borings are advanced, cuttings must be removed. In cased borings, the cuttings are removed using water that is forced down and out of the drill rods, carrying the cuttings to the top of the casing. The time required to flush the cuttings from the casing increases as the hole becomes deeper. The water velocity necessary to flush the cuttings increases as the size and weight of the individual soil grains increases. As a result, it may become difficult if not impractical to flush the casing "clean" as the depth of the borehole increases. The ability to flush the casing can be improved by using a more powerful pump, reducing the size of the annulus between the casing and drill rods, and, with the prior approval of DEP, through the use of additives mixed with the drill water to increase the viscosity of the drilling fluid.

In hollow-stem augers, cuttings are kept from the interior of the augers by the "plug" (pilot bit) at the bottom of the augers. However, when the augers are below the water table, soils are most likely to "flow" up into the augers after the plug is withdrawn. This is caused by the unequal hydrostatic pressure that exists between the soil at the base of the augers and the fluid level in the augers. Flow of soil into the bottom of the augers can be limited by keeping the water level in the augers/casing above the water table. If the soil at the base of the augers/casing is under hydrostatic pressures in excess of the water table, it may be necessary to use drilling additives to increase the density of the fluid to prevent artesian flow into the augers/casing. This solution is subject to prior approval by DEP at publicly funded sites. At other sites, the consultants report on field activities should explicitly describe the use of drilling additives.

3.4-5.1.2 Loss of Sample

Various sampling devices are equipped with check valves, pressure release valves, sample retaining springs, baskets, or lifters. These devices are designed to help retain soil samples. These devices should be checked frequently; they must be kept in good working order. In addition to the sample retention devices, sample recovery of soils
sensitive to disturbance can be improved by using extreme care not to vibrate or hit the drill rods as the sampler is withdrawn from the borehole.

3.4-5.1.3 Blockage of Sampler

Poor recovery may be the result of the presence of material large enough to block the entry of soil into the sampler. As a result, the sampler is either advanced pushing the obstruction ahead with no soil recovery, or does not advance due to resistance by the soil beneath the obstruction. The obstruction can be penetrated by:

- o Advancing the augers/casing through or past the obstruction.
- o Drilling ahead of the casing in an effort to crush or "push aside" the obstruction.
- o Coring the obstruction.

3.4-5.1.4 Densification or Frictional Resistance

Relatively loose or soft soils may decrease in volume during sampler penetration. Such soils may develop sufficient frictional resistance to prevent entry into the sampler before the sampler is completely advanced.

3.4-5.2 Sample Disturbance

A problem common to all forms of soil sampling is sample disturbance, influenced by:

- o The type of soil to be sampled.
- o Sampling equipment.
- o Diameter of the sampling equipment.
- o Method of advancing the sampler.
- o Drilling methodology.
- o Borehole disturbance.

Selection of the appropriate drilling and sampling methodology must be consistent with the objectives of the investigative effort. Disturbance of soil samples obtained for environmental site assessments is not a major concern for most projects. The most important aspect of an environmental sample is that it be representative of the material from which it is obtained. Disturbance of samples is a significant factor when the samples are to be used in laboratory tests to determine specific engineering parameters.

The American Society for Testing and Materials (ASTM) publication Special Technical Publication (STP) 483, "Sampling of Soil and Rock" (1970) presents several technical papers by various authors regarding sampling methodologies and associated sample disturbance.

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IN-SITU SAMPLING OF SOIL

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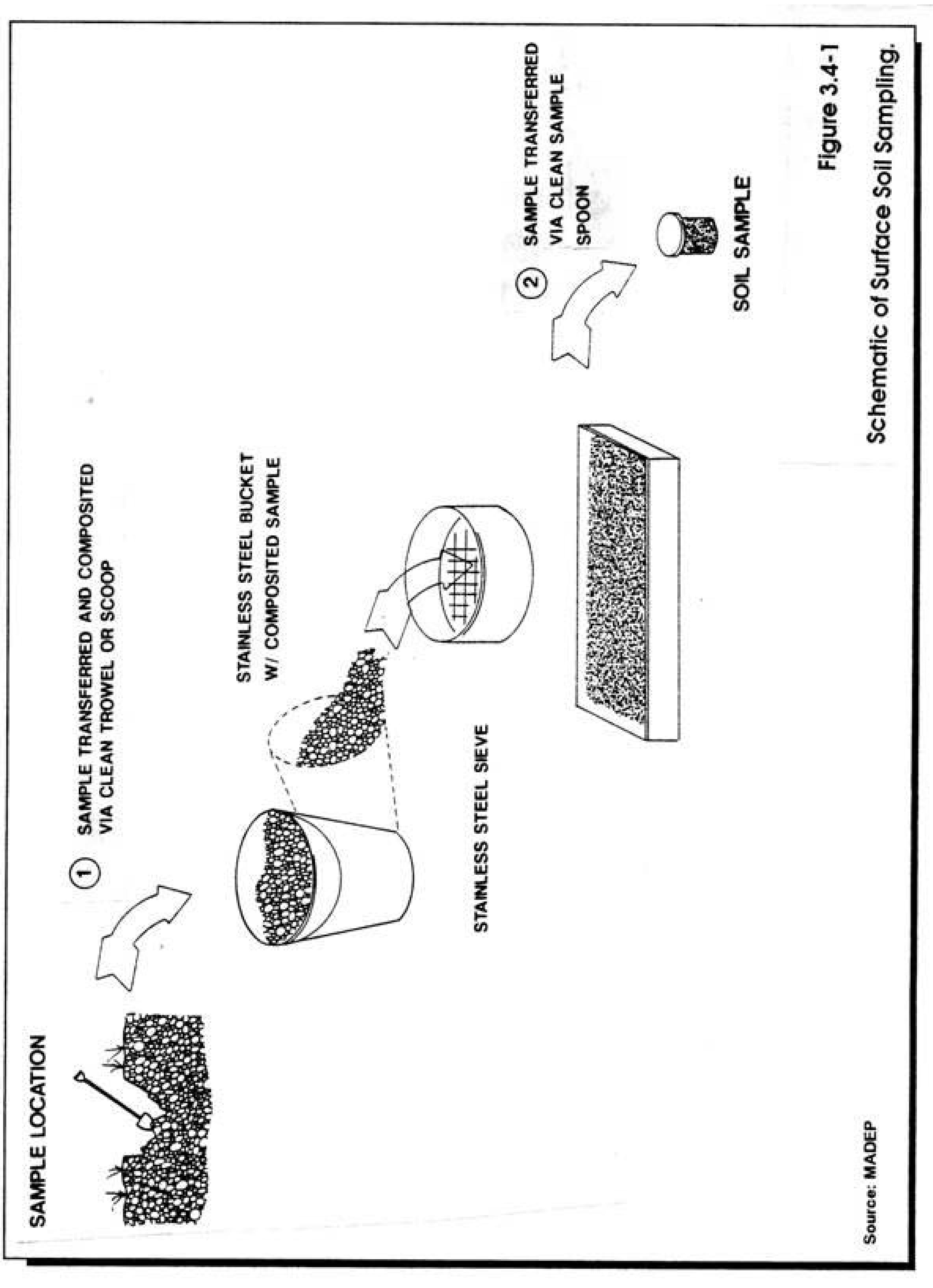
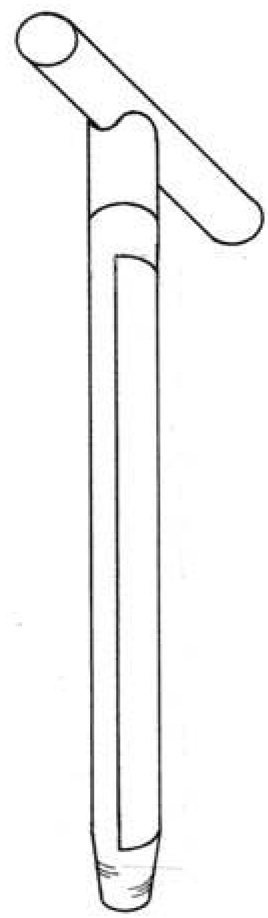


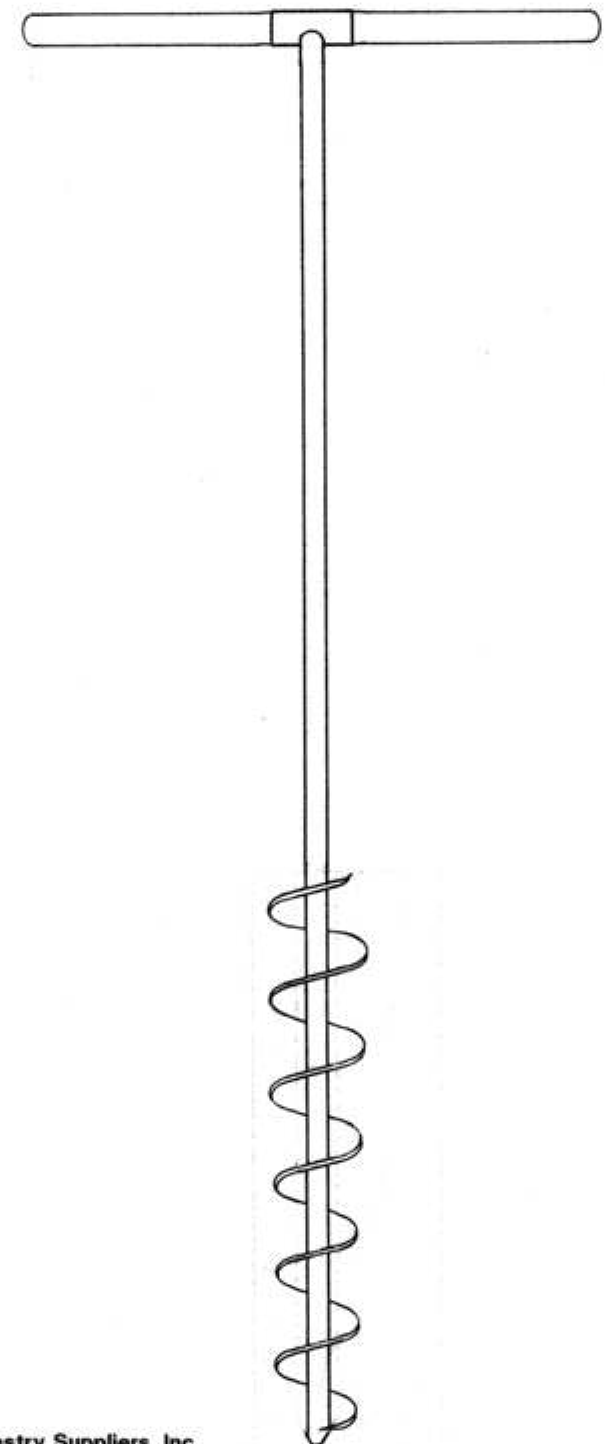
Figure 3.4-1
Schematic of Surface Soil Sampling.



Source: After JMC Soil Investigation Equipment
Catalogue No. 8

Figure 3.4-2

Soil Sampling Tube.



Source: After Forestry Suppliers, Inc.
Catalogue No. 36

Figure 3.4-3

Hand Auger.

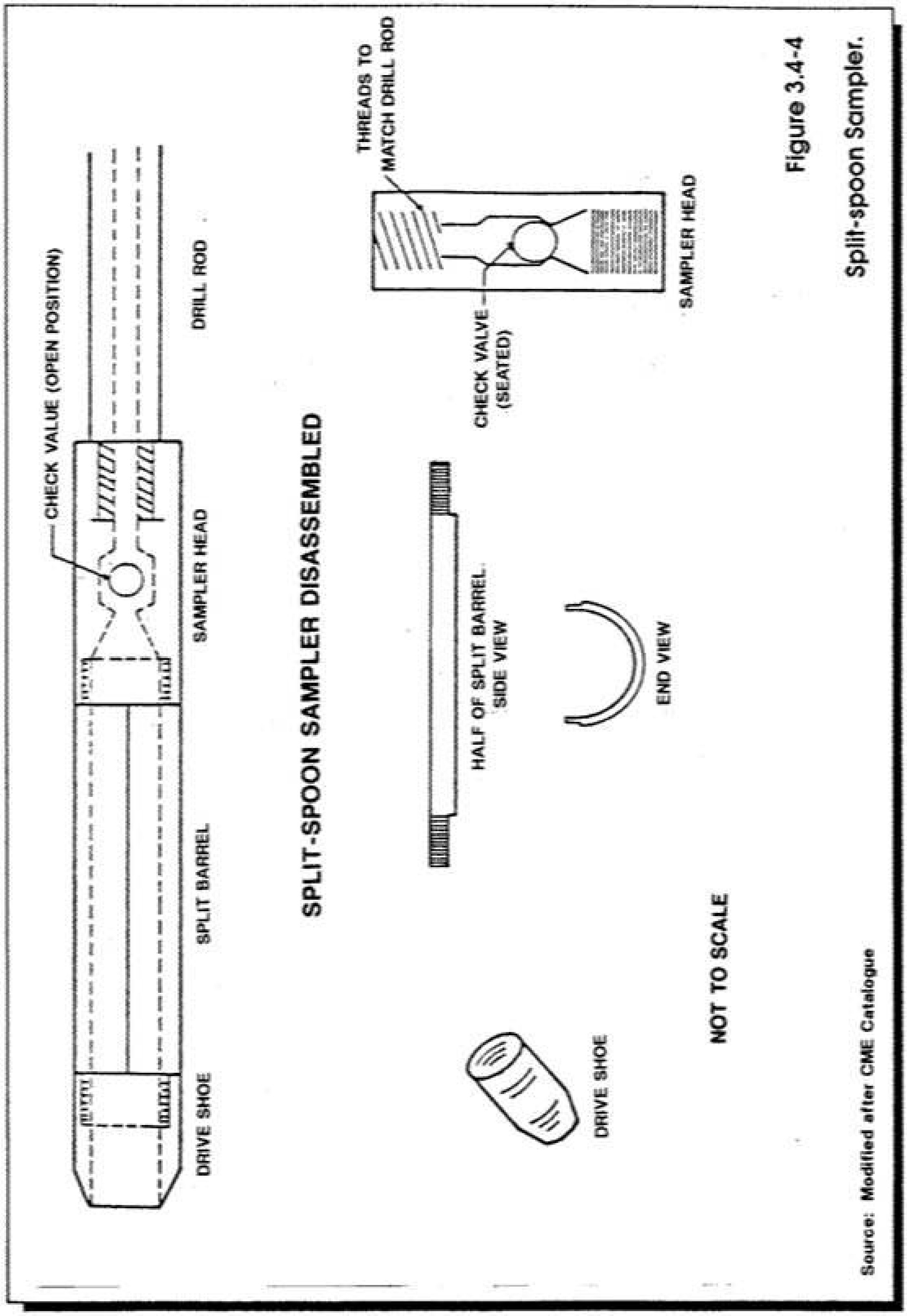
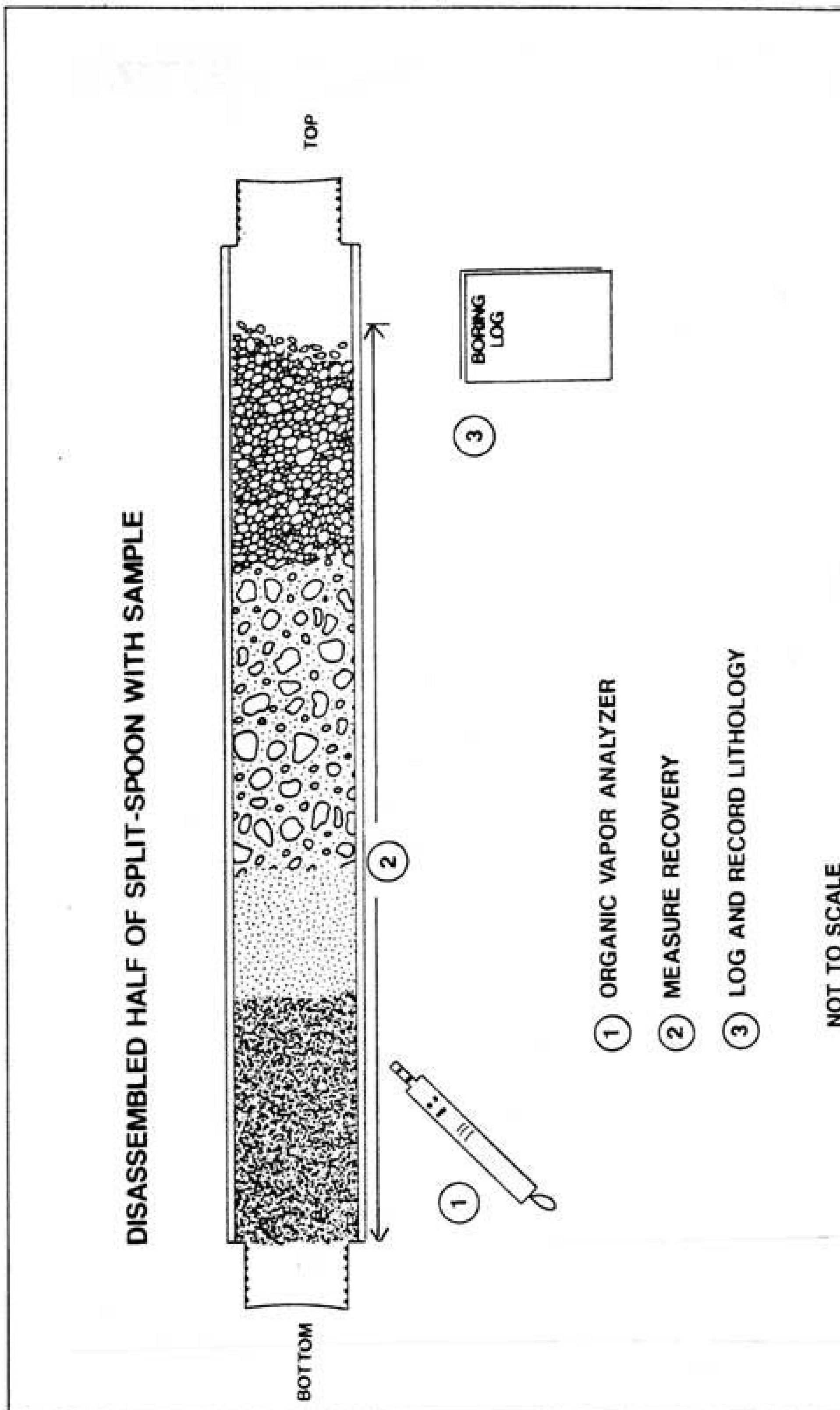


Figure 3.4-4
Split-spoon Sampler.

Source: Modified after CME Catalogue



Source: Modified after CME Catalogue

Figure 3.4-5
Schematic of Split-spoon Soil Sample Logging.

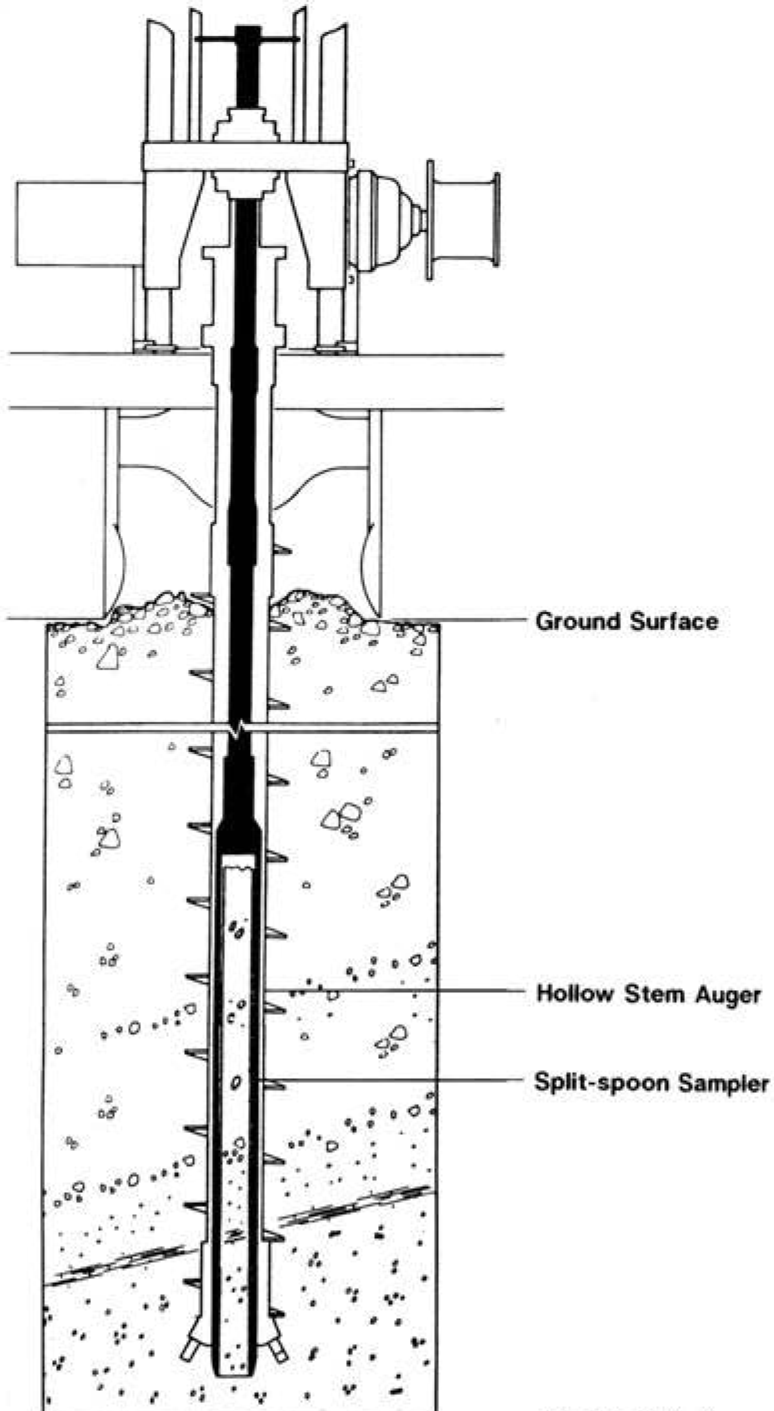


Figure 3.4-6

Source: CME Brochure

Auger-advanced Split-spoon Sampler.

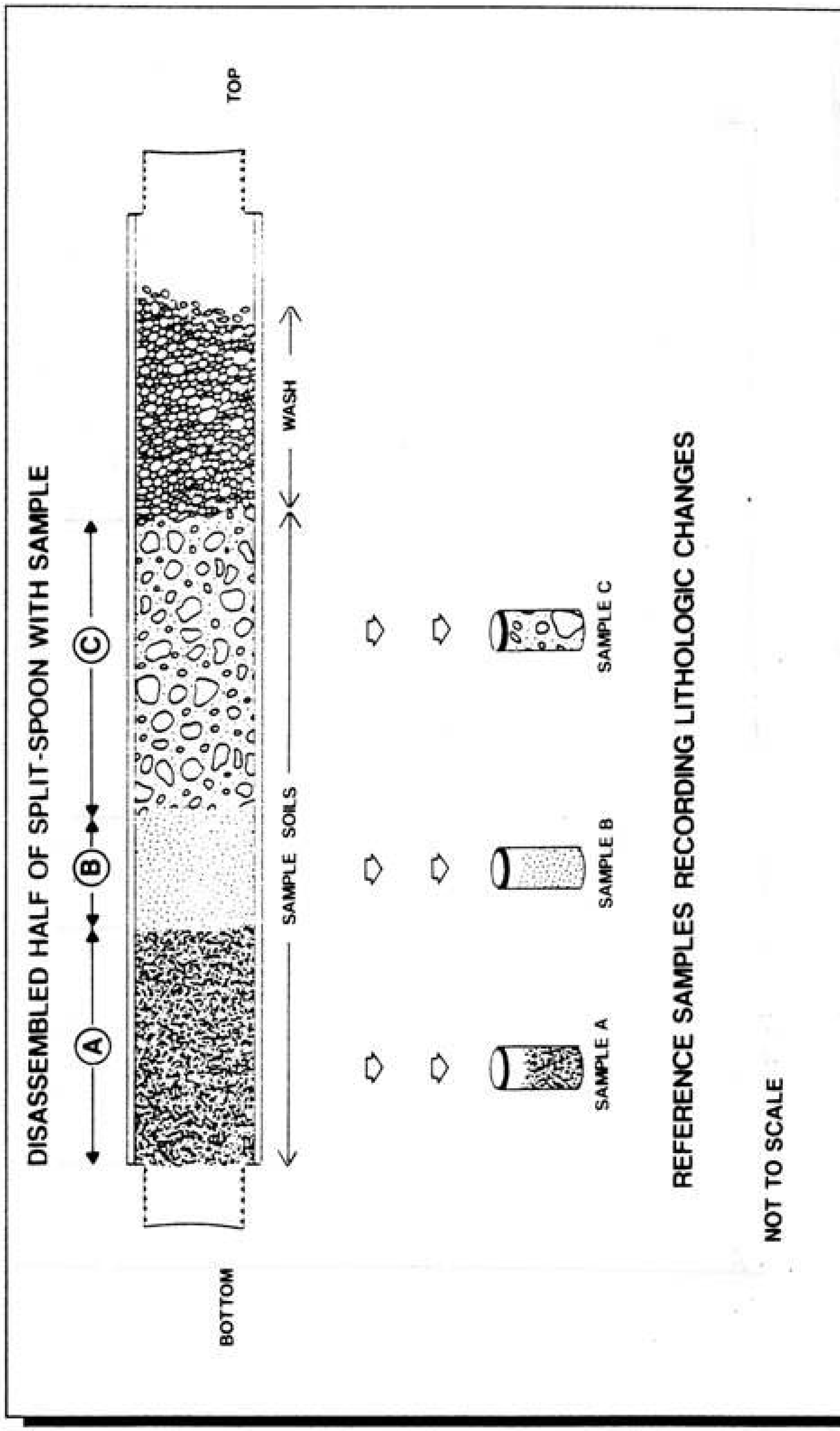
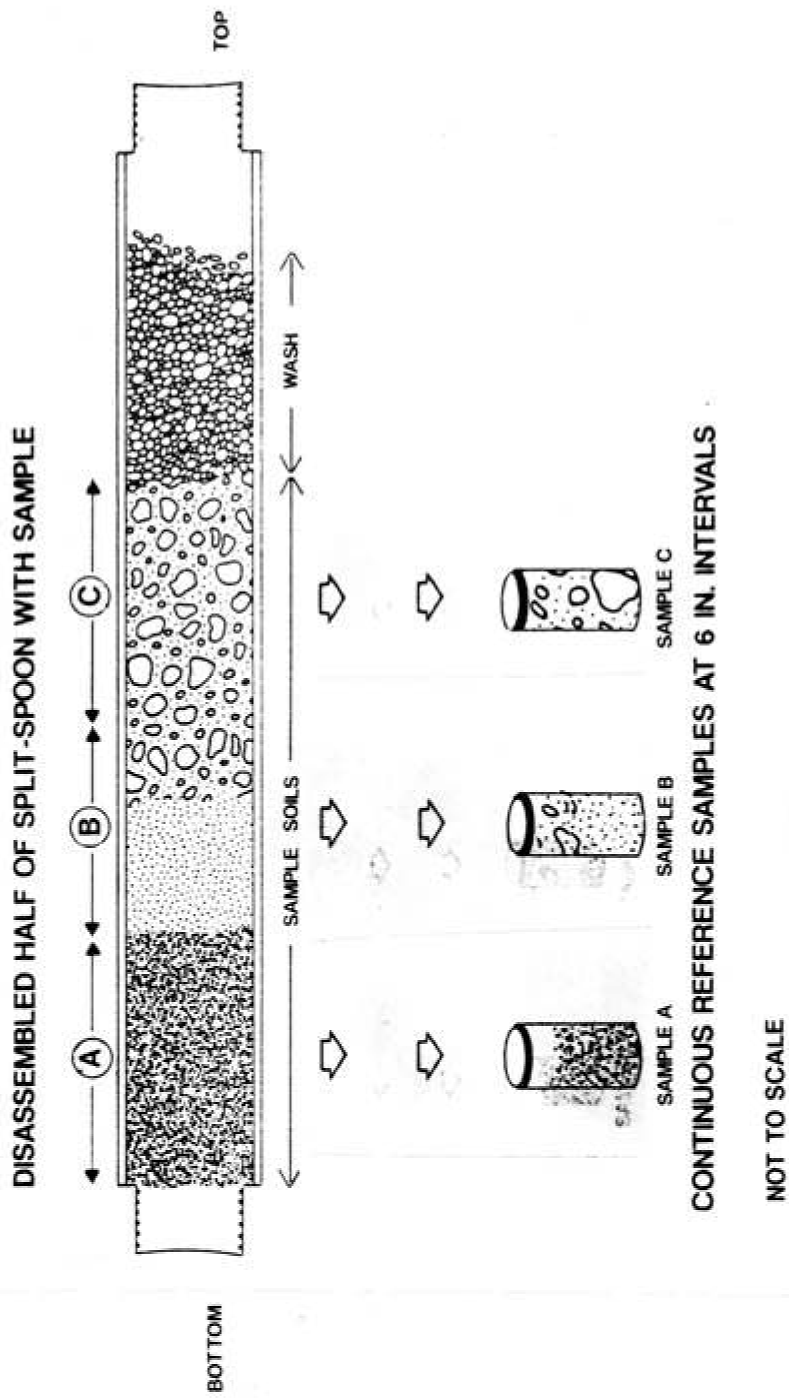


Figure 3.4-7

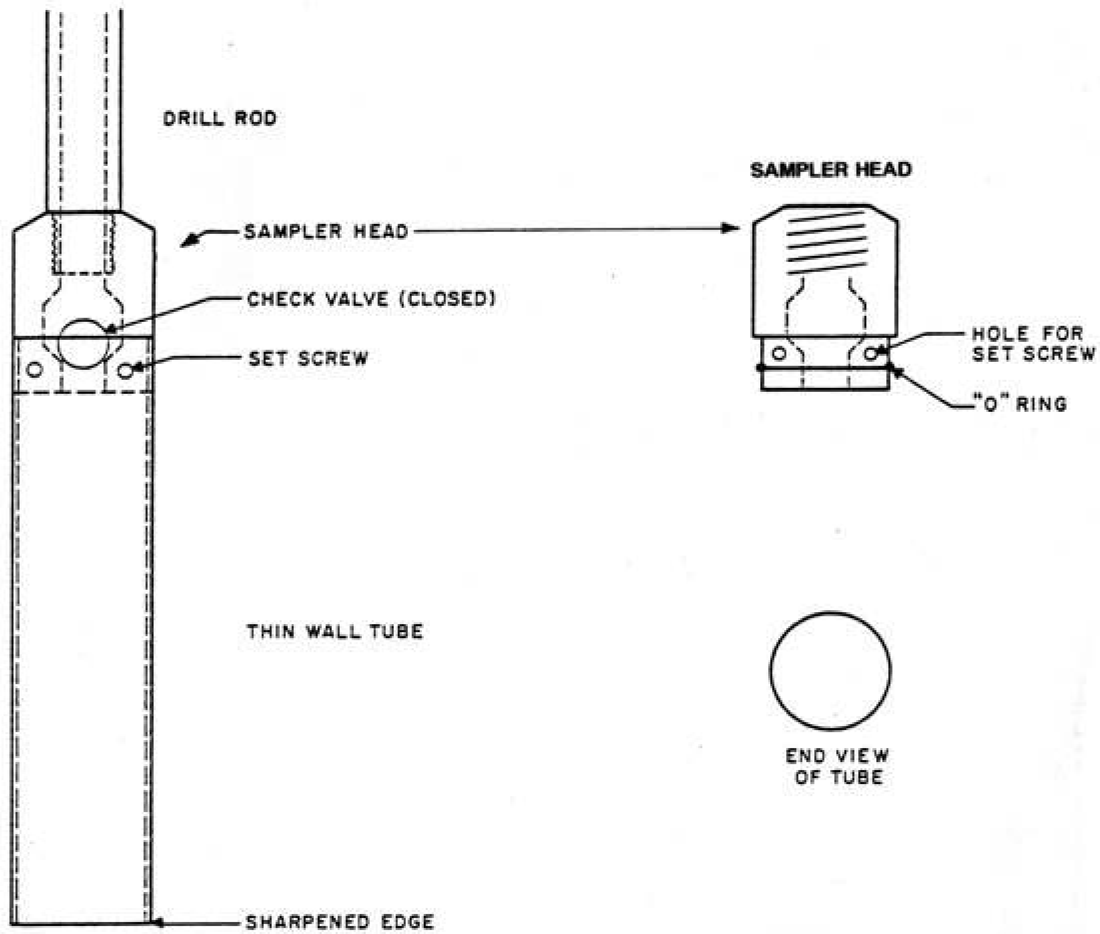
Split-spoon Samples Recording Lithologic Changes.

Source: Modified after CME Catalogue



Source Modified after CME Catalogue

Figure 3.4-8
Split-spoon Samples at 6-inch Intervals.

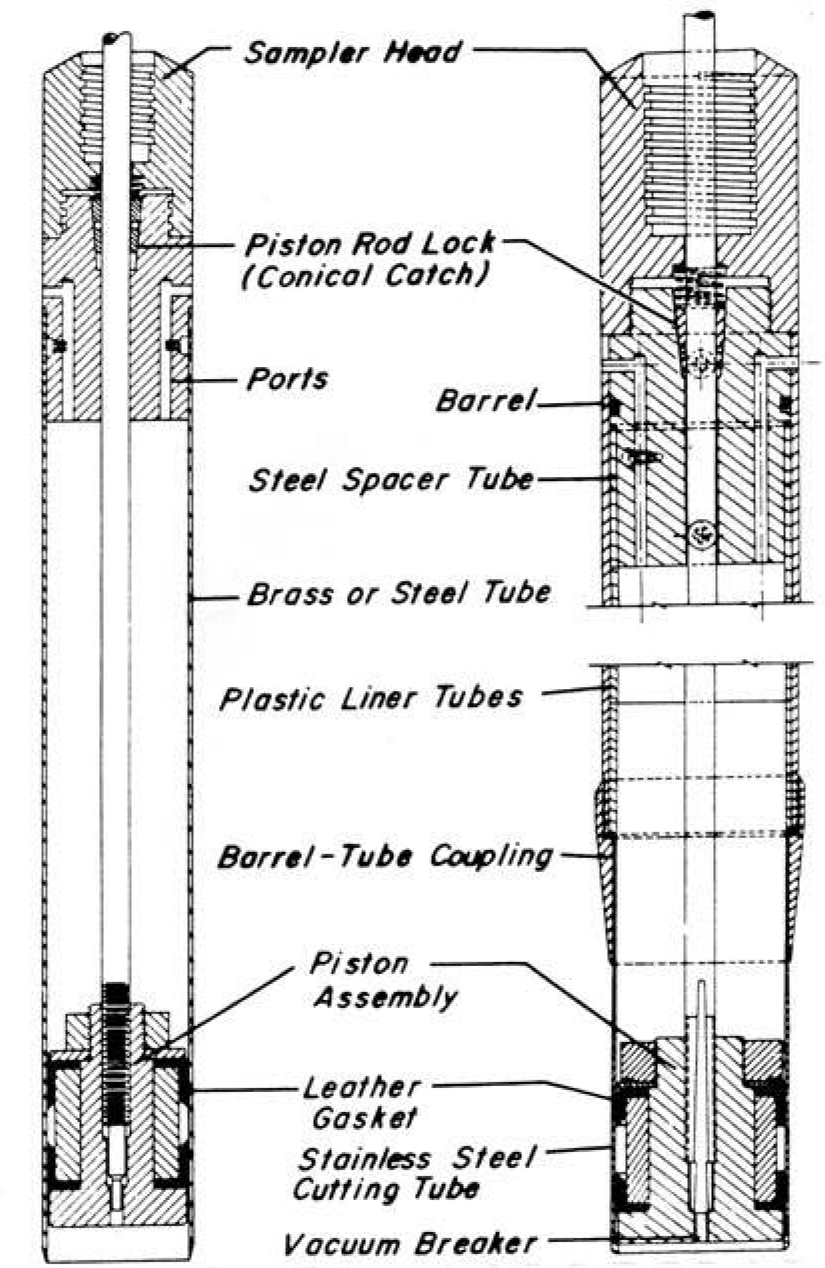


NOT TO SCALE

Source Modified after Winterkorn et al. (1975)

Figure 3.4-9

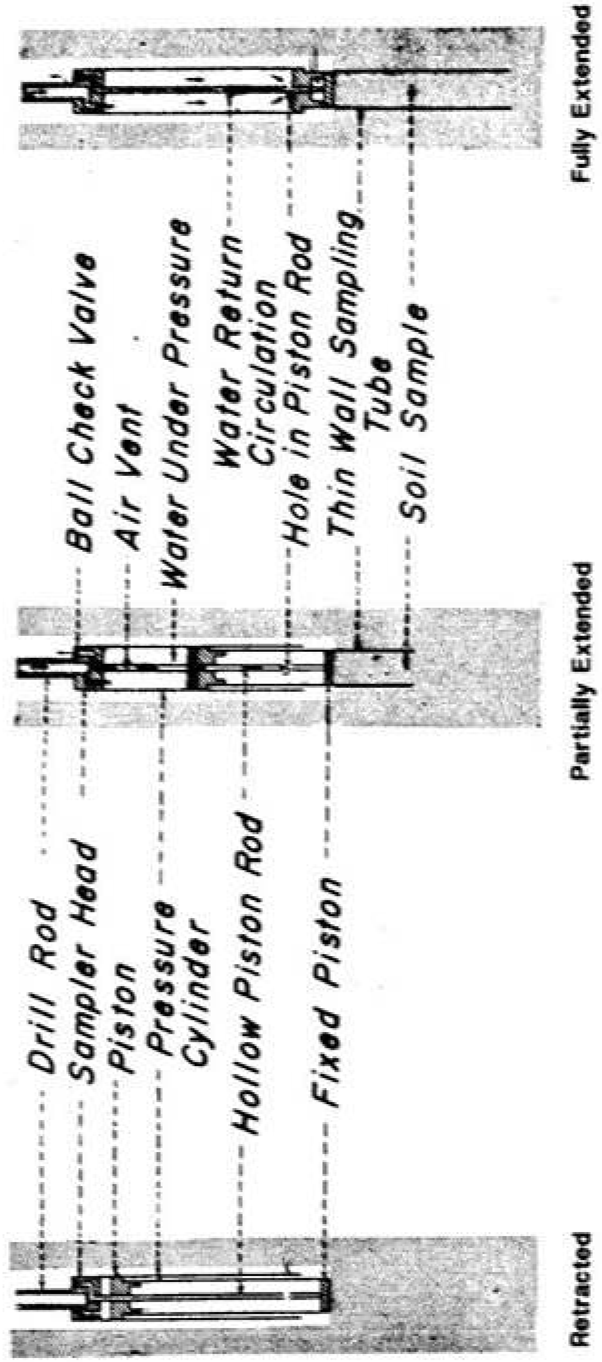
Thin Wall Sampling Tube.



Source: Winterkorn et al. (1975)

Figure 3.4-10

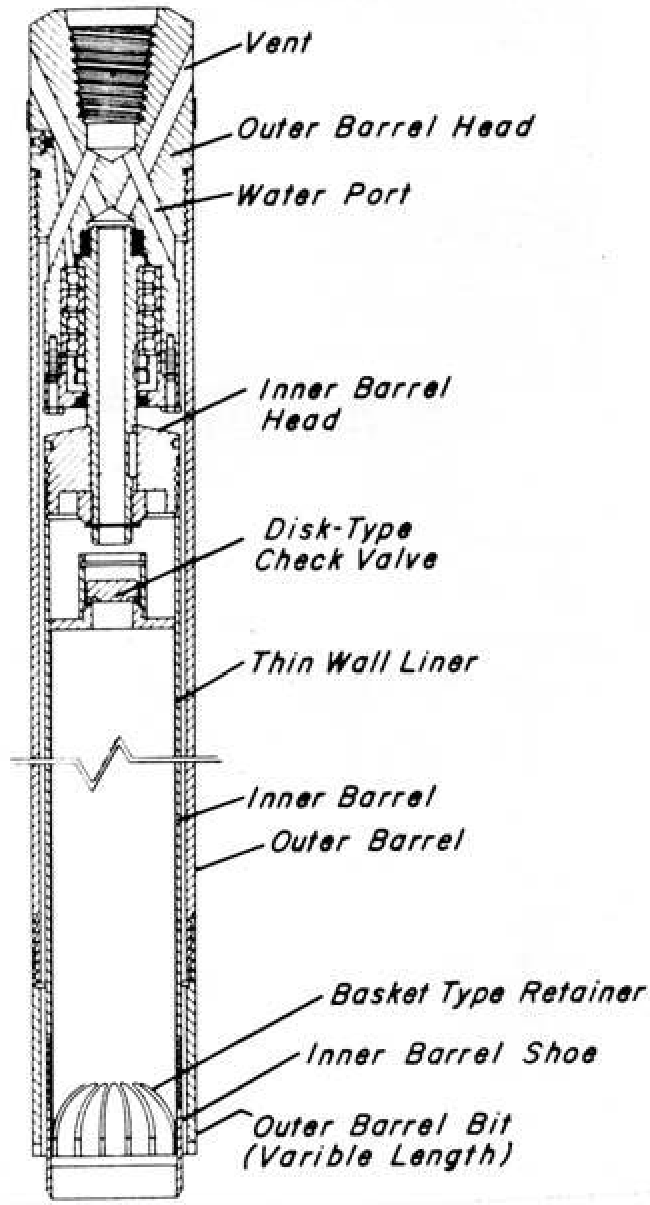
Stationary Fixed Piston Sampler.



Source: Winterkorn et al. (1975)

Figure 3.4-11

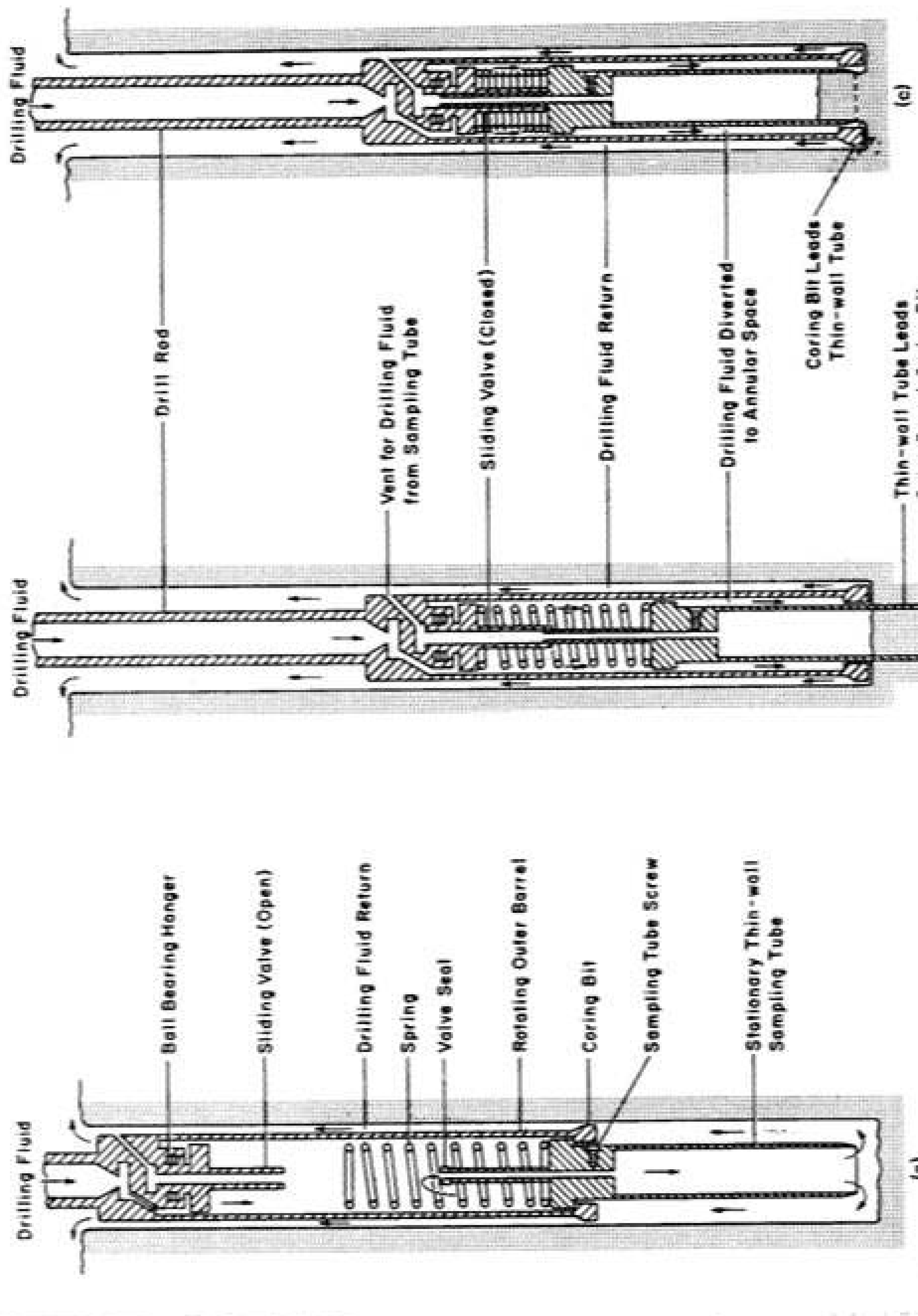
Hydraulic (Osterberg) Piston Sampler Operation.



Source: Winterkorn et al. (1975)

Figure 3.4-12

Denison Sampler.



Source: Winterkorn et al. (1975)

Figure 3.4-13

Pitcher Sampler.

Dimensions			
I.D.		O.D.	
in.	mm	in.	mm
1.878	48	2.000	51
2.838	72	3.000	76
4.170	106	5.000	127

Source: After Winterkorn et al. (1975)

Table 3.4-1

Standard Dimensions for Thin-wall tubing.

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STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.5   SOIL CLASSIFICATION

SECTION 3.5
SOIL CLASSIFICATION

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SECTION 3.5 SOIL CLASSIFICATION

3.5-1 PURPOSE

The purpose of soil classification is to systematically group soils with similar physical characteristics in the same classification category. The use of a soil classification system produces a consistent description of soil samples that can be readily understood by engineers, geologists, drillers, and other members of the project team. Soil classification systems group soils based on physical characteristics (e.g., grain size, gradation, and plasticity). General engineering and hydrologic properties of soils can be estimated from these physical characteristics allowing rapid preliminary assessment of site conditions during a field investigation program. Often this preliminary assessment of the subsurface soil conditions is the primary basis for modification of a field investigation program when little time is available for laboratory analyses.

A systematic grouping of similar soil types based on physical characteristics aids in the identification and correlation of subsurface stratigraphy. Accurate identification of subsurface variations is an essential element in contamination investigations because the existence of subsurface structures or heterogeneities can have a significant impact on rates and directions of contaminant movement.

Care should be taken to assure that soil-classified samples are representative of the strata from which they were obtained. If significant subsurface variation occurs or if poor recovery is obtained, it should be noted on the boring log. Soil samples may be obtained from surface sampling programs, borings, and test pits. Samples should be collected and labeled according to the procedures described in the Standard Reference (SR) for that specific sampling method (see Section 3.4).

Soils are classified on the basis of visual-manual tests and laboratory tests. This SR describes visual-manual classification techniques that are used in the field; some applicable standard laboratory testing techniques are discussed in Section 3.8 Laboratory Testing of Soil and Rock. With adequate training and experience, it is possible to accurately and consistently classify soils on the basis of visual-manual field tests. The comparison of visual-manual classifications to laboratory test results (e.g., grain-size analyses) is necessary to confirm and refine the field descriptions.

3.5-2 CLASSIFICATION SYSTEMS

Several soil classification systems have been developed to describe soils, including the Unified Soil Classification System; the Burmister System; and systems developed by the U.S. Department of Agriculture (USDA), American Association of State Highway Officials (AASHO), Massachusetts Institute of Technology, and British Standards Institute. Table 3.5-1 is a comparison of the components of various soil classification schemes as they relate to grain size.

The Unified Soil Classification System is the most commonly used classification system in the U.S. Developed by A. Casagrande in 1953, it has been adopted by the U.S. Bureau of Reclamation and several other state and federal agencies. Another classification system commonly used in the northeastern U.S. is the

Burmister System, developed in the 1940s by the American Society of Engineering Education.

As shown in Figure 3.5-1, the major difference between the Unified System and Burmister System is in the breakdown of the coarse-grained components. Additionally, the Burmister System includes a determination of the percentage by weight of various soil components, and a description of the relative percentages through the use of the following modifiers: and, some, little, and trace. A combination of the Unified System and the Burmister System has been used as the procedure for classifying soils described herein. A list of key soil properties, along with specific field tests, is described in the following section.

3.5-3 METHODOLOGY

For the purpose of providing consistent sample descriptions, the flow chart (Figure 3.5-2) can be used as a general guide for the soil classification process. The following soil characteristics/properties have been identified in the sample description in the order of presentation:

- Color (Section 3.5-3.1)
- Gradation: coarse-grained soils versus fine-grained soils (Section 3.5-3.2)
  - -coarse-grained soil identification procedures (Section 3.5-3.2.1)
  - -fine-grained soil identification procedures (Section 3.5-3.2.2)
- Gradation Designation (Section 3.5-3.3)
- Relative Density/Consistency (Section 3.5-3.4)
- Particle Angularity (Section 3.5-3.5)
- Moisture Content (Section 3.5-3.6)
- Structure (Section 3.5-3.7)
- Reaction to Hydrochloric Acid (Section 3.5-3.8)
- Geologic Name (Section 3.5-3.9)
- Unified Classification Designation (Section 3.5-3.10)
- Special Conditions or Notes (Section 3.5-3.11)

3.5-3.1 Color

Sample color should be determined, if possible, immediately after the sample is retrieved, while it is still at its natural moisture content. Soil color is particularly important in the description of fill, organic, weathered, or natural soils that may have been contaminated. Sample layers or patches of different coloration should be noted.

Color descriptions may vary considerably from one person to another; the use of a Munsell Soil Color Chart will assure more consistent color descriptions. The Munsell Soil Color Chart uses standard color chips against a neutral background. Small holes in the color chart next to the chips allow the user to view the sample next to the chip to find an accurate match. Although not typically used in soil classification, a color can be described by a series of symbols representing the hue, value, and chroma (example: 5YR 6/4).

3.5-3.2 Gradation: Coarse-grained Soils Versus Fine-grained Soils

Individual soil particles are given the following descriptors based on size: boulders, cobbles, gravel, sand, silt, and clay. Table 3.5-1 presents the particle size descriptors by their size in inches or standard sieve size, and familiar reference sizes for approximation purposes.

For the purpose of sample classification, soils will be broken down into two major groups according to weight percentages: coarse-grained soils and fine-grained soils.

- Coarse-grained soils are defined as containing more than 50 percent by weight larger than the No. 200 sieve (sands and gravels, up to 3 inches in diameter). Section 3.5-3.2.1 presents procedures for classifying coarse-grained soils according to the Burmister System.

- Fine-grained soils are defined as containing more than 50 percent passing the No. 200 sieve (silts and clays). Section 3.5-3.2.2 presents procedures for classifying fine-grained soils according to the plasticity and the percentage of clay versus silt as estimated from various field tests.

3.5-3.2.1 Coarse-grained Soil Identification Procedures

The Burmister System provides a consistent framework to estimate the distribution of gravel-, sand-, and silt-size particles. Percentage ranges in weight for various particle sizes are given in Table 3.5-2.

Two examples of a sample description using Burmister System designations are as follows:

> Fine to Medium SAND, little coarse gravel, trace to little silt.
>
> Fine SAND and silt, trace medium to coarse sand, and fine gravel.

When a sample contains significant amounts of silt- and clay-size particles (greater than 12 percent by weight), the fine portion will be classified by procedures for fine-grained soils in Section 3.5-3.2.2. The presence of boulders and cobbles will be indicated and, if possible, the percentage estimated if observed in test pits or excavations.

3.5-3.2.2 Fine-grained Soil Identification Procedures

Field procedures for the determination of fine-grained soil properties are described in this subsection. After performance of one or more of the field tests, the fine-grained soils are given a material designation (e.g., silty clay or clayey silt) and a plasticity description (e.g., slight, medium, or high). Appropriate designations (ASTM 1988) relating to the field test classifications are given in each section. The following field tests may be applied to differentiate between cohesionless silt and plastic silty clay soils.

(a) Dilatancy

A pat of wet soil is shaken in the palm of the hand and alternately squeezed and released. Materials that are predominantly silt will show a dull, dry surface upon squeezing, and a glassy wet surface upon releasing the pressure and upon shaking or vibrating the pat. With increasing clay content, this phenomenon becomes less pronounced due to the lower mobility of the pore water.

The criteria used to describe dilatancy based on the manual field test are as follows:

- None: No visible change in the specimen
- Slow: Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing.
- Rapid: Water appears quickly on the surface of the specimen during shaking and disappear upon squeezing.

(b) Dry Strength

A portion of the soil is allowed to dry out completely in air. A cube of soil about ½ inch square is formed and dried and pressed between the fingers. The cubes with very high strength cannot be broken at all, whereas those with very low strength disintegrate completely on gentle pressure. The soil strength is described as medium if the fragment can be reduced to a powder only with a great effort. Those materials with greater dry strengths are predominantly clay. Further, the dried soil cube can be polished on one's fingernail. If the polished surface is shiny, it is indicative of predominantly clay soils, whereas a dull surface indicates silt. The criteria for determining dry strength in the field is as follows:

- o None: The dry specimen crumbles into powder with mere pressure of handling.
- o Low: The dry specimen crumbles into powder with some finger pressure.
- o Medium: The dry specimen breaks into pieces or crumbles with considerable finger pressure.
- o High: The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
- o Very High: The dry specimen cannot be broken between the thumb and a hard surface.

(c) Stiffness/Plasticity

A high degree of stiffness and a very smooth smear in the natural state are indicative of high plasticity. The techniques for determining stiffness/ plasticity in the field are described below:

- o Nonplastic: A 1/8 inch (3 mm) thread cannot be rolled at any water content.
- o Low: The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit.
- o Medium: The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
- o High: It takes considerable time rolling and to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

(d) Soil Thread Test

This test is an aid in estimating the degree of plasticity and differentiating between organic and inorganic soils. Take a portion of the sample, adding water as necessary, and attempt to roll out on a flat surface with the palm of the hand into threads approximately 1/8-inch in diameter. Fold and repeat procedures until thread begins to crumble into a number of small pieces.

(1)... The fact that a soil can be rolled into threads without crumbling indicates plasticity and the presence of clay. Note the number of times that the process can be repeated. This is indicative of the degree of plasticity; the greater the number of repetitions for fine soils started at the same water content, the more plastic the clay.

(2) As the plastic limit is approached, note the toughness of the threads. Highly plastic, inorganic, fat clays will feel very tough. Leaner, sandy or silty clays will feel weak and will crumble easily. This distinction in the toughness of threads can only be felt when the water content is close to the plastic limit. The criteria for describing toughness based on manual field tests are as follows:

- o Low: Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft.

- o Medium: Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness.

- o High: Considerable pressure is required to thread to near the plastic limit. The thread and the lump have very high stiffness.

(3) Organic soils and inorganic diatomaceous or micaceous soils will feel very spongy and elastic.

(e) Ball Thread Test

Identification can also be made on the following basis: The soil is molded and water content adjusted until a 1½-inch-diameter ball formed from the soil shows a flattened contact surface of 7/8-inch-diameter when dropped from a height of 2 feet. (Gravel sizes are not included in the ball.) The smallest thread possible without crumbling is then rolled from the above soil sample. The following approximate relationships are then used for identification:

Thread Diameter	Descriptive Term
1/4 inch	SILT, trace clay
1/8 to 1/16 inch	Clayey SILT
1/32 inch	Silty CLAY
1/64 inch	CLAY

(f) Test Tube Test

Silt- and clay-size particles may also be differentiated by determining their approximate settling rates in water. The settling rate may be measured in the field by shaking a small sample of soil in a test tube filled with water and then allowing the particles to settle. The time required for particles to fall a distance of 4 inches is about 30 seconds for 0.074-mm particles (the boundary between sand and silt) and about 50 minutes for 0.005-mm particles (the boundary between silt and clay). An approximate idea of the grain sizes present in a sample of the fine-grained soil may be obtained by this method.

To accurately determine the properties of fine-grained soils, evaluation of Atterberg Limits may be desirable. Atterberg Limits are laboratory procedures used to identify the plasticity of fine-grained soils. Atterberg Limits should be performed according to American Society of Testing and Materials (ASTM) for the liquid limit determination (D 4318-84) and for plastic limit and plasticity (D 4318-84). If Atterberg Limit determinations are made for individual samples, they will be classified according to the plasticity chart shown in Figure 3.5-3.

3.5-3.3 Gradation Designation

A determination of the approximate percentages of various particle sizes in a soil sample is also important. Soil samples can be described as widely graded, uniformly graded, and gap graded. Laboratory gradation tests (ASTM D 422-63) for particle sizes retained on No. 200 sieve can be used to determine the clay and silt content of a sample. Figure 3.5-4 is an example of the various types of grading that can be described in soil samples.

- Widely Graded: a soil sample with a wide range of grain sizes, including a substantial amount of intermediate grain sizes. A glacial till is an example of a widely graded sample. This term is synonymous with poorly sorted. Engineering terminology will describe this as "well-graded."

- Uniformly Graded: a soil sample consisting predominantly of one grain size. A beach sand is an example of uniformly graded sand. This term is synonymous with well sorted. Engineering terminology will describe this as "poorly graded."

- Gap Graded: a soil sample that has a wide range of sample sizes, with some intermediate particle sizes missing. A water-washed till might be gap graded. This term is synonymous with bi-model. Engineering terminology will describe this as "poorly graded".

3.5-3.4 Density/Consistency

Relative density or consistency terms will be used as description modifiers for coarse- and fine-grained soils, respectively.

3.5-3.4.1 Relative Density: Coarse-grained Soils

Relative density descriptors for coarse-grained soils will be based on Standard Penetration Test (SPT) N-Values (ASTM D 1586-84) or a qualitative assessment based on the in-situ sample appearance. The following relative density descriptors will be used:

Relative Density Descriptor	SPT N-Value (Number of Blows/Foot)
Very Loose	0 to 4
Loose	5 to 10
Medium Dense	11 to 30
Dense	31 to 50
Very Dense	51 +

3.5-3.4.2 Consistency: Fine-grained Soils

Consistency descriptors for fine-grained soils can be determined from field tests such as SPT N-Values, or undrained shear strength or unconfined compressive strength data obtained with a torvane or pocket penetrometer. Table 3.5-3 presents field tests that can be performed to determine the consistency of fine-grained soils.

3.5-3.5 Particle Angularity

Particle angularity terms are to be given to coarse-grained soils, as descriptions of the shape of the larger-size, coarse sand and gravel particles and cobbles and boulders. The degree of angularity, while qualitative, is important in evaluating the mode of deposition for the sample recovered. Rounded and subrounded particles might suggest the deposit was waterlaid, whereas subangular to angular particles might suggest the deposit was subjected to abrasion in the deposition. Angularity modifiers (ASTM 1988) to be used are as follows:

- Angular: Particles have sharp edges and relatively plane sides with unpolished surfaces.
- Subangular: Particles are similar to angular description but have rounded edges.
- Subrounded: Particles have nearly plane sides but well-rounded corners and edges.
- Rounded: Particles have smoothly curved sides and no edges.

See also Figure 3.5-5 for classifying particle angularity.

3.5-3.6 Moisture Content

A qualitative judgment of the moisture content of the sample should be noted as soon after recovery of the sample as possible. The determination of soil moisture is important in evaluating ground water levels where piezometric data are insufficient or nonexistent, and in evaluating future behavior of fine soils if excavated or disturbed. The terms (ASTM 1988) to be used for describing moisture content modifiers:

- o Dry: Dry, absence of moisture, dry to touch
- o Damp: No visible water
- o Moist: Little visible water, wet to touch
- o Wet: Some free water visible
- o Saturated: Visible free water, should only be used if 100-percent saturation is to be implied.

3.5-3.7 Structure

The structure of both coarse-grained and fine-grained soils should be carefully observed and is important in identification of depositional environments and in the identification of a local geologic unit. The following descriptive terms should be used:

- o Homogeneous: uniform, non-directional properties of fabric without stratification.
- o Stratified: alternating, horizontal layers of different soils or soil-particle sizes greater than 1/8-inch in thickness.
- o Laminated: repeating, alternate horizontal layers less than 1/8-inch thick in fine-grained soils.
- o Banded: alternate contrasting layers in residual soils.
- o Blocky: cohesive soils that may be broken down into small angular lumps without further degradation.
- o Lens: a body of material that is thick in the middle and thin toward the edges.
- o Root holes: small holes caused by root fibers.
- o Heterogeneous: very irregular structure without definite form.
- o Parting: less than 1/16-inch thick horizontal bed (granular soils).
- o Laminae: 1/16- to 1/2-inch thick bed.
- o Layer: 1/2 to 12 inches thick bed.
- o Stratum: bed that is usually greater than 1 foot thick, but occasionally less (e.g., topsoil).
- o Varves: freshwater lake deposit usually in layers (less than 1 inch) but occasionally in alternating light and dark bands of silt and clay up

to 3 inches thick. Typically implies alternating seasonal deposition in a glacial lake.

- Pocket: small, erratic deposit usually less than 1 foot in diameter.
- Occasional: one or less per foot of vertical thickness.
- Interbedded: applied to strata of soil or beds of rock lying between or alternating with other strata of a different nature (e.g., coarse to fine gravelly sand with interbedded layers of fine sandy silt).
- Stratification: the formation, accumulation, or deposition of materials in layers which can be differentiated on the basis of texture, hardness, cohesion, color, mineralogy, or cementation.
- Mottled: marked with spots or blotches of different color, or shades of color, as if stained.
- Topsoil: the upper most in-situ, nutrient-rich, humic soils, frequently consisting of dark brown loamy silt with trace amounts of sand, gravel, and cobbles, and a pronounced structure of living root fibers.

3.5-3.8 Reaction to Hydrochloric Acid

Calcium carbonate is commonly found in soils as a cementing agent. Dilute hydrochloric acid will react with calcium carbonate displaying no reaction or a weak or strong effervescence depending on the amount of calcium carbonate in the soil. The reaction of the soil to hydrochloric acid should be noted in the field. The following criteria have been established to describe the hydrochloric acid reaction:

- None: No visible reaction
- Weak: Some reaction, with bubbles forming slowly
- Strong: Violent reaction, with bubbles forming immediately

3.5-3.9 Geologic Name

A descriptive geologic term should be assigned to identifiable geologic units, designating their depositional origin, if possible (e.g., alluvial sand, glacial till, or outwash). Place names are used only in the soil classification system and by the Soil Conservation Service. Place names identifying type locations are not assigned to soil classifications by any other system. Some examples of geological terms follow:

- Glacial Till: Material ranging in particle size from silt and clay to boulders, which is neither stratified nor sorted according to size. It is a dense, heterogeneous mass usually lying directly over bedrock. Two different till zones may overlie each other. A less dense, weathered, brownish-gray granular till may overlie a very dense, gray basal till. One or the other units may be missing depending on the environment. A presence or lack of an adjacent marine environment, and type of bedrock, will control the presence or absence of clay-size particles. Various types include ground moraine till, drumlin till, and ablation, lodgement, or flow till.

- Loess: A widespread, homogeneous, unstratified, porous, friable soil consisting predominantly of a loose yellow-brown to rust-brown silt with varying amounts of soft sand, root fibers, and trace amounts of gravel immediately underlying the topsoil. May vary in thickness from a few inches to several feet. Frosted grains suggest deposit by wind.

- Saprolite: A soft, earthy, clay-rich, thoroughly decomposed rock formed in place by chemical weathering of the bedrock.

- Lacustrine: Pertaining to, produced by, or formed in a lake.

- Fluvial: Pertaining to, produced by, or formed in a river.

- Varved: Alternating thin layers of silt and clay ranging in thickness from a fraction of an inch to several inches that represents annual cycles of deposition.

3.5-3.10 Unified Soil Classification (USC) Designation

The Unified Soil Classification (USC) designation should be given for each soil sample. Figure 3.5-2 is a flow chart depicting the procedure for classifying soils. Figure 3.5-6 is a presentation of the USC designation that may be used as a guide. USC designation symbols follow:

- GW: well-graded gravels; gravel-sand mixtures
- GP: poorly graded gravels
- GM: silty gravels; gravel-sand-silt mixtures
- GC: clayey gravels; gravel-sand-clay mixtures
- SW: well-graded sands; sand-gravel mixtures
- SP: poorly graded sands
- SM: silty sand
- SC: clayey sands; sand-clay mixtures
- ML: silts; silty, very fine sands or clayey silts
- CL: clays of low to medium plasticity; silty, sandy, or gravelly clays
- CH: inorganic clays of high plasticity; fat clays
- MH: plastic silts; micaceous or diatomaceous silts

- o OL: organic silts and organic silty clays of low plasticity

- o OH: organic clays of medium to high plasticity

3.5-3.11 Special Conditions or Notes

During the sampling process, observations made which may be of importance in the overall sample identification, should be noted after the sample description. Items such as sample disturbance and foreign substances (e.g., bricks, mortar, or other substances which may indicate filled material or contamination) should be noted with the sample description. Separate measurements for contaminants should be made and recorded separately beside the sample description in the field log.

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U.S.Army Corps of Engineers, 1953, The unified soil classification system: Vicksburg, MS, Waterways Experiment Station, Technical Memorandum no. 3-357, v. 1, 30 p.

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SECTION 3.5 SOIL CLASSIFICATION

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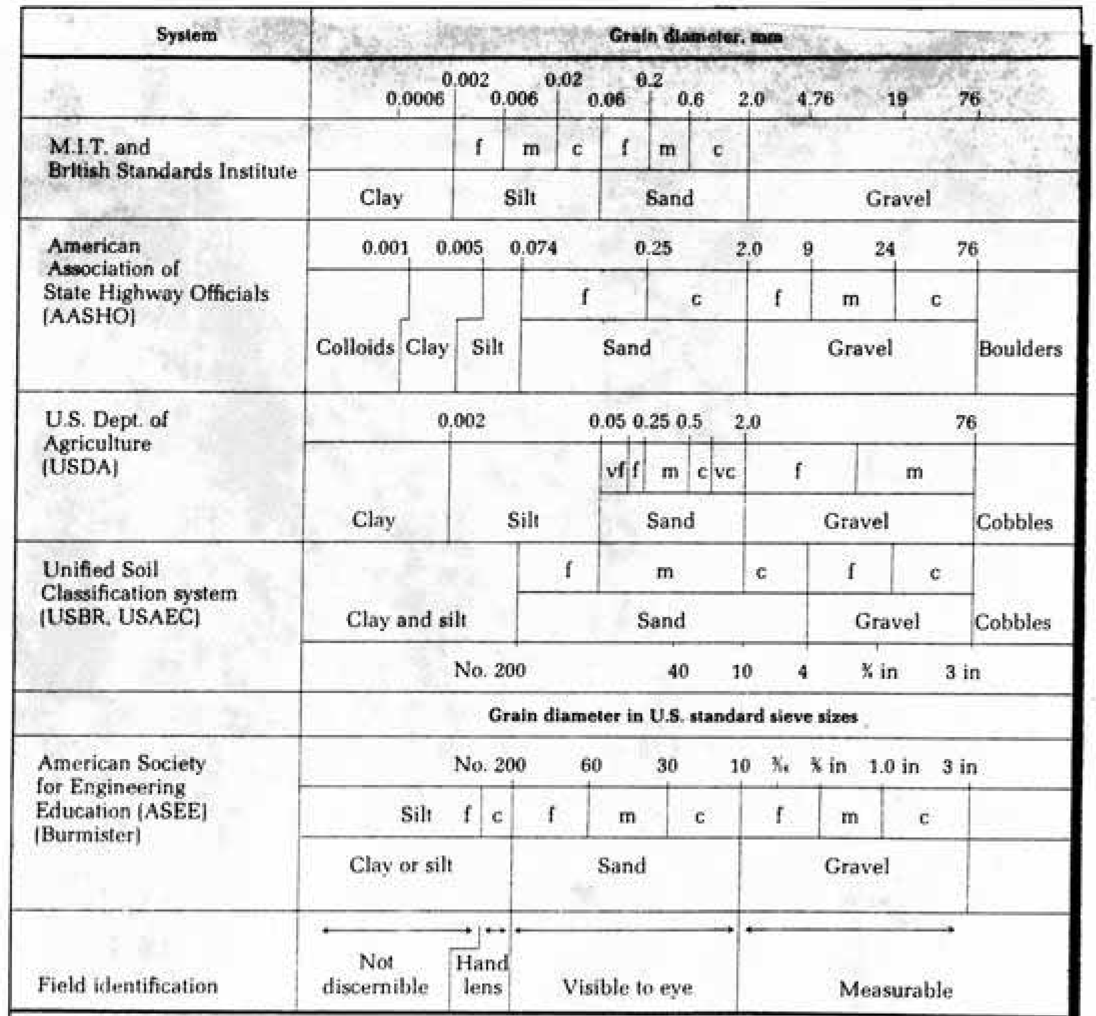


Source: Hunt (1984)

Figure 3.5-1

Soil Classification Systems Based on Grain Size.

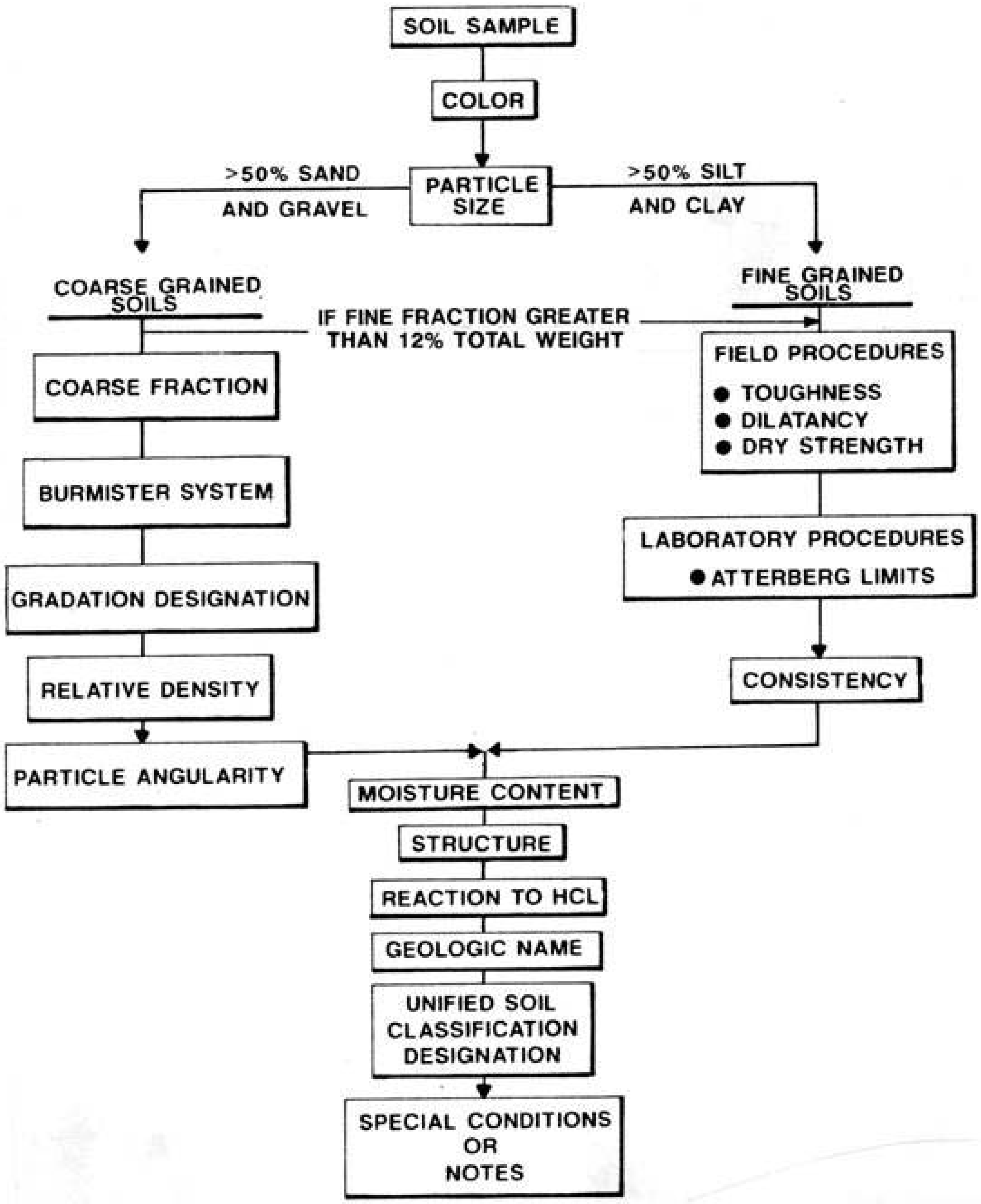
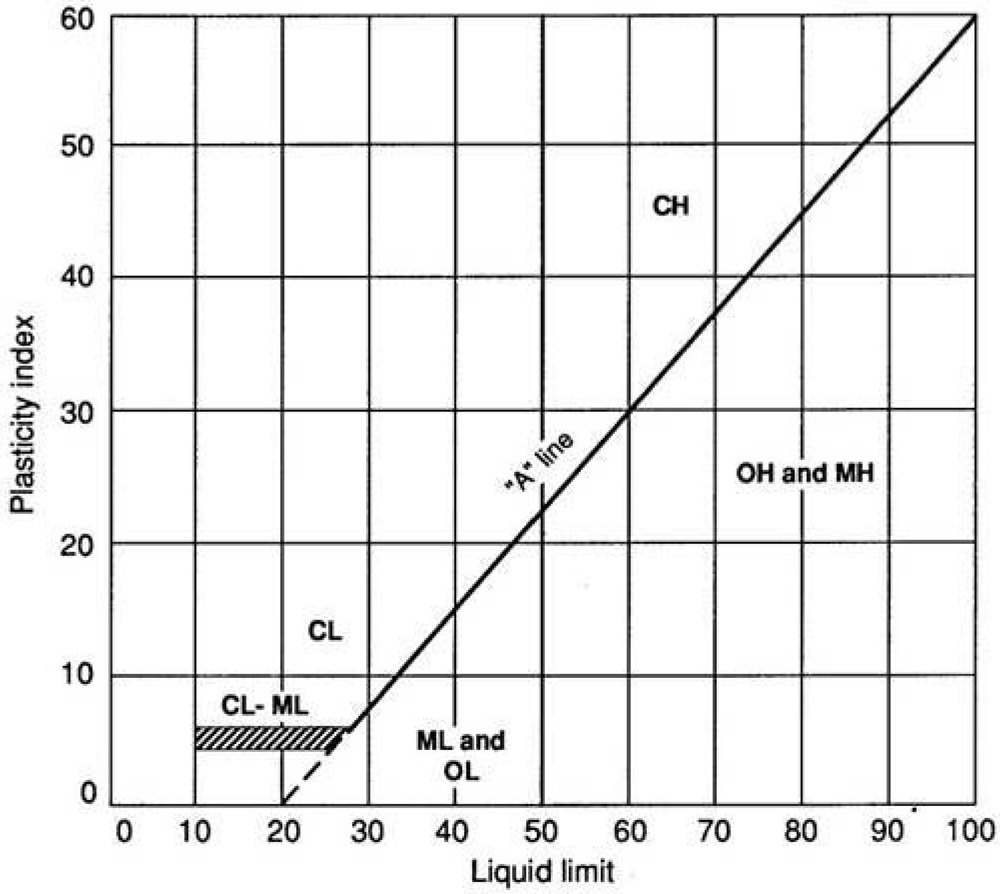


Figure 3.5-2

Source: MADEP

Soil Classification Flow Chart.

Plasticity Chart

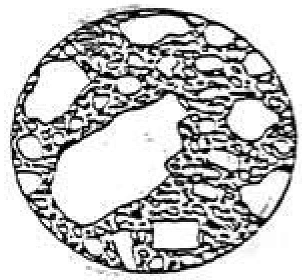


CH = Inorganic Clay - high plasticity
CL = Inorganic Clay - low to medium plasticity
MH = Inorganic Silt - elastic silt
ML = Inorganic Silt - slight plasticity
OH = Organic Clays - medium to high plasticity
OL = Organic Silts - low plasticity

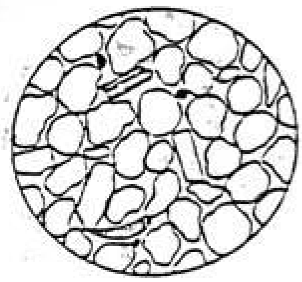
Figure 3.5-3

Plasticity Chart

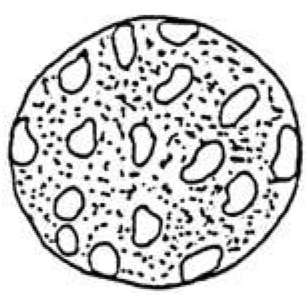
Source: Winterkorn et al. (1975)



WIDELY GRADED
(Poorly Sorted)



UNIFORMLY GRADED
(Well Sorted)

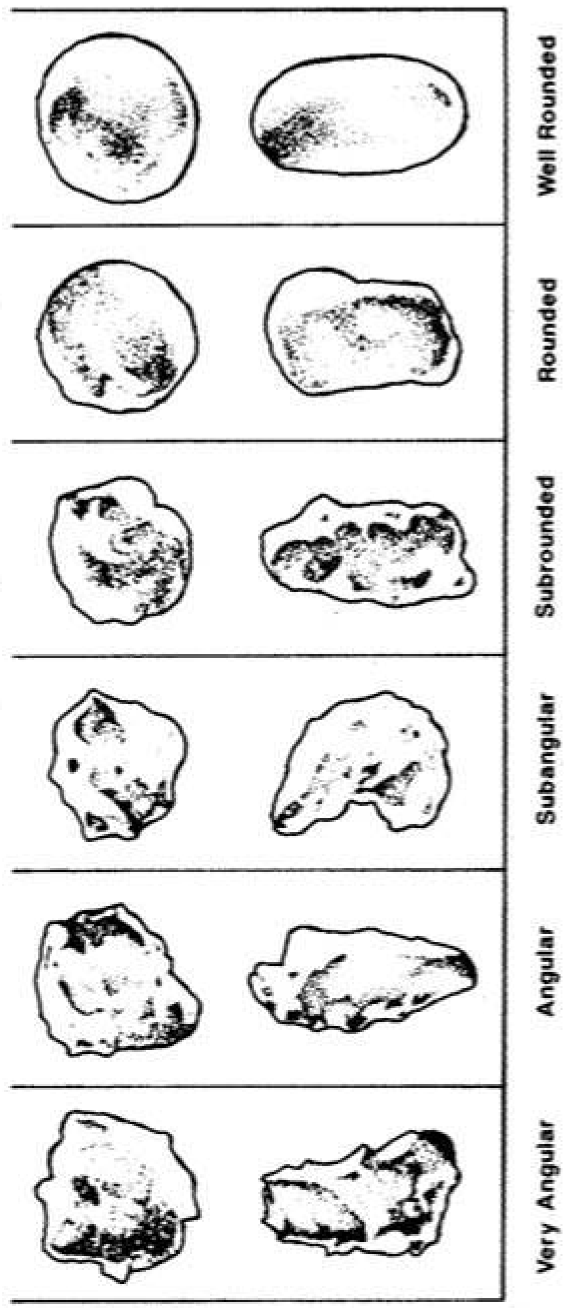


GAP GRADED
(Bi-Model)

Source: Modified After Compton (1962)

Figure 3.5-4

Gradation Designation.

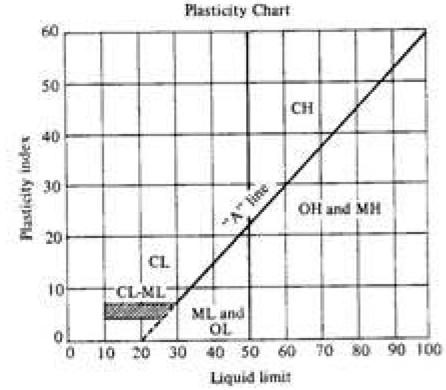


Source: Compton (1985) after Powers (1953)

Figure 3.5-5
Particle Angularity.

Major Divisions			*Group Symbols*	*Typical Names*	*Laboratory Classification Criteria*		
Coarse-grained soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size)	Clean gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows: Less than 5 per cent: GW, GP, SW, SP; More than 12 per cent: GM, GC, SM, SC; 5 to 12 per cent: *Borderline* cases requiring dual symbols[b]	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravels with fines (Appreciable amount of fines)	GM[a] d / u	Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures		Atterberg limits below "A" line with P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines		$C_u = \frac{D_{60}}{D_{10}}$ greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP	Poorly graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM[a] d / u	Silty sands, sand-silt mixtures		Atterberg limits above "A" line or P.I. less than 4	Limits plotting in hatched zone with P.I. between 4 and 7 are *borderline* cases requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures		Atterberg limits above "A" line with P.I. greater than 7	
Fine-grained soils (More than half material is smaller than No. 200 sieve)	Silts and clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	Plasticity Chart (see below)		
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL	Organic silts and organic silty clays of low plasticity			
	Silts and clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts			
			CH	Inorganic clays of high plasticity, fat clays			
			OH	Organic clays of medium to high plasticity, organic silts			
	Highly organic soils		Pt	Peat and other highly organic soils			

Plasticity Chart



Source: Winterkorn et al. (1975)

Figure 3.5-6

Unified Soil Classification System.

NAME	SIZE LIMITS (SIEVE SIZES)	FAMILIAR REFERENCE
Boulders	12 inches or more	Basketball or larger
Cobble	3 to 12 inches	Softball
Coarse Gravel	3/4-inch to 3 inches	Baseball
Fine Gravel	No. 4 Sieve to 3/4-inch	Pea
Coarse Sand	No. 10 to No. 40 Sieve	Rock Salt
Medium Sand	No. 40 to No. 10 Sieve	Sugar, Table Salt
Fine Sand	No. 200 to No. 40 Sieve	Powdered Sugar
Silt and Clay	Less than No. 200 Sieve	Flour

Table 3.5-1

Particle Size Identification Based on Unified Soil Classification System.

Source: Hunt (1984)

Component	Written	Descriptor	Percentage Range by Weight
Principal	Capitals		> 50 percent
Minor	Lower Case	and	35 to 50
		some	20 to 35
		little	10 to 20
		trace	0 to 10

Source: Hunt (1984)

Table 3.5-2

Burmister System Desciptors Suitable for Estimating the Distribution of Gravel-, Sand-, and Silt-size Particles.

DESCRIPTION	CRITERIA
Very Soft	Extruded between fingers
Soft	Molded by slight pressure
Medium (firm)	Molded by strong pressure
Stiff	Indented by thumb
Very Stiff	Indented by thumbnail
Hard	Difficult to indent

Consistency Descriptor	SPT N-Value	Undrained Shear Strength (tsf)*	Unconfined Comp. Str. Descriptor (tsf)*
Very Soft	<2	<0.10	<0.25
Soft	2 to 4	0.10 to 0.25	0.25 to 0.50
Medium (firm)	4 to 8	0.25 to 0.5	0.50 to 1.0
Stiff	8 to 15	0.5 to 1.0	1.0 to 2.0
Very Stiff	15 to 30	1.0 to 2.0	2.0 to 4.0
Hard	>30	>2.0	>4.0

* Tons per Square Foot

Source: Hunt (1984)

Table 3.5-3

Criteria for Describing Consistency Based on Field Tests.

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.6 IN-SITU SAMPLING OF ROCK

SECTION 3.6
IN-SITU SAMPLING OF ROCK

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SECTION 3.6 IN-SITU SAMPLING OF ROCK

3.6-1 PURPOSE

Environmental assessments at contaminated sites often require the determination of the presence of chemical contamination in bedrock and the extent to which the contamination can migrate in the rock mass. Hydrogeological assessments for water supply purposes require a thorough understanding of the competency of the bedrock and its water quality. To assess the presence and potential for fluid migration in rock, samples of the rock mass must be obtained for visual and laboratory analysis. These analyses will yield the following characteristics of the rock, which are necessary for classification:

- lithology
- mineralogy
- structure
- weathering
- hardness
- permeability

Methods of sampling rock for environmental assessments include the following:

- surface rock sampling
- rock core sampling

Field mapping of exposed bedrock (outcrops) is usually the first step in a site investigation. Field mapping is limited to a description of the near-surface bedrock type and conditions, and this method is often severely hampered in New England due to the limited number of exposures in glaciated regions. Consequently, surface mapping is often supplemented with subsurface investigations (i.e., drilling and logging of bedrock borings). Drilling bedrock borings has an added advantage in that it provides data on how the bedrock conditions change with depth. Typically, monitoring wells are installed in these borings to obtain hydrogeologic data. Generally, a thorough hydrogeologic or geotechnical field investigation incorporates all three methods to adequately characterize the bedrock conditions at the site.

This Standard Reference (SR) presents devices/equipment and techniques for the collection of both surface and subsurface rock samples. While many sampling devices are available to collect rock samples, this section provides SRs for only those most commonly used in environmental assessments. Other equipment commonly used for traditional geotechnical engineering studies are listed without detailed SRs.

3.6-2 SURFACE ROCK SAMPLING

3.6-2.1 Methodology

Sampling the rock surface can be done manually with picks and hammers or other probing devices, or with a mechanized excavator (e.g., a backhoe). The depth of sampling is limited by the ability of the equipment to penetrate the rock surface.

3.6-2.2 Procedure

1. Sketch the area to be sampled noting the following:

    - orientation of rock structure
    - orientation of sample site to other physical features
    - areas of observed contamination, if any

2. Obtain a sample of rock using equipment capable of breaking a piece of the rock mass. The equipment used will be decontaminated in accordance with the protocols established in the project plans, if necessary.

3. Log and classify the rock sample in accordance with Section 3.7 Rock Classification.

Advantages

- Inexpensive method to obtain several surficial samples.

- A larger surface of the rock is available for inspection and measurement of fracture and foliation patterns.

Disadvantages

- Only shallow samples can be obtained.

- Limited to outcrops or areas where the bedrock surface can be exposed.

- Limited information regarding the rock mass.

- Increased potential for worker exposure to contaminants, if present where samples are obtained.

3.6-3 ROCK CORE SAMPLING

3.6-3.1 Sampling Equipment

The primary objective of rock core sampling is to obtain a continuous sample of the intact rock mass to allow determination of the geologic and engineering properties of the rock. In addition to collection of rock samples, the completed rock-core borehole may be tested and monitored to determine permeability, in-situ stresses, orientation and openness of discontinuities, ground water conditions, the presence of gas, and squeezing or expansive properties of the rock. The borehole may be further utilized for in-situ testing purposes, borehole geophysical surveys, and the installation of various types of monitoring equipment or instrumentation.

Rock core is obtained with a core barrel sampling device. The primary purpose of the core barrel is to recover in a relatively undisturbed state the total length of rock that has been physically cored. When drilling in competent rock, total recovery is rarely a problem; however, when the formation is highly weathered, fractured, or soft, core recovery becomes more troublesome. The strength and behavior of the rock mass is primarily dependent on various inherent discontinuities; core that is not recovered may be the result of such factors, which might represent significant environmental implications.

Selection of the most practical core barrel for the anticipated bedrock conditions is important. Selection of the correct drill bit is also essential to good recovery and drilling production. Selection of the diamond size, bit crown contour, and number of water ports is dependent on the characteristics of the rock mass. The use of an incorrect bit can be detrimental to the overall core recovery. Generally, fewer and larger diamonds are used to core soft formations. Smaller diamonds mounted on the semiround bit crown are used in hard formations. Special impregnated diamond core bits have been developed for use in severely weathered and fractured formations where bit abrasion can be very high. Different types of core bits are shown in Figure 3.6-1. Table 3.6-1 shows the standard sizes of diamond core bits and wireline. W.L. Acker III summarizes drilling equipment and bits in Chapters 10 and 11 of "Basic Procedures for Soil Sampling and Core Drilling" (1974). Core barrels to be considered for use in environmental assessments include the following:

- double-tube core barrel (Section 3.6-3.1.1)
- triple-tube core barrel (Section 3.6-3.1.2)
- wireline core barrel (Section 3.6-3.1.3)
- oriented-core equipment (Section 3.6-3.1.4)

Other rock coring equipment occasionally used for geotechnical engineering studies include the following:

- shot-core barrel (Section 3.6-3.5.1)
- steel-tooth cutter barrel (Section 3.6-3.5.2)
- percussion core barrel (Section 3.6-3.5.3)
- single-tube core barrel (Section 3.6-3.5.4)
- integral sampling method (Section 3.6-3.5.5)

However, such equipment/methods are not used for environmental assessments; therefore, SRs are not provided in this section. A brief description of these items is included in Section 3.6-3.5.

The following subsections describe the rock core sampling equipment and associated advantages and disadvantages for the equipment most commonly used for environmental assessments.

3.6-3.1.1 Double-tube Core Barrel

The most widely used rotary-core barrel is the double-tube. It is a single-tube barrel containing a separate and additional inner tube. It is available with either a rigid or swivel-type inner tube construction (Figure 3.6-2). In the rigid types, the inner tube is fixed rigidly to the core barrel head so that it rotates with the outer tube. In contrast, the swivel-type inner liner is supported on a ball-bearing carrier, which allows the inner tube to remain stationary (or nearly so) during rotation of the outer barrel. The sample or core is cut by rotation of the diamond bit. The bit is in constant contact with the drilling fluid as it flushes out the borehole cuttings. The addition of bottom discharge bits and fluid control valves to the core barrel system minimizes the amount of drilling fluid and its contact with the sample, which further decreases sample disturbance.

The swivel-type, double-tube core barrel or equivalent is the preferred type of double-tube core barrel for environmental assessments. This core barrel has a nonrotating, adjustable, chrome-plated inner liner that is available in either solid- or split-tube versions. The split-tube version is preferred for environmental assessments.

Depending on the quality of the rock being cored, the inner tube may be alternately used in the solid or split inner modes. The solid tube is used primarily in very sound and competent portions of the rock, while the split tube is used in the weaker and more weathered portions.

The design of the split inner tube allows expansion of the two liner halves during the core recovery process. This feature allows swelling clays or highly fractured material, which could normally block a conventional solid liner, to move up into the chrome-plated liner, reducing blockage of the core and improving recovery in lower-quality rock. This expansion feature, however, limits its usefulness in wireline systems. Wireline systems utilize a rope made of steel wires. This steel rope (wireline) in used, to hoist drill pipes, and drilling tubes up the inside of the bore hole.

An additional and major advantage of the split tube is apparent during subsequent surface handling of the recovered core. The inner tube is easily removed from the core barrel, and the filament tape that binds the liner halves together is cut, separating the two sections and exposing the recovered core in a nearly in-situ state. This design feature of the split liner eliminates the necessity of "banging out" the core sample with a hammer, as is frequently done with a conventional solid tube. Such core removal may severely disturb and alter the quality of the recovered core, potentially leading to erroneous conclusions about the overall rock mass.

The split inner tube is used in various types and sizes of double-tube core barrels. The capability of improving recovery in poor-quality rock and the subsequent surface handling advantages make it a valuable addition to the equipment for rock core evaluation.

Advantages

- Widely used.
- May block less frequently than solid tube.
- Improved recovery over single-tube barrel.
- Suitable for highly fractured or weathered rock.
- Less disturbance of the rock core compared to a single-tube barrel.
- Provides an opportunity to view the core in its "as drilled" state when the barrel is opened.

Disadvantages

- Not suitable for wireline systems.
- More complex and difficult than the single-tube core barrel to decontaminate, if necessary.

3.6-3.1.2 Triple-Tube Core Barrel

The triple-tube core barrel adds a separate, nonrotating liner to the double-tube core barrel inner tube. This liner, which retains the sample, consists of a clear plastic solid tube or a split, thin metal liner. Each type of liner has its distinct advantages and disadvantages; however, they both have the advantage of minimizing sample handling and disturbance during removal from the core barrel.

The NWM3 triple-tube core barrel, manufactured by Acker Drill Co., Inc., is an example of a double-tube core barrel modified to include an additional (third) inner, solid, clear plastic liner, which retains the sample.

The purpose of the third, nonrotating inner liner is to provide a temporary storage container for the recovered rock core during transportation and storage. The NWM3 incorporates an adjustable inner liner that can control the flow of water to the bit, an important design feature in variable formation conditions. Triple tube systems yield smaller core sizes than double tube systems of the same letter designation because more room is taken up by the extra tube.

A special hydraulic or pneumatic jack is required for inner tube removal and subsequent sample extraction from the inner tube. Although the solid plastic sample liner tube has definite advantages during transportation and storage, it can impede field examination, photography, and evaluation of the core immediately upon recovery.

Advantages

- o May improve core recovery of poor-quality rock compared to single-tube core barrel.

- o Core can be seen in its "as drilled" state when the barrel is opened in the laboratory - important in highly fractured or weathered rock.

Disadvantages

- o Large number of components require more time to decontaminate, if necessary, than single-tube barrels.

- o Potential for jamming of the rock core.

- o Core not readily available for field examination.

3.6-3.1.3 Wireline Core Barrel

In conventional rock coring, the entire drill stem and core barrel must be removed after each core run. This is a time-consuming operation in deep boreholes; in addition it creates an inherent risk of collapse of the rock into the unsupported borehole. The wireline system is designed to recover rock core without removing the drill stem from the borehole after each core run. An illustration of a wireline core barrel assembly is shown in Figure 3.6-3.

When drilling is completed, a special latching mechanism is attached to the end of a cable and lowered through the drill rods; it attaches to the inner tube head of the core barrel. The inner tube, containing the rock core, is rapidly brought to the surface, leaving the outer core barrel and drill rods still in position within the borehole. The wireline can also be adapted for horizontal drilling and triple-tube applications.

Advantages

- o Reduces time to retrieve the rock core sample in deep boreholes.
- o Borehole remains supported for entire length.

Disadvantages

- o Is more time consuming if borehole is less than 50 feet deep.

- o Special inner core tube and special latching mechanism are expensive to rent or purchase.

- o Large number of parts discontinued.

3.6-3.1.4 Oriented Core Equipment

Determination of the true attitudes of planar structural discontinuities of rock encountered during subsurface explorations may be accomplished in two ways: (1) by measuring the azimuth and dip of the discontinuities recorded on the physical core recovered; or (2) by determining the orientation of the structural features from their presence on the borehole wall. This information is of particular importance to the engineering geologist and geotechnical engineer. Although not frequently used for environmental assessments because of cost, it can be strategically used to provide cost-effective information on the orientation of rock mass discontinuities and their influence on contaminant migration.

Various methods, ranging from simple to complex, have been developed to establish a reference point of known orientation so that all structural aspects of the borehole may be related to it and their absolute orientations determined. The Integral Sampling Method is one of the more complex methods of achieving structural orientation of the in-situ rock and total rock core recovery. The most frequently used equipment are orienting core barrels, which combine conventional rotary rock drilling equipment with specialized core barrels that mark the core so that it can be subsequently oriented using geologic interpretive methods.
Other techniques and equipment available but not considered suitable for most environmental assessments include paint and acid markers, Craelius core orientator and physical core alignment methods. The latter includes the following:

(a) Orienting Core Barrel

Specialized core barrels have been developed that scribe a reference mark on the core as it is drilled. Special recording devices within the core barrel relate known azimuth orientations to the reference mark so that when the core is subsequently removed from the core barrel, it can be oriented to the position it occupied in-situ.

(b) BHP Orienting Core Barrel

The BHP core barrel, developed by Broken Hill Proprietary Co. of Australia, utilizes a compass and chart recording system that aligns itself with a scribing diamond. As the core passes the drill bit into the inner liner, a reference line of known orientation is scribed on the rock core.

(c) Christensen-Hugel Orienting Core Barrel

Operation of the C-H core barrel, developed and patented by the Christensen Diamond Products Co., is similar to that of the BHP barrel. Incorporated within the core barrel is an Eastman multi-shot directional survey instrument that photographically records the compass bearing and plunge of the borehole. In addition, it records the orientation of reference grooves that are cut into the core as it enters the barrel.

Advantages

- o Determines actual orientation of rock discontinuities.

Disadvantages

- o Very expensive.
- o Requires staff experienced in its use.
- o Good recovery is required for accurate interpretation.
- o Will not function in strongly magnetic environments.

3.6-3.2 Rock Coring Procedure

1. Advance the borehole to the rock surface using the techniques described in Section 3.2 Drilling Techniques.

2. Firmly seat the casing into the bedrock surface to seal off the borehole from the overlying strata and flush the borehole is with clean water.

3. Carefully inspect the core barrel to ensure that all equipment is operating properly. If necessary, decontaminate the core barrel in accordance with the project plans.

4. Select bit types to produce the optimum recovery of each type of rock to be cored. It may be desirable to change bits depending on the rock types encountered. When production drops worn out or damaged bits must be changed.

5. Lower the core barrel into the borehole and connect the drill stem to the drill rig.

6. Use potable water the drilling fluid unless an alternate source has been approved by DEP and is identified in the project plans. No exceptions are allowed if the bedrock to be cored is an identified aquifer. Test the water source if chemical samples are to be obtained later from the borehole or the monitoring well.

7. Place marks between 1 and 6 inches apart on the slide piston to monitor the rate of advancement of the core barrel.

8. Advance the core barrel by controlling the rate of feed, rotation speed, and flow of drilling fluid. To minimize core losses in soft, erodable rock, the following measures are recommended:

   - o Restrict drilling to short runs of 2 to 3 feet each.

   - o Keep drilling water pressure low (under 150 pounds per square inch [psi].)

   - o Keep feed pressure under 100 psi.

- o Use a split inner core barrel.

9. Screen return water for volatile organic compounds (VOCs) using an organic vapor analyzer.

10. Once the core barrel is advanced to the required depth or progress stops as a result of a blockage, stop the rotation, terminate the circulation of drilling fluid, and raise the drill stem a few inches to break the rock core from the rock mass.

11. Retrieve the core barrel. The drill rods and core barrel must be screened using an organic vapor analyzer as they are removed from the borehole.

12. Open the core barrel, observe and log the core, and place the recovered rock core in rock core boxes. If the drilling is taking place in a contaminated area, scan the core with an organic vapor analyzer. Details regarding rock core handling and logging are discussed in the next subsection (Sections 3.6-3.3 and 3.6-3.4).

13. Repeat steps 5 through 12 until the desired depth is achieved. When drilling in a contaminated area, a decontaminated core barrel must be used.

14. Split-spoon drive samples may be taken in any zones where it is not possible to drill and obtain satisfactory recovery of soft erodable rocks. Satisfactory recovery for this purpose is defined as 50 percent or greater.

The inspecting geologist must not permit a full coring run to be drilled if he/she suspects that residual core was left in the hole on the previous run. If this is believed to have occurred, he/she should direct that the next coring run be shortened by the length of core believed to have been left in the hole. This is necessary to prevent blocking the core barrel, grinding of the core and splitting open split-tube core barrels.

3.6-3.3 Sample Handling and Storage

Upon removal of the core barrel from the drillhole, wash the core while it rests in the liner half if a split tube has been used. Care must be used in washing to avoid removing small pieces of core or soft joint or vein fillings. If the rock is soft, friable, or otherwise erodable, and, in the opinion of the inspecting geologist, washing will damage the core, the washing process may be omitted.

Place the core in wooden boxes specially constructed to hold and store rock cores (Figure 3.6-4). Place the core in the core box with the top of the run at the upper left corner; place the remaining core sequentially from left to right and from the rear (nearest the cover hinge) of the box to the front. If a split tube has been used, transfer the core to cardboard or plastic half-rounds prior to placement in the box.

Place wood blocks marked with the appropriate depth and run number between each separate core run. In addition, wherever core is lost due to the presence of a cavity or large joint (open or filled), place a spacer block in the proper relative position in the core box. The spacer is the same length as that of the lost core. Mark the depth range on the spacer along with the reason for the missing core (e.g., cavity or large joint).

Mark the core box on the top and both ends with the project name, site identification, boring number, depth range, and box number. The Rock Quality Designation (RQD) should be indicated on all core boxes.

3.6-3.4 Logging Rock Cores

The basic objective of describing rock cores is to provide a concise record of important geologic and physical characteristics of the rock core (e.g., rock type/name, lithological/structural features, any physical conditions, including alteration, and any special geologic, mineralogic, or other features pertinent to interpretation of the subsurface conditions).

Drill core of some rock types change (sometimes rapidly) once removed from its natural environment. These can be a change in physical properties on exposure to air, often aggravated by physical degradation of the core due to rough handling. It is, therefore, advisable to do all the logging immediately at the drill site. Note all physical changes that the core incurs; therefore, look at and possibly relog all cores that have been exposed to the air for some time. Note effects on the physical properties of the rock (e.g., slaking action or effects of melting of frost or ice). This will give some indication of the long-term behavior of the material once it is exposed to the atmosphere.

Personnel who handle diamond-drill core must avoid rough handling. Sampling should be done with the minimum possible destruction of the core. Permanently store core in a well-protected shelter or core shack. Depending on the situation, it is often advisable to photograph the core at the drilling site before it is transported or damaged. Photographs provide an inexpensive permanent record of the core and may prove valuable at a later date for general lithological, fracture density, and rock quality assessments, as well as for pictorial documentation in reports and evidence during litigation.

3.6-3.4.1 Geologic Core Log

The geologic borehole core log should contain a systematic description of lithological characteristics of each rock type encountered, using the procedures provided in Section 3.7 Rock Classification. Include a graphic or symbolic log. Typical borehole core logs are shown in Figures 3.6-5 and 3.6-6.

The structural part of the log should contain details on major and minor structures and information on mechanical properties of the rock. Log both descriptively and graphically any discontinuities in the core. Record all relevant geologic structural features in the core logger

Recognition of the generic type of discontinuity may not be possible in the core. The logger should be concerned with mapping only naturally occurring discontinuities. Do not record any cracks or irregular fractures caused by poor coring and handling techniques. Special effort should be made to familiarize the logger with the difference between induced and naturally occurring fractures in the core.

The mechanical properties of the rock core can be assessed in terms of core recovery, RQD, hardness, weathering, strength, and fracture density to indicate the variation in rock quality.

3.6-3.4.2 Logging Procedures

Note the following features for all rock types:

- Rock type description (see Section 3.7).
- Attitude of bedding, cleavage, or foliation planes, and the ease of splitting along such planes.
- Attitude and degree of jointing, whether open or filled, as well as evidence of shearing, crushing, or faulting.
- Degree of alteration or weathering, hardness of the rock, and other engineering properties.
- RQD for NQ or larger-size cores.

3.6-3.4.3 Rock Quality Determination (RQD)

The RQD (Deere, 1964) method of determining rock quality is as follows:

1. Sum the total lengths of core fragments, counting only those pieces of core that are 4 inches (10 cm) in length or longer (as measured along the vertical axis) and are hard and sound. If the core is broken by handling or by the drilling process, the fresh broken pieces are fitted together and counted as one piece, provided they form the requisite length of 4 inches (10 cm).

2. The RQD is represented as a percentage. The percentage is derived by dividing the total sum of core pieces (4 inches or greater) by length of the run minus the length of the core left in the hole times 100. See equation below:

$$RQD = \frac{\sum L(>4")}{(R-C)} \times 100$$

Where: ∑L(>4") = Sum of total length of core pieces 4 inches or greater
R = Length of total core run
C = Length of core left in borehole

Below is a table relating the RQD percentage to a qualifier word for use in the well logs when coring in bedrock.

RELATION OF RQD AND ROCK QUALITY

RQD (%)	Description of Rock Quality
0 to 25	very poor
25 to 50	poor
50 to 75	fair
75 to 90	good
90 to 100	excellent

NOTE: RQD can only be used on NQ core or larger. The RQD should always be shown on the core log as a percentage.

3.6-3.4.4 Documentation

All descriptive data shall be noted on the geologic core log by the geologist responsible for core logging. All completed boring logs shall be reviewed by a qualified geologist to assure completeness and technical accuracy. Any changes, additions, or deletions to the original field logs shall be made so that the original entry (words and/or numbers) remains legible. Under no circumstances will any erasures be allowed. If extensive deletions and additions are necessary, a second boring log form may be attached to the original and labeled with the original sheet number and a small "a" after said number. Upon completion of the review, the supervising geologist will initial and date the "Checked By" section of the boring log. All documentation originals shall remain in the project files.

3.6-3.4.5 Logging Equipment

The following equipment is used for geologic core logging:

- water supply for wetting core
- timepiece
- wooden core boxes (standard size) with wood blocks and hinged lids
- markers (indelible felt tip)
- labels
- acid bottle (dilute hydrochloric acid)
- pocket knife
- protractor (clear)
- magnifying hand lens
- collapsible, 6-foot folding ruler (marked in tenths)
- tape, 100-foot length (marked in tenths)
- sounding device
- reference materials and forms
- field notebook (waterproof) with a supply of pencils and pens
- camera (optional)
- Schmidt hammer (optional)
- point load tester (optional)

3.6-3.5 Other Specialty Core Barrels

Other types of specialty core barrels not normally used for environmental assessments include the following:

- calyx or shot-core barrel
- steel-tooth cutter barrel
- percussion core barrel
- single-tube core barrel

Because these types of core barrels are not commonly used, only a brief description of each type follows and advantages and disadvantages of each will not be included.

3.6-3.5.1 Calyx or Shot Core Barrel

This device, used to obtain large-diameter samples of competent rock core, derives its name from the use of chilled, hard steel shot as the cutting medium. Single-tube, heavy-walled, soft-steel cutter barrels of varying lengths and diameters are manufactured by Ingersoll-Rand Co. especially for this purpose. The steel shot is fed into the annular space between the core and core barrel and grinds its way to the bottom of the barrel. The steel shot, which is added as the drilling progresses, wears away the rock beneath the rotating barrel. A special "calyx" at the top of the barrel causes a reduction in the rate of the returning wash water and serves to collect the borehole cuttings and worn-out shot.

The core is removed from the borehole by a special large-diameter core lifter or by grouting the core inside the barrel with gravel. Considerable driller expertise is required with this method. The diameter of the core that can be recovered is limited only by the capability of the equipment to turn the core barrel and subsequently recover it.

3.6-3.5.2 Steel-tooth Cutter Barrel

Single-tube core barrels equipped with metal teeth are used for obtaining large-diameter cores in soft or seamy rock. However, any type of core barrel may be equipped with steel cutter teeth if the situation does not require the use of diamond bits. The Denison and Pitcher samplers discussed in Section 3.4 In-situ Sampling of Soil are generally equipped with this type of cutter bit. The steel cutter teeth may also be equipped with hard metal alloy inserts (e.g., tungsten-carbide) to improve drilling rates. The metal inserts may be replaced in the bit very readily, renewing a dull or damaged bit for additional drilling.

The steel-tooth cutter barrels are operated in the same manner as conventional rotary core barrels, except that they are rotated at much slower speeds.

3.6-3.5.3 Percussion Core Barrel

This core barrel consists of an outer barrel with a hardened steel bit and an inner barrel equipped with a pressure-release system and core retainer. The inner barrel remains in contact with the rock and slides down over the core as the surrounding material is cut away by raising and dropping the outer barrel.

Cores can be obtained in materials ranging from partially cemented soils to medium-hard rock. However, some disturbance and breakage of the core usually occurs during the dynamic sampling process.

3.6-3.5.4 Single-tube Core Barrel

The simplest type of rotary-core barrel is the single tube, which consists of a case-hardened, hollow steel tube with a diamond drilling bit attached at the bottom. The diamond bit cuts an annular groove or kerf in the formation to allow passage of the drilling fluid and cuttings up the outside of the core barrel. However, the drilling fluid must pass over the recovered sample during drilling; the single-tube core barrel cannot be employed in formations subject to erosion, slaking, or excessive swelling. Although the single tube is a very rugged core barrel and easy to operate, its limitations during sampling of both soil and rock are contributing to its declining application.

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SECTION 3.6
IN-SITU SAMPLING OF ROCK

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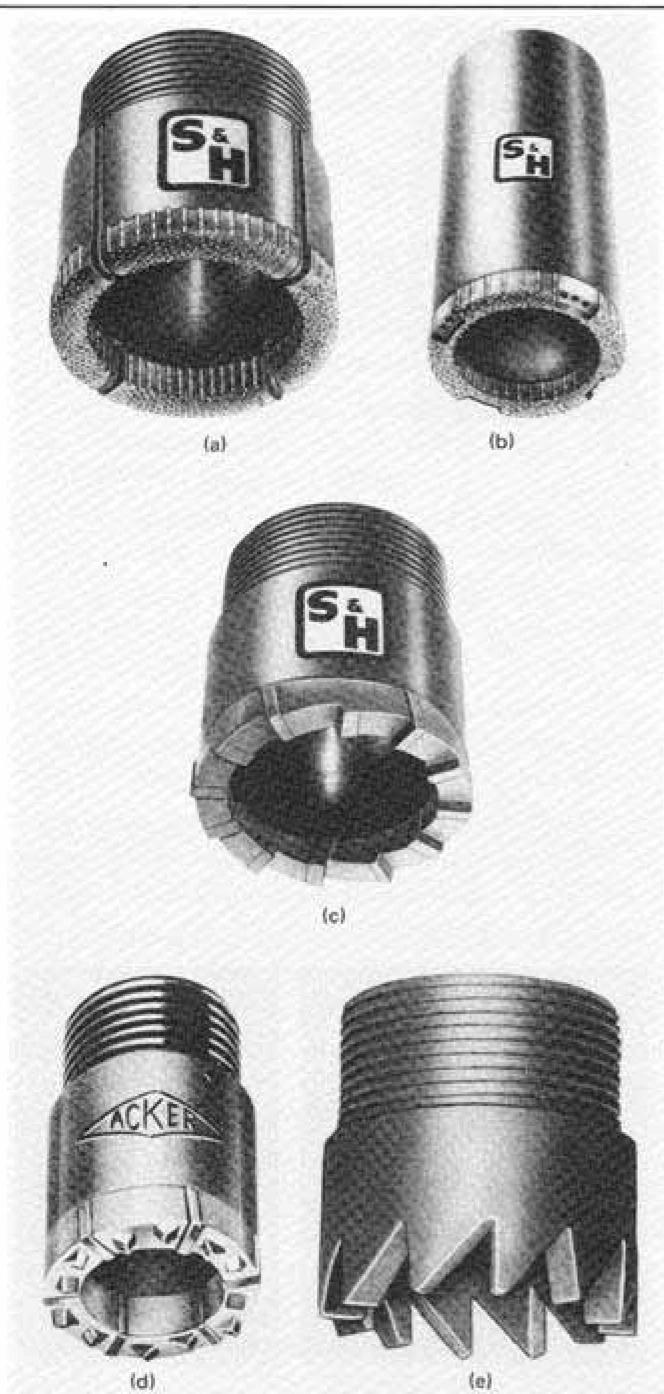
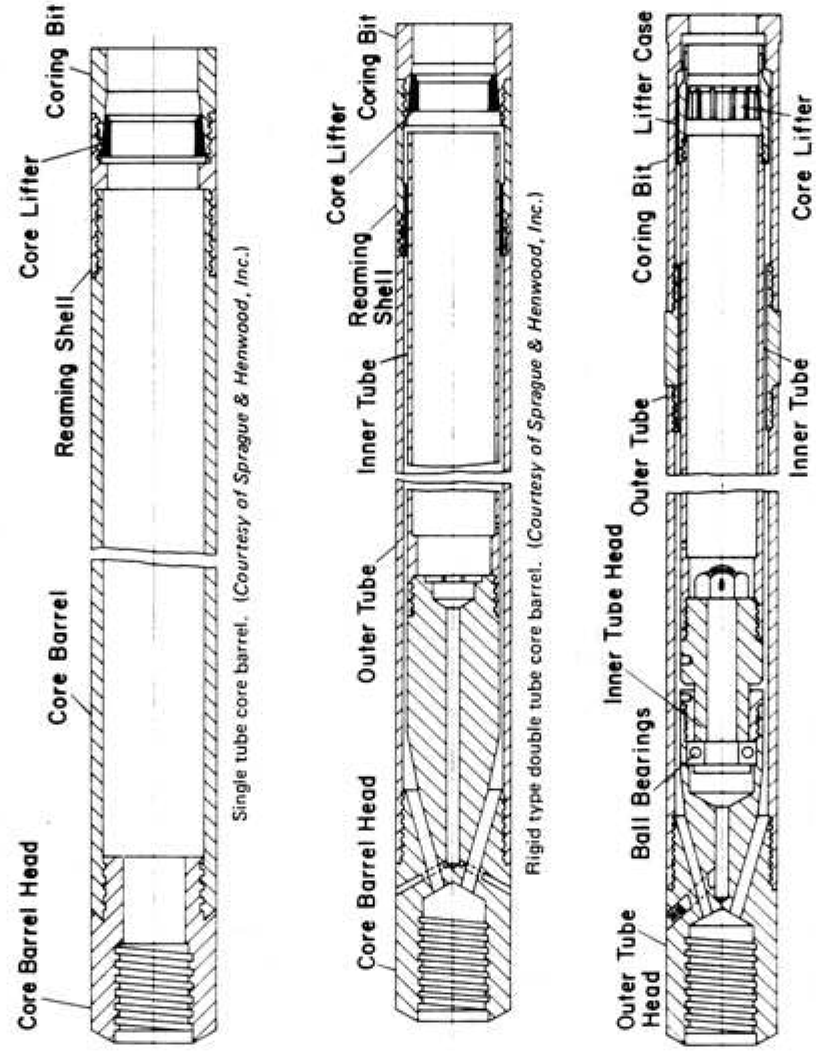


Fig. 1.36 Coring bits: (a) diamond with conventional waterways; (b) diamond with bottom discharge waterways; (c) carbide insert, blade type; (d) carbide insert, pyramid type; (e) sawtooth. (*Courtesy of Sprague & Henwood, Inc. and Acker Drill Co., Inc.*)

Source: Winterkorn et al. (1975)

Figure 3.6-1

Different Types of Core Bits.



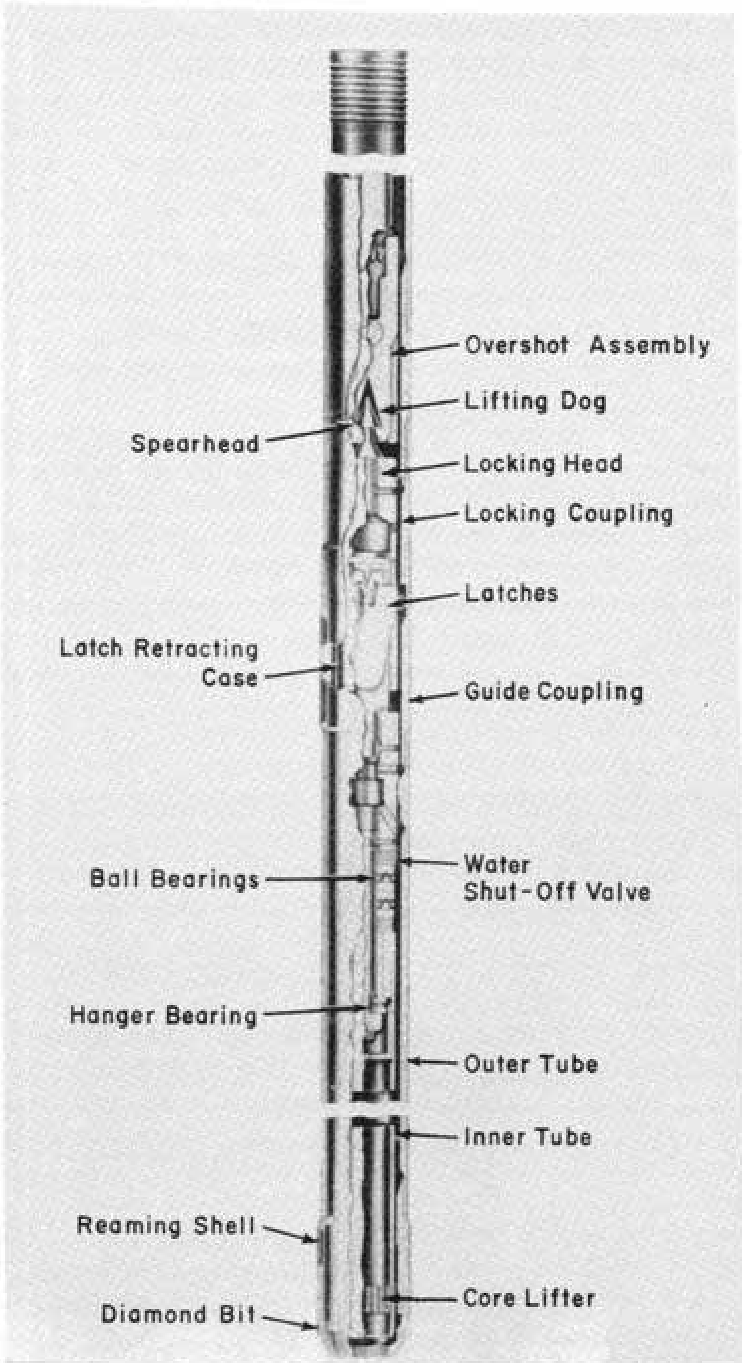
Single tube core barrel. (*Courtesy of Sprague & Henwood, Inc.*)

Rigid type double tube core barrel. (*Courtesy of Sprague & Henwood, Inc.*)

Figure 3.6-2

Single-and Double-tube Core Barrels.

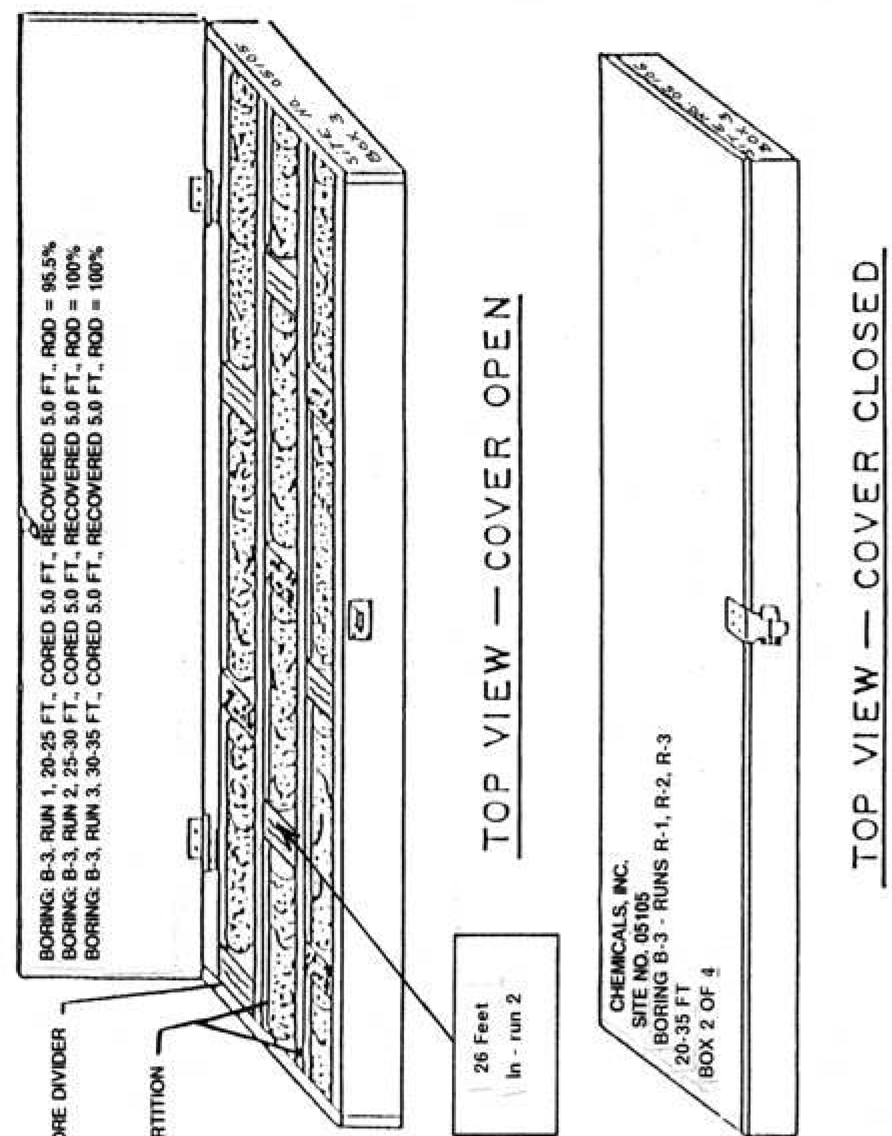
Source: Winterkorn et al. (1975)



Source: Winterkorn et al. (1975)

Figure 3.6-3

Wireline Core Barrel.



After Winterkorn et al. (1975)

Figure 3.6-4 Core Box.

			Boring no:
Client			Project no:
Contractor		Date started	Completed
Method	Casing size	PID	Protect'n level
Ground el.	Soil drilled	Rock drilled	⊻ Below grnd
Logged by	Ch'd by	Date	Site

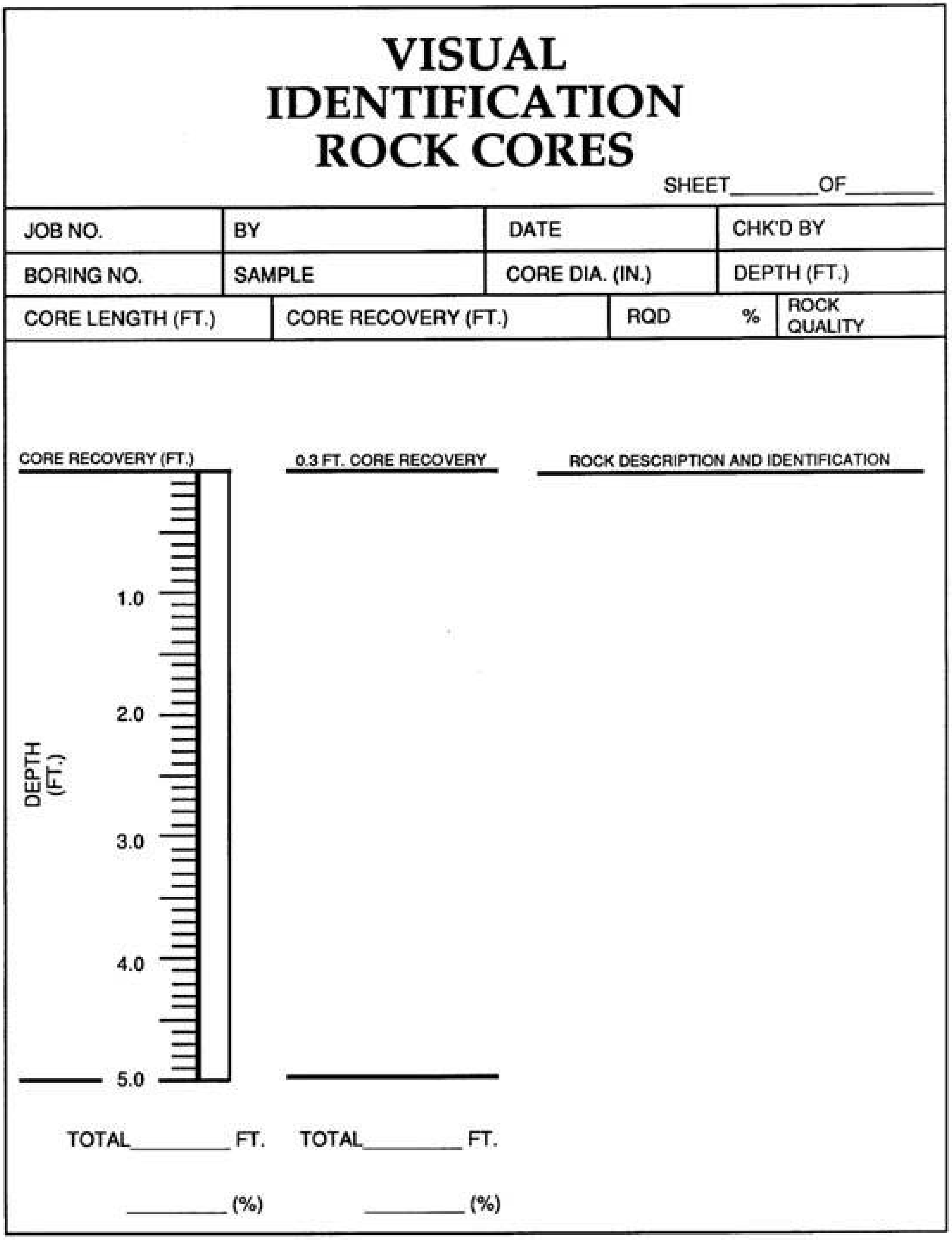
Depth (ft)	PID ambient air	Sample no. and type[1]	Sample	Pen / Rec	CLP	GC	PID sample (ppm)	Soil/rock description	Lithologic symbol	Well data	Soil class	Blows/6-in. or RQD % (0 20 40 60 80 100)	Elevation (ft)

[1] U = Thin wall tube S = Split spoon R = Rock

Source: ABB-ES

Figure 3.6-5

Example No. 1 of Borehole Core Log.



VISUAL IDENTIFICATION ROCK CORES

SHEET_______ OF_______

JOB NO.	BY	DATE	CHK'D BY	
BORING NO.	SAMPLE	CORE DIA. (IN.)	DEPTH (FT.)	
CORE LENGTH (FT.)	CORE RECOVERY (FT.)	RQD %	ROCK QUALITY	

CORE RECOVERY (FT.) | 0.3 FT. CORE RECOVERY | ROCK DESCRIPTION AND IDENTIFICATION

DEPTH (FT.)

1.0
2.0
3.0
4.0
5.0

TOTAL________ FT. TOTAL________ FT.

________ (%) ________ (%)

Source: ABB-ES

Figure 3.6-6

Example No. 2 of Borehole Core Log.

DCDMA standards	Core diam. (bit ID)		Hole diam. (reaming shell OD)	
Size	in	mm	in	mm
EWX and EWM	0.845	21.5	1.485	37.7
AWX and AWM	1.185	30.1	1.890	48.0
BWX and BWM	1.655	42.0	2.360	59.9
NWX and NWM	2.155	54.7	2.980	75.7
2¾ in, 3⅞ in	2.690	68.3	3.875	98.4
4 in, 5½ in	3.970	100.8	5.495	139.6
8 in, 7¾ in	5.970	151.6	7.755	196.8
Wireline Size				
AQ	1 1/16	27.0	1 57/64	48.0
BQ	1 7/16	36.5	2 23/64	60.0
NQ	1 7/8	47.6	2 63/64	75.8
HQ	2 1/2	63.5	3 25/32	96.0
PQ	3 11/32	85.0	4 53/64	122.6

Source: Hunt (1984)

Table 3.6-1

Standard Sizes of Diamond Core Bits and Wireline

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.7 ROCK CLASSIFICATION

SECTION 3.7
ROCK CLASSIFICATION

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3.7 ROCK CLASSIFICATION

3.7-1 PURPOSE

In hydrogeological and geotechnical studies, the purpose of rock classification is to identify the properties of the bedrock that influence site conditions, particularly such factors as water quality, ground water movement, and stability. Bedrock field investigations usually involve two parts: (1) description of the rock type(s) and associated textural characteristics, and (2) description of weathering and structural features of the bedrock. These properties affect the water-bearing and water transmission qualities of the bedrock. Field bedrock investigations may employ any or all of the following methods:

- Mapping bedrock exposures (outcrops) to determine rock type and condition; description of surface weathering and structural features.

- Subsurface investigations; logging of rock core or chips; geophysical logging of borehole.

- Installing bedrock monitoring wells to measure horizontal and vertical gradients, hydraulic conductivity, and water quality.

Descriptions used for the purpose of rock classification should employ, as much as possible, commonly accepted terms that will convey the same meaning to all who read them.

General reference material describing rock characteristics for classification purposes are contained in Appendix A. Examples of appropriate field logs are also included in Appendix A.

3.7-2 METHODOLOGY

A procedure for classifying and describing rocks in hand specimen or rock core is presented in the following paragraphs. The procedure has been divided into two parts: (1) determining the rock type and describing its associated petrologic properties, and (2) describing both large- and small-scale structural features.

3.7-2.1 Rock Type

Rocks are divided into three fundamental categories: igneous, sedimentary, and metamorphic. Categorization is based primarily on origin and secondarily on mineral content, grain size, and texture. Mineral content, grain size, and texture have a direct influence on the chemical and mechanical properties of a rock and, consequently, are important in hydrogeologic and engineering assessments. For example, many sedimentary sandstones have a primary permeability of 10^{-} to 10^{-} cm/sec due to the pore space between the grains that comprise the rock. In comparison, most intrusive igneous rocks are made up of interlocking mineral crystals, which in the absence of secondary fractures have a very low primary permeability range of 10^{-} to less than 10^{-} cm/sec. Proper identification of the basic rock type and associated properties is essential for accurate assessment of the hydrogeologic and engineering properties of the rock.

For a given rock sample, the following five rock properties will be described, and used to determine the basic rock type. The method and terminology for determining each petrologic property will be described in detail.

- hardness
- color
- texture
- grain size
- mineral content

Examples of field notes, tables, and logs to aid in describing rock types are included as figures and tables at the end of this section.

3.7-2.1.1 Hardness

Hardness is a measure of a rock's resistance to scratching or abrasion. Hardness should be measured by scratching the rock with a knife or hitting it with a geologist's hammer. The following criteria can be used to determine the hardness characteristics of a rock:

- Hard: can be scratched with knife or pick only with difficulty; hard blows of hammer required to detach hand specimen.

- Moderately hard: can be scratched with knife or pick; gouges or grooves to 1/16-inch deep can be incised by hand blow of point of a geologist's pick; hand specimens can be detached by moderate blow.

- Moderately soft: can be grooved or gouged 1/4-inch deep by firm pressure on knife or pick point; can be excavated in small chips to pieces about 1 inch maximum size by hard blows of the point of a geologist's pick.

- Soft: can be gouged or grooved readily with knife or pick point; can be excavated in fragments from chips to several inches in size by moderate blows of a pick point; small, thin pieces can be broken by finger pressure.

3.7-2.1.2 Color

Color is an important rock property used to distinguish one rock type from another. When describing the color, use only common names (e.g., gray, brown, or green) or simple combinations of these (e.g., yellow-brown). Also, the degree of color (i.e., light versus dark) should be employed. If minerals of different colors are present in the rock, a combination of color terms can be used to describe the dominant colors (e.g., white and black). Color descriptions should apply only to fresh rock surfaces. If the color refers to a weathered specimen, this should be noted. If more detail is needed, use the Rock Color Charts of the Geological Society of America, which incorporate hue, value, and chroma numbers.

3.7-2.1.3 Grain Size

Determination of grain size is important in assigning a rock sample to the correct rock group. Grain-size descriptions for clastic sedimentary rocks differ from those for crystalline sedimentary rocks and igneous and metamorphic rocks. The criteria for each category are presented herein. A hand lens is helpful in determining grain size. The following scheme can be used to describe the grain size for various rock types.

(a) Igneous, Metamorphic, and Crystalline Sedimentary Rocks

For igneous, metamorphic, and crystalline sedimentary rocks, the following textural terms should be used:

- Aphanitic: particles too small to be seen with the naked eye.
- Fine-grained: particles barely seen with the naked eye (<1 mm).
- Medium-grained: Particles seen with the naked eye to 1/8 inch (1 to 5 mm).
- Coarse-grained: particles greater than 1/8 inch (>5 mm).

(b) Clastic Sedimentary Rocks

For clastic sedimentary rocks, the following textural terms should be used:

- boulder: greater than 256 mm (>10 inches)
- cobble: 256 to 64 mm (10 to 2.5 inches)
- pebble: 64 to 4 mm (2.5 to .16 inches)
- granule 4 to 2 mm (.16 to .08 inches)
- very coarse sand: 2 to 1 mm (<.08 inches)
- coarse sand: 1 to 1/2 mm
- medium sand: 1/2 to 1/4 mm
- fine sand: 1/4 to 1/8 mm
- very fine sand: 1/8 to 1/16 mm
- silt: 1/16 to 1/256 mm
- clay: less than 1/256 mm

Figure 3.7-1 may be used to aid in the determination of grain size.

3.7-2.1.4 Texture

The texture of a rock refers to the overall aspect imparted by the sizes, shapes, and arrangement of grains. Textures and small-scale structures are often easier to recognize than minerals, and are a fundamental basis for rock classification. Textural terminology is generally specific to each basic rock type. A simplified, but adequate, list of textural terminology and criteria follows.

a) Igneous Rocks.

- Aphanitic: crystalline grains too small to be seen without magnification.
- Phaneritic: small grains are visible without magnification.
- Porphyritic: large crystals embedded in a more finely crystalline ground mass.
- Glassy: having no definite mineral grains.
- Fragmental: composed of fragments of minerals or angular, broken fragments of rocks.

(b) Sedimentary: Clastic Category

These rocks are made up of fragments or grains transported to the site of deposition (e.g., sandstone.)

- Sorting: a measure of how closely the clastic grains in a sediment approach being one size; ranges from poorly sorted to well-sorted (see Figure 3.7-2 to determine the appropriate classification.) In soils this referred to as grading (Section 3.5-3.3)
- Angularity: degree of rounding of individual grains; ranges from very angular to well-rounded (see Figure 3.7-3 to determine classification.)
- Sphericity: the degree to which the shape of the grain approaches that of a sphere.
- Bedding (Layering): parallel-banded or streaked appearance.
- Lamination: thin, 1/8-inch or less, parallel layers or beds.

(c) Sedimentary: Crystalline Category

These rocks are produced by in-situ mineral growth.

- Oolitic: consisting of spherical grains, (oolites).
- Massive: rock constituents neither grouped in layers nor oriented in parallel position.

(d) Metamorphic

Metamorphic textures are presented in Figure 3.7-4.

- Foliation: A planar arrangement of textural or structural features imparting a tendency to split into layers similar to the way the mineral mica breaks.
- Slaty: a pervasive parallel directional structure in fine-grained metamorphic rocks that permits splitting into thin sheets. The main difference between this and foliation is the slaty texture is finer grained.
- Phyllitic: a foliation that exhibits a silky sheen due to the parallel orientation of micaceous minerals. This is due to minute platy crystals.
- Schistose: a foliation in schist or other coarse grained rock due to parallel or elongate alignment of grains visible without magnification.
- Gniessic: a foliation due to compositional banding and roughly parallel alignment of minerals. This texture exhibits a striped appearance.

3.7-2.1.5 Mineral Content

If possible, the primary minerals in the rock will be identified (e.g., quartz, feldspars, and mica) and percentages estimated. Figure 3.7-5 can be used to aid in estimating percentages. Primary minerals are listed, starting with least abundant and progressing to the most abundant. A common rock name can be substituted for mineral names (e.g., granite or dolomite).

3.7-2.1.6 Identifying Rock Type

Rock types are identified using the five descriptive criteria as a basis. (The estimated percentages presented in Figure 3.7-5 rely on the visual prominence of the properties of texture, grain size, and mineralogy.) A simplified rock classification flow chart based on mineralogy, grain size, and texture is shown in Figure 3.7-6. Classification diagrams for each rock category (i.e., igneous, metamorphic, and sedimentary) are presented in Figure 3.7-7.

A descriptive rock name should be assigned. The degree of complexity will be based on the need for detail and the field person's ability. Generally, a simple rock name is sufficient. Examples of typical rock names, ranging from simple to detailed, follow:

- light gray limestone
- moderately soft, light brown to black phyllite
- hard, light gray, porphyritic granite
- soft, reddish-brown, well-sorted, rounded, pebble-cobble conglomerate

If possible and desirable, the formation name can be assigned to the rock; for example, "soft light gray to brown, garnet-staurolite schist, BERWICK FM".

3.7-2.2 Description of Weathering and Structural Features

In addition to describing the lithology of a rock sample, note the typical weathering and structural characteristics. Generally, these characteristics are identified by the inspection of surface exposures of bedrock in the vicinity of the area of interest. If possible, use a compass and clinometer to determine the orientation of structural features (e.g., foliation, bedding, and joints). Generally, outcrops are located on a site map and corresponding descriptions are noted in a field book. An example of a field description and tables to aid in describing weathering and structural features of bedrock outcrops are included in Appendix B. General methods for describing the weathering condition of an outcrop and its structural features are presented in the following section.

3.7-2.2.1 Weathering

Weathering results from the natural alteration of rock by physical and chemical processes. These processes include action of air and water, biological activity, and mechanical alteration. Weathering characteristics are important in both hydrogeological and geotechnical investigations. For example, permeability tends to increase as a function of weathering, and ultimately decreases again as the rock deteriorates towards a clayey soil. To classify the materials and attributes of the weathered rock, it is necessary to distinguish differing degrees of weathering in a rock. A descriptive classification of weathering based on simple field tests follows:

- Fresh: rock looks fresh; crystals look bright; a few joints may show slight staining; rock rings under hammer, if crystalline.

- Slight: rock generally looks fresh; joints stained and discoloration extends into rock up to 1 inch; may show thin clay coatings, if open; open joints may contain clay; in granitoid rocks, some occasional feldspar crystals are dull and discolored; crystalline rocks ring under hammer blows.

- Moderate: significant portions of the rock show discoloration and weathering effects; in granitoid rocks, most feldspars are dull and discolored, some appear like clay; rock has dull sound under hammer blows and shows significant loss of strength compared to fresh rock.

- o Moderately severe: all rock material except quartz minerals discolored or stained; in granitoid rocks, all feldspars dull and discolored and majority show kaolinization; rock shows severe loss of strength and can be excavated with geologist's pick; rock gives "clunk" sound when struck by hammer.

- o Severe: all rock material except quartz minerals discolored or stained; rock "fabric" clear and evident but reduced in strength to strong soil; in granitoid rocks, all feldspars kaolinized to some extent; some fragments of strong rock usually remain.

- o Complete: rock reduced to "soil"; rock "fabric" not discernible or discernible only in small scattered locations; quartz may be present as dikes or stringers (i.e., saprolite).

3.7-2.2.2 Structure

Structure refers to the general disposition, attitude, arrangement, or relative positions of a rock body or portion of a rock body. Structures represent a discontinuity or major heterogeneity in the rock body. The term "texture" is generally used for small-scale features affecting the minerals and particles in a rock, whereas "structure" generally refers to variations in the component parts of a rock body as a whole. Generally structural features are best observed in outcrops rather than hand specimens. Rock continuity descriptions specific to drill cores are presented at the end of this section. It is important that measurements of structural orientations be made on in-place rock, rather than boulders. If the nature of the outcrop (e.g., outcrop or erratic) is uncertain, it should be noted.

(a) Discontinuities

Discontinuities are surfaces representing breaks or fractures separating the rock mass into discrete units. Descriptive terminology and criteria for describing discontinuities follow.

(1) Types of Discontinuities. (For more detailed descriptive terms, see Appendix B).

- o Fracture: break in a rock due to mechanical failure by stress. Includes cracks, joints, and faults.

- o Crack: a partial or incomplete fracture.

- o Joint: a set of simple fractures along which no shear displacement has occurred (usually occur with parallel joints to form part of a joint set.)

- o Shear: a fracture along which differential movement has taken place parallel to the surface sufficient to produce slickensides, striations, or polishing; it may be accompanied by a zone of fractured rock up to a few inches wide.

- o <u>Shear Zone</u>: a band or zone of parallel, closely spaced fractures in rocks that are crushed or brecciated; it may range from less than a foot to many feet in width.

- o <u>Fault</u>: a fracture along which there has been obvious displacement. Faults may be accompanied by gouge, brecciation and/or mylonization.

(2) <u>Spacing</u>. Spacing refers to the perpendicular distance between discontinuities. The following items are recommended to describe fractures.

- o very close: spacing is less than 2 inches
- o close: spacing is 2 to 12 inches
- o moderately close: spacing is1 to 3 feet
- o wide: spacing is 3 to 10 feet
- o very wide: spacing is more than 10 feet

3) <u>Tightness</u>: Tightness describes the degree of closure of the opposing faces of the discontinuity.

- o <u>Tight</u>: discontinuity clearly visible; interlocking surfaces; may require force to separate.

- o <u>Open</u>: spaces clearly visible along discontinuity; opening may be filled with weathered material (i.e., clay); easily separated.

- o <u>Healed</u>: discontinuity visible; generally will not separate easily; most commonly rehealed with calcite and quartz.

(4) Attitude. Attitude is the spatial arrangement (i.e., strike and dip) for all sets of discontinuities. Descriptive terms for dip are as follows:

Description	Degrees of Dip
Horizontal	0 - 5°
Shallow or low angle	5 - 35°
Moderately dipping	35 - 55°
Steep or high angle	55 - 85°
Vertical	85 - 90°

(5) Regularity. Regularity is the levelness of the surface of the fracture.

- o Plane: The fractured rock surface is flat and uniform.
- o Smooth: The fracture is smooth to the touch; may appear polished and uniform in appearance.
- o Undulating: The surface is wavy.
- o Rough: The fractured surface is rough to the touch; hand does not slide easily along the surface.
- o Slickenside: The fracture surface exhibits parallel striations resulting from brittle movement; "ridged" surface, usually feels smooth in one direction and rough in the opposite direction.

(6) Consistency. Consistency is a determination of the uniformity of the discontinuities throughout the formation.

(7) Filling. Filling describes the nature and thickness of the material, if any, in the space between discontinuities. This filling may consist of weathered or altered rock, clayey material, etc.

(b) Vertical Spacing of Layering

The vertical spacing of layering or planar features within a rock should be described. Layering is a generic term and includes such planar features as bedding and foliation. It is used when the exact category is uncertain. Suggested terminology is as follows:

Descriptive Term	Spacing
very thin	less than 2 inches
thin	2 to 12 inches
medium	1 to 3 feet
thick	3 to 10 feet
very thick	greater than 10 feet

(c) Descriptions Specific to Rock Cores

(1) Rock Core Discontinuity Rock core discontinuity is any natural break in a rock whether or not it has undergone relative displacement. Where applicable, utilize the following terminology in describing rock continuity:

Terminology	Length of Drill Stem Pieces*
extremely fractured	less than 1 inch
moderately fractured	1 to 4 inches
slightly fractured	4 to 8 inches
sound	greater than 8 inches

* Length of drill stem pieces between natural fractures, not mechanical breaks due to the coring process

(2) Rock Quality Determination (RQD) The RQD (Deere, 1964) method of determining rock quality described in Section 3.6-3.4.3 is repeated here for convenience:

Sum the total lengths of core fragments, counting only those pieces of core that are 4 inches (10 cm) in length or longer (as measured along the vertical axis) and are hard and sound. If the core is broken by handling or by the drilling process, the fresh broken pieces are fitted together and counted as one piece, provided they form the requisite length of 4 inches (10 cm).

The RQD is represented as a percentage. The percentage is derived by dividing the total sum of core pieces (4 inches or greater) by length of the run minus the length of the core left in the hole times 100.

$$RQD = \frac{\sum L(<4)}{(R-C)} \times 100$$

Where: ∑L(<4) = Sum of total length pf core pieces 4 inches or greater
R = Length of total core run
C = Length of core left in borehole

RELATION OF RQD AND ROCK QUALITY

RQD (%)	Description of Rock Quality
0 to 25	very poor
25 to 50	poor
50 to 75	fair
75 to 90	good
90 to 100	excellent

Note: RQD can only be used on NQ core (1-7/8 inch) or larger. The RQD should always be shown on the core log as a percentage.

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SECTION 3.7
ROCK CLASSIFICATION

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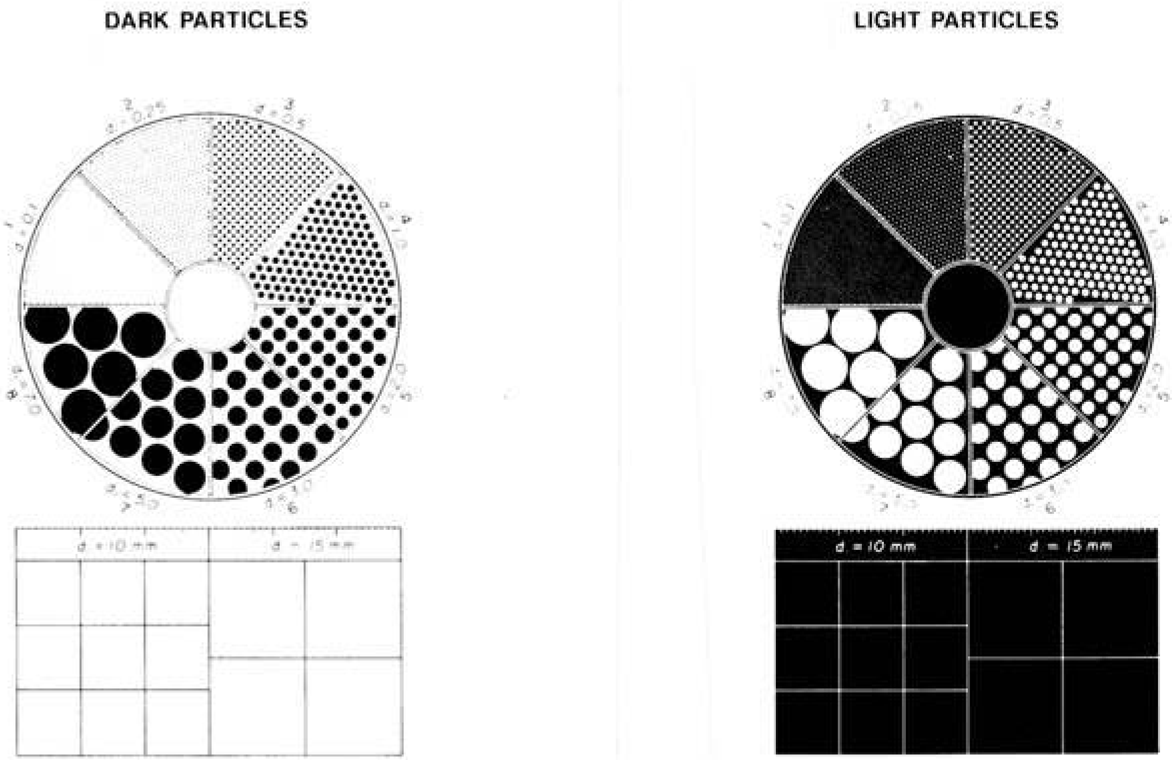


Place sand grains or rock particles in the central part of the circle. Compare the size of the particles with those on the graph with the aid of a magnifying glass. Record the corresponding number (1,2,3,4,5,6,7,8) in notebook. For samples with particles of varying sizes, record the most common size first.

Source: AGI Data Sheets (1982)

Figure 3.7-1

Charts for Determining the Size of Sedimentary Rock Particles.

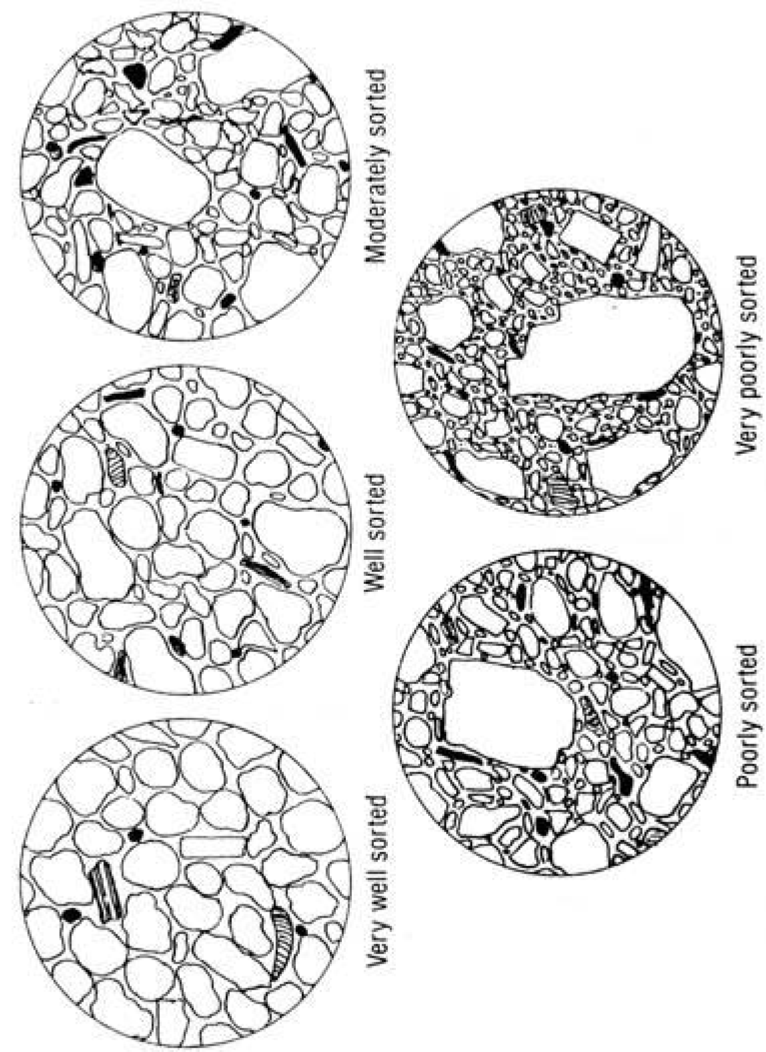
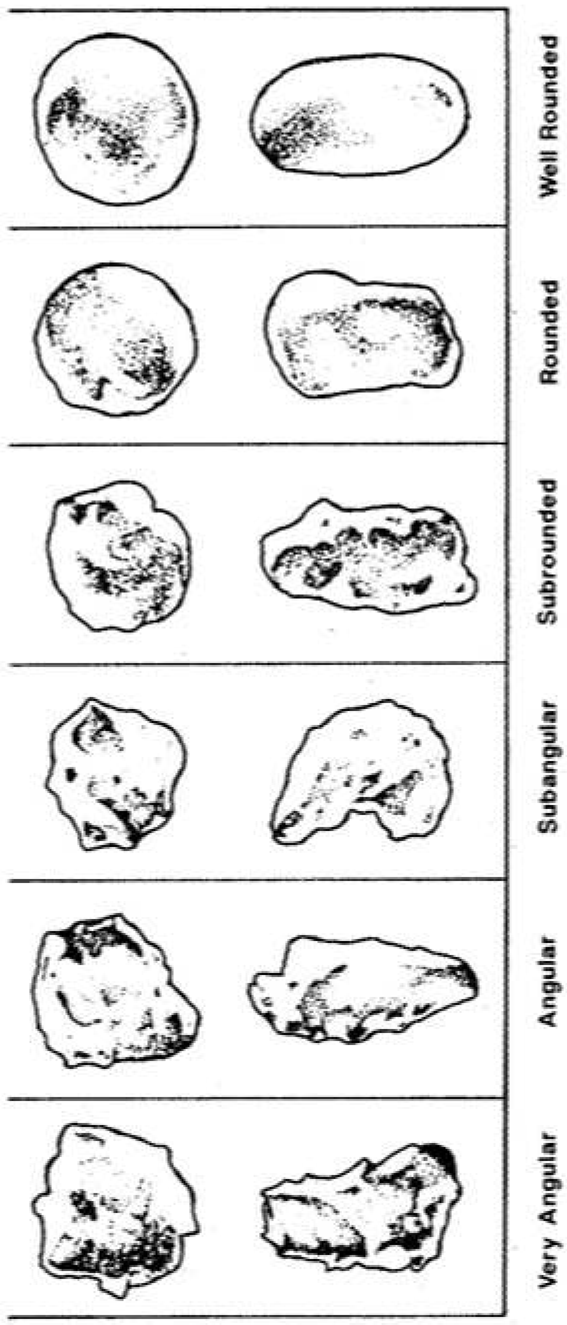


Figure 3.7-2

Classification Aid for Evaluating Degree of Sorting of Clastic Materials in Rocks.

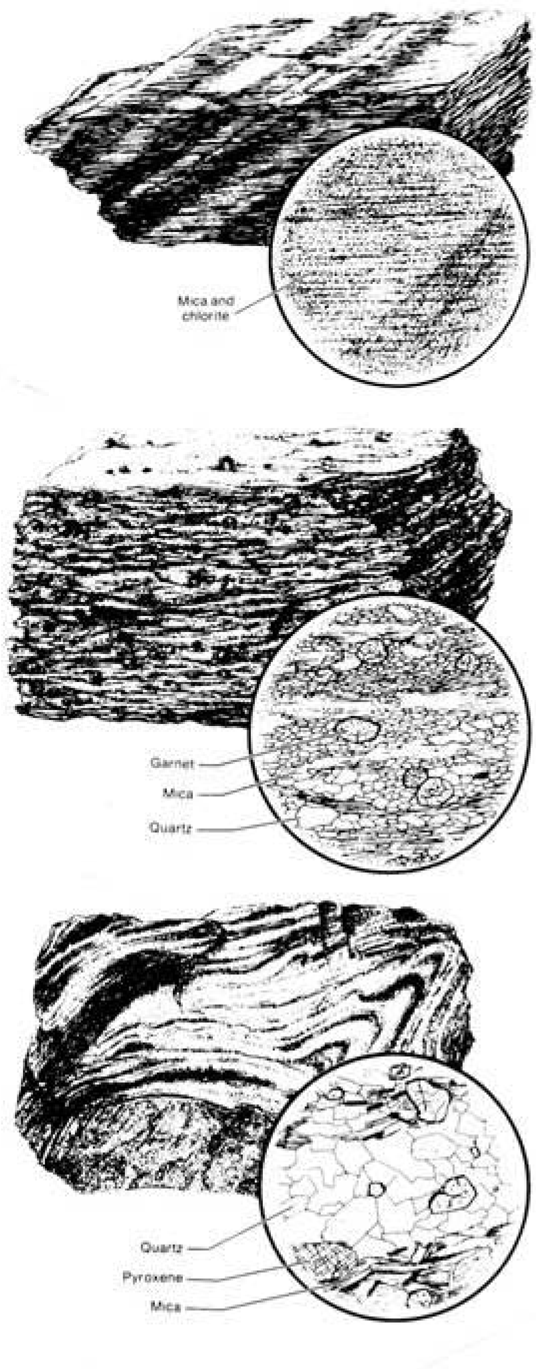
Source: Compton (1985)



Source: Compton (1985) after Powers (1953)

Figure 3.7-3

Classification Aid for Determining the Degree of Angularity of Particles in Rocks.



Slaty Texture-becomes Phyllitic with an Increased Orientation of Micaceous Minerals to Produce a Sheen.

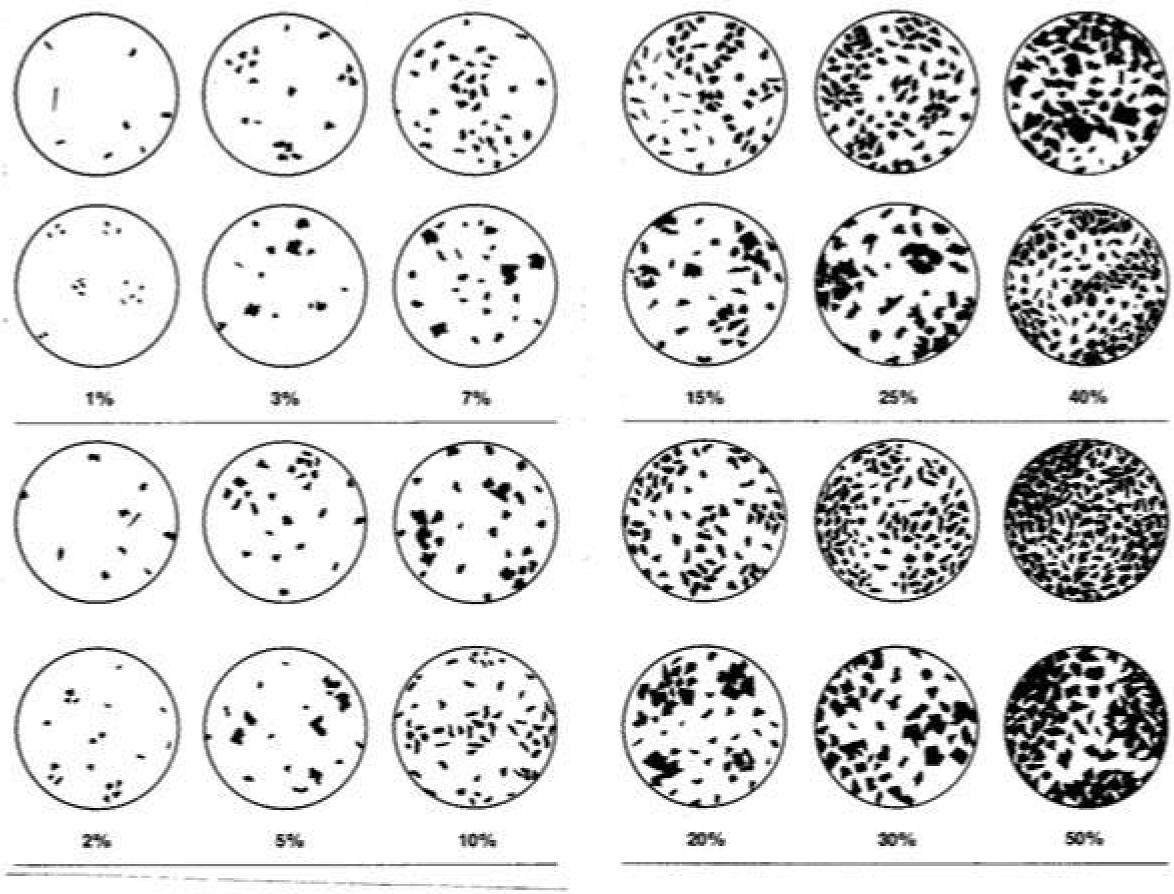
Schistose Texture-alignment of visable grains.

Gneissic Texture-foliation due to compositional banding and alignment of minerals.

Source: Hamblin (1975)

Figure 3.7-4

Metamorphic Textures.



Source: AGI Data Sheet (1982)

Figure 3.7-5

Comparison Chart for
Estimating Percentage Composition.

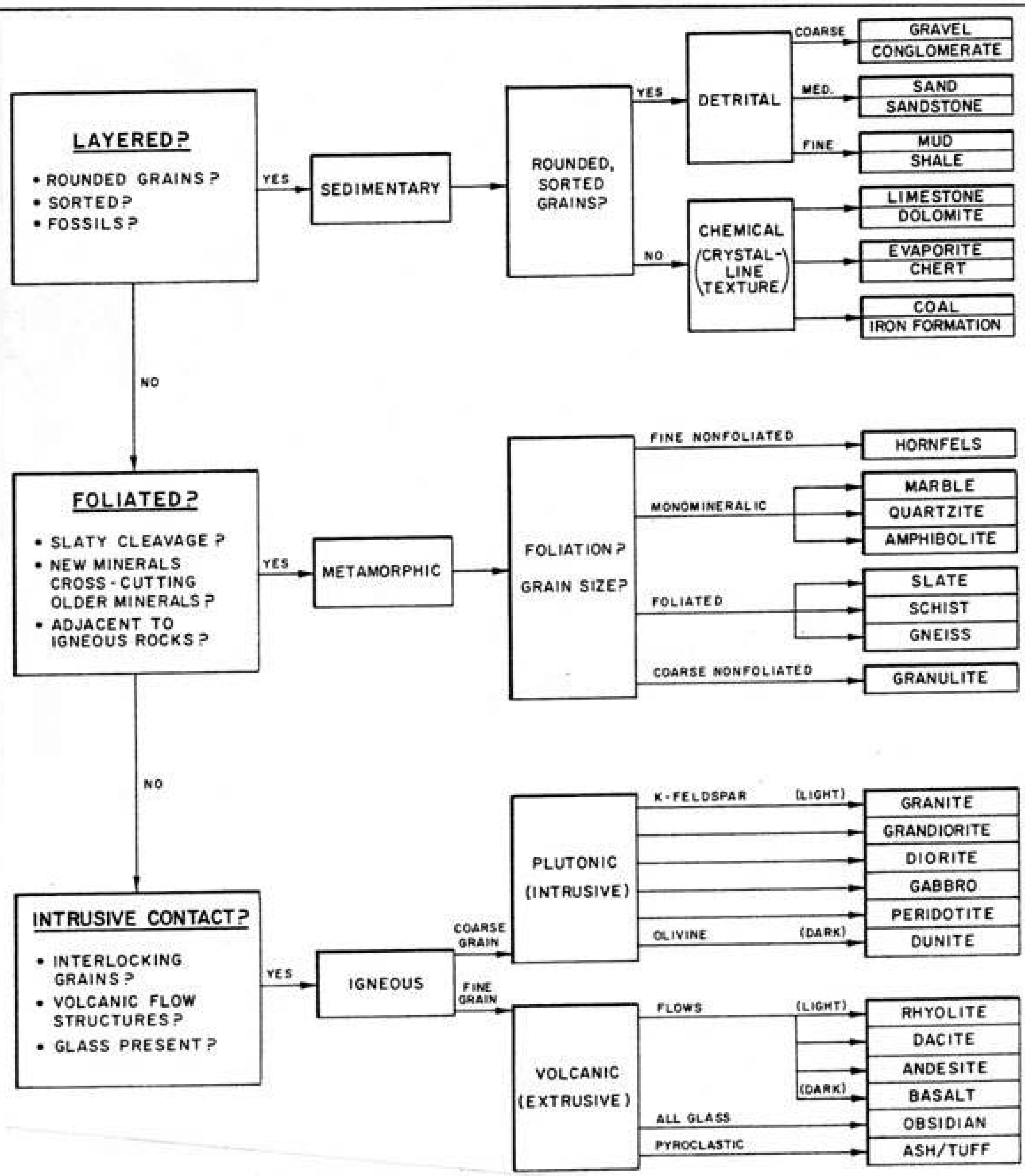


Figure 3.7-6

Rock Identification Flow Chart.

Source: After Press and Siever (1982)

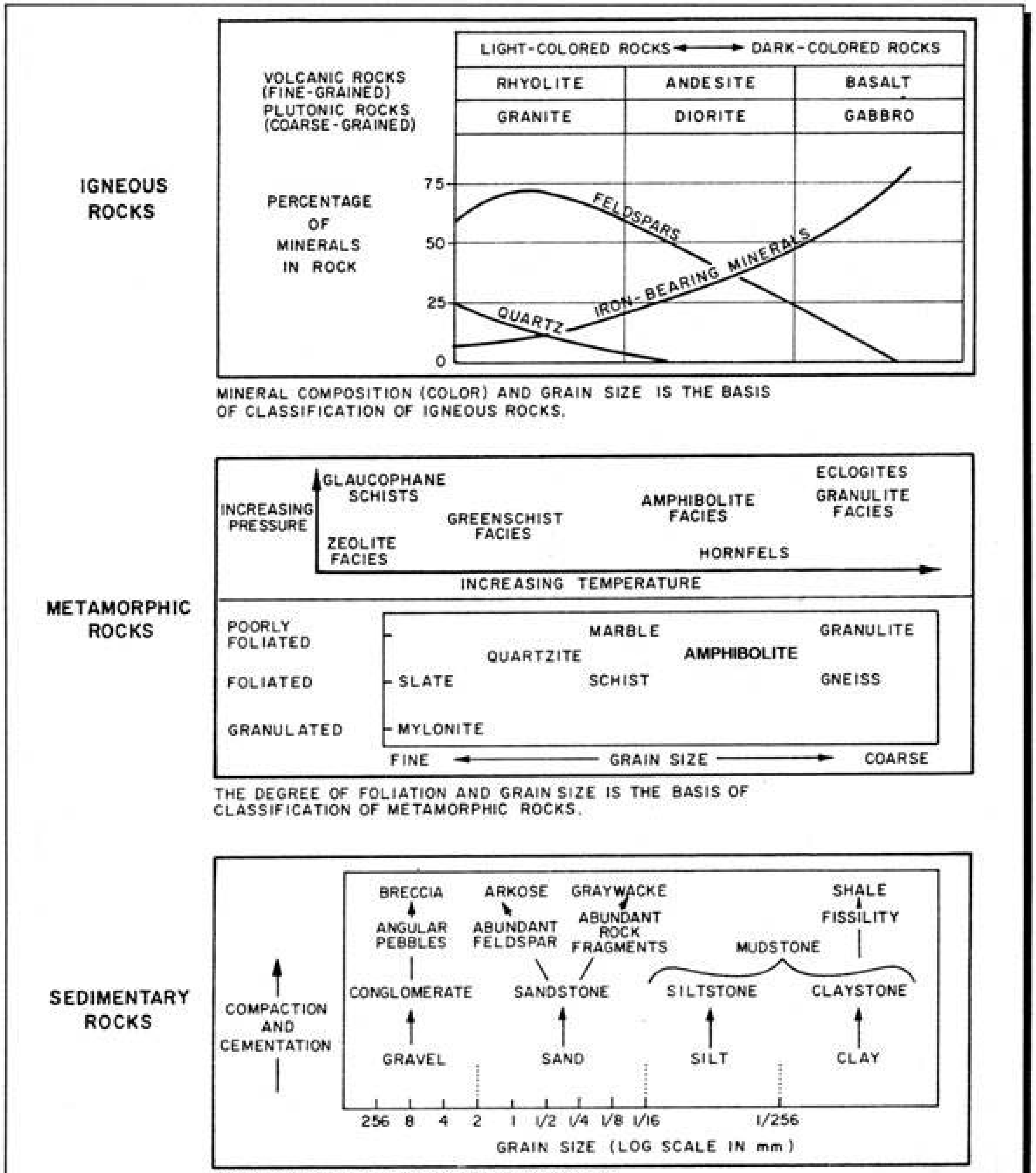


Figure 3.7-7

Source: After Press & Siever

Classification Schemes for Igneous, Metamorphic and Sedimentary Rocks.

APPENDIX A

EXAMPLES OF FIELD PROCEDURES, TABLES, AND LOGS FOR ROCK DESCRIPTIONS

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APPENDIX A

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Characteristic	Description of grade or class
INTACT ROCK	
Hardness	Class I–V, extremely hard to very soft.
Weathering grade	F, WS, WM, WC, RS, fresh to residual soil.
Rock type	Identify type, minerals, and cementing agent.
Coloring	Red, gray, variegated, etc.
Texture (gradation)	Coarse, medium, fine, very fine.
Fabric: Form	Equigranular, porphyritic, amorphous, platy, (schistose or foliate), isotropic, anisotropic.
Orientation	Horizontal, vertical, dipping (give degrees).
DISCONTINUTIES	
Joint spacing	Very wide, wide, moderately close, close, very close. Give orientations of major joint sets. Solid, massive, blocky, fractured, crushed mass.
Joint conditions Form	Stepped, smooth, undulating, planar.
Surface	Rough, smooth, slickensided.
Openings	Closed, open (give width).
Fillings	None, sand, clay, breccia, other minerals.
Other discon-tinuities and mass characteristics	Faults, slickensides, foliation shear zones, cleavage, bedding, cavities, and groundwater conditions. Included in overall mass description.

NOTE: Example as applied to a geologic unit: "Hard, moderately weathered GNEISS, light gray, medium grained (quartz, feldspar, and mica); strongly foliated (anisotropic), joints moderately spaced (blocky), planar, rough, open (to 1 cm), clay filled."

Source: Hunt (1984)

Figure A-1

Field Description of Rock Masses.

Major classes	Subdivisions of major classes based on mineral composition							
Minerals†	Light-colored rocks				Medium-colored		Dark-colored rocks	
	Orthoclase feldspar		Ortho- or Plagio-clase feldspar		Plagioclase		Plagio-clase	No feld-spar
	BHP		BHP		BHP	HBP	PHOA	OPHBA
Grain size	With Q	Without Q	With Q	Without Q	With Q	Without Q	Without Q	No Q
Coarse > 1 mm	Pegmatite Granite							
Phanerites Equigranular > 1 mm	Granite	Syenite	Grano-diorite	Monzonite	Tonalite (quartz diorite)	Diorite	Gabbro	Peridotite Pyroxenite Dunite (O)
Micro-phanerites Equigranular < 1 mm	Aplite	Micro-syenite	Micro-grano-diorite	Micro-monzomite	Micro-tonalite	Micro-diorite	Dolerite (diabase)	
Porphyries	All phanerites are found with phenocrysts (granite porphyry, etc.)							
Aphanites and aphanite porphyries	Rhyolite	Trachyte	Quartz, latite	Latite	Dacite	Andesite	Basalt	
	Felsite (and felsophyre)							
Classes	Obsidian and pitchstone							
Porous	Pumice				Scoria		Vesicular basalt	

Legend: Plutonic rocks – [open box] Volcanic rocks – [hatched box] Border rocks – [heavy-bordered box]

† Minerals: A = augite, B = biotite, H = hornblende, P = pyroxene,
O = olivine, Q = quartz.

*After Pirsson and Knopf (1955).[3] (Excludes pyroclastic rocks.) Adapted with permission of John Wiley & Sons, Inc.

Source: Hunt (1984)

Figure A-2

Classification of Igneous Rocks.

Rock	Characteristics
	FINE-GRAINED—RAPID COOLING
Andesite	Generally dark gray, green, or red. Pure andesite is relatively rare, and it is usually found with phenocrysts. Porphyritic andesite and basalt compose about 95% of all volcanic materials.
Basalt	Most abundant extrusive rock; found in all parts of the world and beneath the oceans. Colors range from grayish to greenish black to black. Fine-grained with a dense compact structure. Often contains numerous voids (vesicular basalt).
Rhyolite	The microcrystalline equivalent of granite formed at or near the surface. Characteristically white, gray, or pink and nearly always contains a few phenocrysts of quartz or feldspar.
Felsite	Occurs as dikes, sills, and lava flows. The term felsite is used to define the finely crystalline varieties of quartz-porphyries or other light-colored porphyries that have few or no phenocrysts and give but slight indications to the unaided eye of their actual mineral composition.
	GLASSY ROCKS—VERY RAPID CHILLING
Obsidian	Solid natural glass devoid of all crystalline grains, generally black with a brilliant luster and a remarkable conchoidal fracture.
Pitchstone	A variety of obsidian with a resinous luster.
Pumice	Extremely vesicular glass; a glass froth.
Scoriae	Formations that have as much void space as solids.

Rock	Characteristics
	COARSE TO MEDIUM GRAINED—VERY SLOW TO SLOW COOLING
Pegmatite	Abundant as dikes in granite masses and other large bodies. Chiefly quartz and feldspar appearing separately as large grains ranging from a centimeter to as large as a meter in diameter.
Granite	The most common and widely occurring igneous rock. Fabric roughly equigranular normally. Light colors contain chiefly quartz and feldspar; gray shades contain biotite mica or hornblende.
Syenite	Light-colored rock differing from granite in that it contains no quartz, consisting almost entirely of feldspar but often containing some hornblende, biotite, and pyroxine.
Diorite	Gray to dark gray or greenish, composed of plagioclase feldspar and one or more of the ferromagnesian minerals. Equigranular fabric.
Gabbro	Dark-colored rock composed chiefly of ferromagnesian minerals and plagioclase feldspar.
Peridotite	Dark-colored rocks composed almost solely of ferromagnesian minerals. Olivine predominant; negligible feldspar. Hornblende or pyroxenes associated. Readily altered.
Pyroxenite	As above but pyroxene alone or predominant.
Hornblendite	As above but hornblende alone or predominant.
Dunite	Major constituent is olivine, which alters readily to serpentine.
Dolerite (or diabase)	Dark-colored rock intermediate in grain size between gabbro and basalt. Abundant as thick lava flows that have cooled slowly.

Figure A-3

Source: Hunt (1984)

Characteristics of Some Igneous Rocks.

Rock type	Material*	Diameter, mm	Composition	Depositional environment
			DETRITAL	
Conglomerate	Boulders	>256	Same as source rock.	Along stream bottoms. Seldom found in rock masses.
	Cobbles	256–64	Same as source rock.	Along stream bottoms. Deposited as alluvial fans and in river channels.
	Pebbles	64–4	As for cobbles or sand.	As for cobbles; also deposited in beaches.
	Granule	4–2	As for cobbles or sand.	As for pebbles and sand.
Sandstone	Sand	2–0.02	Primarily quartz; also feldspar, garnet, magnetite. Some locales: hornblende, pyroxene, shell fragments.	All alluvial deposits: stream channels, fans, floodplains, beaches, deltas. Occasionally aeolian.
Siltstone	Silt	0.02–0.002	As for sand; often some clay particles.	Deltas and floodplains.
Shales	Clay	<0.002	Colloidal sizes of the end result of decomposition of unstable minerals yielding complex hydrous silicates (see Art. 5.3.3)	Quiet water. Salt water: Clay particles curdle into lumps and settle quickly to the bottom. Show no graded beds. Freshwater: Settle slowly; are laminated and well-stratified, showing graded bedding.
			NONDETRITAL	
Limestone	Calcareous precipitate		Massive calcite ($CaCO_3$).	Deep, quiet water.
Coquina	Calcareous precipitates		Cemented shells.	Along beaches, warm water.
Chalk	Calcareous precipitates		Microscopic remains of organisms.	Clear, warm, shallow seas.
Dolomite	Calcareous precipitates		Dolomite—$CaMg(CO_3)_2$.	Seawater precipitation or alteration of limestone.
Gypsum†	Calcareous precipitates		Gypsum—$CaSO_4 \cdot 2H_2O$.	Saline water.
			DETRITAL	
Anhydrite†	Calcareous precipitate		Anhydrite—$CaSO_4$.	Saline water.
Halite†	Saline precipitates		Sodium chloride.	Saline water.
Coal	Organic		Carbonaceous matter.	Swamps and marshes.
Chert	Silicate		Silica, opal.	Precipitation.

*The Wentworth scale.
†Evaporites.

*The Wentworth scale.
†Evaporites.

Figure A-4

Source: Hunt (1984)

Broad Classification of Sedimentary Rocks.

Rock	Characteristics
Metaconglomerate	Heat and pressure cause the pebbles in a conglomerate to stretch, deform, and fuse.
Quartzite	Results from sandstone so firmly fused that fracture occurs across the grains, which are often imperceptible.
Marble	Results from metamorphism of limestone or dolomite and is found with large and small crystals, and in many colors including white, black, green, and red. Metamorphosed limestone does not normally develop cavities. Very hard.
Serpentinite	Derived from serpentine. Generally compact, dull to waxy luster, smooth to splintery fracture, generally green in color and often soft unless it contains significant amounts of quartz. Can have foliate fabric.
Soapstone	Derived from talc; generally gray to green color, very soft and easily trimmed into shapes with a knife, without cleavage or grain, and resists well the action of heat or acids.
Hornfels	Rocks baked by contact metamorphism into hard aphanitic material, with conchoidal fracture, dark gray to black color, often resembling a basalt.
OTHER FORMS	
Migmatite	Signifies a rock that is a complex intermixture of metamorphic and granular igneous rocks such as formed by the injection of granite magma into foliated rocks.
Mylonites	Produced by intense mechanical metamorphism; can show strong lamination but the original mineral constituents and fabric have been crushed and pulverized by the physical processes rather than altered chemically. Common along the base of overthrust sheets and can range from very thin, to a meter or so, to several hundreds of meters thick. Shale mylonites form very unstable conditions when encountered in cut slopes or tunneling. They are formed by differential movement between beds.

Source: Hunt (1984)

Figure A-5

Characteristics of Metamorphic Rocks with Massive Fabric and Other Forms.

Rock	Characteristics
Gneiss	Coarse-grained; imperfect foliation resulting from banding of different minerals. The foliation causes lenticular planes of weakness resulting in slabbing in excavations. Chief minerals are quartz and feldspar, but various percentages of other minerals (mica, amphibole, and other ferromagnesians) are common. The identification of gneiss includes its dominant *accessory* mineral such as hornblende gneiss biotite gneiss or general composition, i.e., granite gneiss
Paragneiss	Derived from sedimentary rocks
Orthogneiss	Derived from feldspathic igneous rocks
Schist	Fine-grained, well-developed foliation, resulting from the parallel arrangement of platy minerals (termed *schistosity*). The important platy minerals are muscovite, chlorite, and talc. Schist is identified by the primary mineral as mica schist chlorite schist, etc. Garnet is a common accessory mineral to mica schist and represents intense metamorphism. Schists and gneisses commonly grade into each other and a clear distinction between them is often not possible.
Amphibolite	Consist largely of amphibole and show more or less schistose form of foliation. Composed of darker minerals and, in addition to hornblende, can contain quartz, plagioclase feldspar, and mica. They are hard and have densities ranging from 3.0 to 3.4. Association with gneisses and schists is common in which they form layers and masses that are often more resistant to erosion than the surrounding rocks.
Phyllite	Soft, with a satinlike luster and extremely fine schistosity. Composed chiefly of chlorite. Very unstable in cut slopes. Grades to schists as the coarseness increases
Slate	Extremely fine-grained, exhibiting remarkable planar cleavage. Generally hard plates split from formations; once used for roofing materials.

Figure A-6

Source: Hunt (1984)

Characteristics of Some Metamorphic Rocks With Foliate Fabric.

Texture	Fabric: Foliated	Fabric: Massive
Coarse	Gneiss Amphibolite	Metaconglomerate Granite gneiss (imperfect foliations)
Medium	Schist (mica, chlorite, etc.)	Quartzite Marble Serpentinite Soapstone
Fine to microscopic	Phyllite Slate	Hornfels
Other forms	Migmatite: Complex composite rocks; intermixtures of metamorphic and igneous rocks.	
	Mylonites: Formed by intense mechanical metamorphism; show strong laminations, but original mineral constituents and fabric crushed and pulverized. Formed by differential shearing movement between beds.	

Source: Hunt (1984)

Figure A-7

Classification of Common Metamorphic Rocks.

Parent rock	Metamorphic derivative
SEDIMENTARY ROCKS	
Conglomerate	Gneiss, various schists, metaconglomerate
Sandstone	Quartzite, various schists†
Shale	Slate, phyllite, various schists
Limestone	Marble†
IGNEOUS ROCKS	
Coarse-grained feldspathic, such as granite	Gneiss, schists, phyllites
Fine-grained feldspathic, such as felsite and tuff	Schists and phyllites
Ferromagnesian, such as dolerite and basalt	Hornblende schists, amphibolite
Ultramafic, such as peridotite and pyroxene	Serpentine and talc schist

*After Pirsson and Knopf (1955).[3] Reprinted with permission of John Wiley & Sons, Inc.

†Depends on impurities.

Source: Hunt (1984)

Figure A-8

Metamophic Derivatives of Igneous and Sedimentary Rocks.

FIELD HARDNESS: A measure of resistance to scratching or abrasion.

Very hard - Cannot be scratched with knife or sharp pick. Breaking of hand specimens requires several hard blows of geologist's pick.

Hard - Can be scratched with knife or pick only with difficulty. Hard blow of hammer required to detach hand specimen.

Moderately hard - Can be scratched with knife or pick. Gouges or grooves to 1/4 in. deep can be excavated by hard blow of point of a geologits's pick. Hand specimens can be detached by moderate blow.

Medium - Can be grooved or gouged 1/16 in. deep by firm pressure on knife or pick point. Can be excavated in small chips to pieces about 1 in. maximum size by hard blows of the point of a geologist's pick.

Soft - Can be gouged or grooved readily with knife or pick point. Can be excavated in chips to pieces several inches in size by moderate blows of a pick point. Small thin pieces can be broken by finger pressure.

Very soft - Can be carved with knife. Can be excavated readily with point of pick. Pieces 1 in. or more in thickness can be broken with finger pressure. Can be scratched readily by fingernail.

WEATHERING: The action of the elements in altering the color, texture and composition of the rock.

Fresh - Rock fresh, crystals bright, few joints may show slight staining. Rock rings under hammer if crystalline.

Very slight - Rock generally fresh, joints stained, some joints may show thin clay coatings, crystals in broken face show bright. Rock rings under hammer if crystalline.

Slight - Rock generally fresh, joints stained, and discoloration extends into rock up to 1 in. Joints may contain clay. In granitoid rocks some occasional feldspar crystals are dull and discolored. Crystalline rocks ring under hammer.

Moderate - Significant portions of rock show discoloration and weathering effects. In granitoid rocks, most feldspars are dull and discolored; some show clayey. Rock has dull sound under hammer and shows significant loss of strength as compared with fresh rock.

Moderately severe - All rock except quartz discolored or stained. In granitoid rocks, all feldspars dull and discolored and majority show kaolinization. Rock shows severe loss of strength and can be excavated with geologist's pick. Rock goes "clunk" when struck.

Severe - All rock except quartz discolored or stained. Rock "fabric" clear and evident, but reduced in strength to strong soil. In granitoid rocks, all feldspars kaolinized to some extent. Some fragments of strong rock usually left.

Very severe - All rock except quartz discolored or stained. Rock "fabric" discernible, but mass effectively reduced to "soil" with only fragments of strong rock remaining.

Complete - Rock reduced to "soil". Rock "fabric" not discernible or discernible only in small scattered locations. Quartz may be present as dikes or stringers.

ROCK CONTINUITY: Any break in a rock whether or not it has undergone relative displacement.

Extremely Fractured - Drill core stem less than 1 in.
Moderately Fractured - Drill core stem 1in. to 4 in.
Slightly Fractured - Drill core stem 4 in. to 8 in.
Sound - Drill core stem greater than 8 in.

TEXTURE: Terminilogy used to identify size, shape and arrangement of constituent elements.

Amorphous - Too small to be seen with naked eye.
Fine Grained - Barely seen with naked eye.
Medium Grained - Barely seen with naked eye to 1/8 in
Coarse Grained - 1/8 in. to 1/4 in.
Very Coarse Grained > 1/4 in.

DISCONTINUITIES: Surfaces representing breaks or fractures separating the rock mass into discrete units.

Crack - A partial or incomplete fracture

Joint - A simple fracture along which no shear displacement has occurred. May form joint sets.

Shear - A fracture along which differential movement has taken place parallel to the surface sufficient to produce slickensides, striations or polishing. May be accompanied by a zone of fractured rock up to a few inches wide.

Fault - A major fracture along which there has been appreciable displacement and accompanied by gouge and/or a severely fractured adjacent zone.

Shear or Fault Zone - A band or zone of parallel, closely spaced shears or faults.

FRACTURES, BEDDING AND FOLIATION, SPACING AND ATTITUDE

Fractures	Bedding and Foliation	Spacing [1]	Attitude	Angle
Very close	Very thin	Less than 2 in.	Horizontal	0° - 5°
Close	Thin	2 in. - 1 ft.	Shallow or low angle	5° - 35°
Moderatley close	Medium	1 ft. - 3 ft.	Moderately dipping	35° - 55°
Wide	Thick	3 ft. - 10 ft.	Steep or high angle	55° - 85°
Very wide	Very thick	More than 10 ft.	Vertical	85° - 90°

Rock Quality Designation (RQD)

RQD in % = [Length of Core in Pieces 4 in. and Longer/Length of Run] x 100

Additional characteristics to further identify and evaluate the rock include: Type, Color, Cavities and Voids, Secondary Mineralization, Fossils, Swelling and Slaking Properties, etc. Visual - manual rock descriptions consist of the following factors in the order presented. Example: Hard, slightly weathered, moderately fractured, gray, coarse grained CAMBRIDGE ARGILLITE, moderately close, tight, shallow dipping, smooth joints; minor shear parallel to bedding at 40 ft.; very thin, horizontal bedding; with siltstone partings and calcite fillings.

NOTE: 1. Spacing - Refers to perpendicular distance between discontunities.

Source: Haley and Aldrich (1977)

Figure A-9

Example of Visual-manual Identification of Rock Guide.

			Boring no:
Client			Project no:
Contractor		Date started	Completed
Method	Casing size	PID	Protect'n level
Ground el.	Soil drilled	Rock drilled	▽ Below grnd
Logged by	Ch'd by	Date	Site

Depth (ft)	PID ambient air	Sample no. and type [1]	Sample	Pen / Rec	CLP	GC	PID sample (ppm)	Soil/rock description	Lithologic symbol	Well data	Soil class	Blows/6-in. or RQD % 0 20 40 60 80 100	Elevation (ft)

[1] U = Thin wall tube S = Split spoon R = Rock

Source: ABB-ES

Figure A-10

Example of Field Boring Log for Rock.

DEFINITIONS	1.	RQD (Rock Quality Designation)- The RQD is equal to the ratio of the cumulative length of pieces of sound core 4 inches or longer to the total length of the core run. If the core is broken by handling or by the drilling process (i.e., the fracture surfaces are fresh irregular breaks rather than natural joint surfaces), the fresh broken pieces are fitted together and counted as one piece provided that they form the requisite length of 4 inches.
	2.	Recovery - total length of core recovered as compared with the total length of the run.
DESCRIPTION OF INTACT ROCK	1.	Structure or texture a) Grain size b) Stratified or bedded 1) Dip and strike 2) Thickness - laminated - less than 1 inch thin - 0 to 0.5 foot (bed thickness) medium - 0.5 to 1.0 feet thick - 1.0 to 3.0 feet very thick - more than 3.0 feet c) Massive - without stratification, foliation, banding, schistosity, etc. d) Foliated - (metamorphic rocks) 1) Highly (very schistose) 2) Moderately 3) Slightly e) Microfolding or contorting f) Banding - banded color changes g) Lineation
	2.	Voids - cavities, vesicles, pitting, fissures
	3.	Degree of weathering a) Extreme - Weathered to a soil. b) Severe - Most of sample weathered to, or almost to, a soil. c) Moderate - Rock is discolored. Some of the minerals have been decomposed and softened so that the soundness of the rock has been affected. Core samples can be abraded under finger pressure on some surface edges. d) Slight - Some discoloration and mineral decomposition. e) Minor - Little evidence of weathering but rock is essentially sound. f) Sound or fresh - Has no discoloration, is fresh in appearance. g) Seamed - Weathering has occurred along joints and fractures within unaltered rock mass.
DESCRIPTION OF ROCK DEFECTS	1.	Joints a) Spacing 1) Very close - less than 2 inches 2) Close - 2 inches to 1 foot 3) Moderately close - 1 foot to 3 feet 4) Wide - 3 feet to 10 feet 5) Very wide - greater than 10 feet b) Open or closed c) Dip and strike
	2.	Fractures and faults - dip and strike, slickensides, striations
	3.	Breaks due to drilling, or discing due to stress relief
	4.	Infillings - products of weathering, mineralization, discoloration, etc.

Source: Haley and Aldrich, Inc.

Figure A-11

Example of Identification Rock Structure Guide.

VISUAL IDENTIFICATION ROCK CORES

SHEET______OF______

JOB NO.	BY	DATE	CHK'D BY
BORING NO.	SAMPLE	CORE DIA. (IN.)	DEPTH (FT.)

CORE LENGTH (FT.)	CORE RECOVERY (FT.)	RQD	%	ROCK QUALITY

CORE RECOVERY (FT.) | 0.3 FT. CORE RECOVERY | ROCK DESCRIPTION AND IDENTIFICATION

DEPTH (FT.)

1.0
2.0
3.0
4.0
5.0

TOTAL________FT. TOTAL________FT.

________(%) ________(%)

Source: ABB-ES

Figure A-12

Example of Field Log of Rock Core.

APPENDIX B

EXAMPLES OF FIELD PROCEDURES AND TABLES TO AID IN DESCRIBING STRUCTURAL ROCK FEATURES

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PROJECT ______ GEOLOGIST ______ DATE ______ FILE NO. ______

BORING NO. ______ RUN NO. ______ DEPTH from ______ to ______ RECOVERY ______ ft. ______ %

RQD ______ ft. ______ % (for entire run) AVERAGE DRILLING RATE ______ (min./ft.)

per foot basis beginning with ______ to ______ ft. (optional)

1 ______ % 2 ______ % 3 ______ % 4 ______ % 5 ______ %

6 ______ % 7 ______ % 8 ______ % 9 ______ % 10 ______ %

NO. OF PIECES ______ NO. OF CHIPS ______ NO. OF SOIL/CLAY LAYERS ______

Size and distribution of pieces in inches SCHMIDT HARDNESS ______

ROCK TYPE ______

MINERALS ______

FORMATION ______

REMARKS ______

RQD = Summation of ≥ NX core lengths ≥ 4" / Length of core run

1. Compute RQD only on rock core which has been moderately weathered or less
2. RQD adjustments required Yes ______ No ______

SAMPLES REMOVED FOR TESTING: None ______ (Depth, lengths) ______

CORE PHOTOGRAPHED ______ WATER LOSS ______

FIELD HARDNESS (Check one)

Very hard ______ Hard ______ Mod. Hard ______ Medium ______ Soft ______ Very Soft ______

WEATHERING (Check one)

Fresh ______ Very Slight ______ Slight ______ Moderate ______

Moderately Severe ______ Severe ______ Very Severe ______ Complete ______

ROCK CORE FRACTURES (CONTINUITY) (Check applicable and indicate depth)

Very Severe ______ Severe ______ Moderate ______ Slight ______ Very Slight ______

TEXTURE (Check one) COLOR

Amorphous (micro) ______ Fine gr. (macro) ______ Med. gr. ($<\frac{1}{8}$") ______ Coarse gr. ($\frac{1}{8}$"$-\frac{1}{4}$") ______ V. Coarse gr. ($>\frac{1}{4}$") ______

DISCONTINUITIES (Indicate No.(s) of each type)

Crack ______ Joint ______ Shear ______ Fault ______ Shear or Fault Zones ______

Attitude: Hor. (0°-5°) ______ Shallow (5°-35°) ______ Mod. (35°-55°) ______ Steep (55°-85°) ______ Vert. (85°-90°) ______

Primary ______ Secondary ______ Other ______ (Indicate attitude by corresponding number)

Tightness: Tight ______ Open ______

Surfaces: Altered ______ Unaltered ______

Spacing: V. Close ______ Close ______ Mod. Close ______ Wide ______ V. Wide ______

Degree of Planeness: Plane ______ Curved ______ Irregular ______

Degree of Smoothness: Slick ______ Smooth ______ Rough ______

Fill between Discontinuities: No ______ Yes ______ Type of Fill ______

BEDDING / FOLLATION (Check one)

Strike ______ Dip ______

Thickness: V. Thin ______ Thin ______ Medium ______ Thick ______ V. Thick ______

AREA OUTCROPS (if applicable) Location ______

Veins ______ Type ______ Brecciation ______

Slickensides ______

Gouge ______ Color ______ Type ______

FIELD HARDNESS	WEATHERING	BEDDING / JOINT SPACING	ROCK CORE FRACTURING
V. Hard - Knife can't scratch	Fresh - Crystals bright	V. Thin / V. Close < 2"	V. Severe - Core < 1"
Hard - Scratches difficult	V. Slight - Joints slightly stained	Thin / Close 2" - 12"	Severe - Core 1" - 2"
Mod. Hard - Scratches readily	Slight - Joints completely stained	Medium / Mod. Close 12" - 36"	Moderate - Core 2" - 4"
Medium - Grooves difficult	Moderate - Core slightly discolored	Thick / Wide 36" - 120"	Slight - Core 4" - 8"
Soft - Grooves readily	Mod. Severe - Core completely discolored	V. Thick / V. Wide > 120"	V. Slight - Core > 8"
V. Soft - Carves	Severe - Strength reduced		
	V. Severe - Only rock fragments		
	Complete - Reduced to soil		

Source: Haley and Aldrich, Inc.

Figure B-1

Field Summary of Rock Characteristics.

Section *Worden Fm. along Rt. 33 in Ringwood Canyon* Unit *7*

Measured thickness *28 m* Attitude *N15W 65W*

Measured by *M. Lawry* Date *2 Apr84* Comments *V. well exposed. Better fossil collections can be made.*

Rock or sediment name: *Sandstone, subquartzose, feldspathic*

Color moist: *v. pale brn 10YR 7/3* Bedding: distinct vague
dry: *" " " 10YR 8/3*

Thicknesses beds: 5 m 1 m .1 m 1 cm 1 mm
laminations:

Fossils:

Primary structures: *Planar x-bedding local; large burrows abundant -- unit 60 – 75 % bioturbated.*

Grain sizes range: 512 128 32 8 2 .5 .13 .03 .003
median: 256 64 16 4 1 mm .25 .06 .015 .004

Degree of sorting: very well **well** **moderate** poor very poor

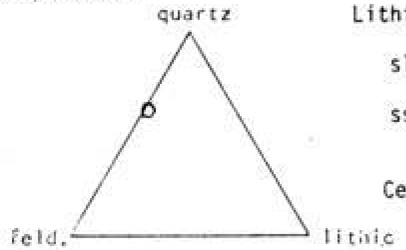
Grain shapes: very angular angular **subangular** **subrounded** rounded

Packing: loose **moderate** tight pressed

Fabric: *Fossils and sparse (3%) mica are locally planar (where not bioturbated)*

Weathering degree much none
depth 100 m 10 m 1 m

Composition:



Lithic clasts: granite **chert** *2-4%* aplite qzt slate argillite hornfels ls dol schist ss basalt rhyolite

Cement: **cal** *~25%* dol qz opal clay Fe-oxide gyp tar anhyd zeolite

Source: Compton (1985)

Figure B-2

Check Sheet for Describing Measured Stratigraphic Units.

Discontinuity	Definition	Characteristics
Fracture	A separation in the rock mass, a break.	Signifies joints, faults, slickensides, foliations, and cleavage.
Joint	A fracture along which essentially no displacement has occurred.	Most common defect encountered. Present in most formations in some geometric pattern related to rock type and stress field. Open joints allow free movement of water, increasing decomposition rate of mass. Tight joints resist weathering and the mass decomposes uniformly.
Faults	A fracture along which displacement has occurred due to tectonic activity.	Fault zone usually consists of crushed and sheared rock through which water can move relatively freely, increasing weathering. Waterlogged zones of crushed rock are a cause of *running ground* in tunnels.
Slickensides	Preexisting failure surface; from faulting, landslides, expansion.	Shiny, polished surfaces with striations. Often the weakest elements in a mass, since strength is often near residual.
Foliation planes	Continuous foliation surface results from orientation of mineral grains during metamorphism.	Can be present as open joints or merely orientations without openings. Strength and deformation relate to the orientation of applied stress to the foliations.
Foliation shear	Shear zone resulting from folding or stress relief.	Thin zones of gouge and crushed rock occur along the weaker layers in metamorphic rocks.
Cleavage	Stress fractures from folding.	Found primarily in shales and slates; usually very closely spaced.
Bedding planes	Contacts between sedimentary rocks.	Often are zones containing weak materials such as lignite or montmorillonite clays.
Mylonite	Intensely sheared zone.	Strong laminations; original mineral constituents and fabric crushed and pulverized.
Cavities	Openings in soluble rocks resulting from groundwater movement, or in igneous rocks from gas pockets.	In limestone range from caverns to tubes. In rhyolite and other igneous rocks range from voids of various sizes to tubes.

Source: Hunt (1984)

Figure B-3

Rock-mass Discontinuities.

Joints	Characteristics
Joint type	
Longitudinal	Parallels bedding or foliation planes
Normal or cross	Intersects bedding or foliations at right angles
Diagonal or oblique	Intersects bedding or foliations obliquely
Foliation	Parallels foliations
Curvilinear	Forms parallel sheets or slabs; often curved
Joint systems	
Joint set	Group of parallel joints
Joint system	Two or more sets or a group of joints with a characteristic pattern
Conjugate system	Two intersecting sets of continuous joints
Orthogonal system	Three sets intersecting at right angles
Cubic system	Forming cubes
Rhombic	Three sets parallel but with unequal adjacent sides and oblique angles
Pyramidal	Sets intersecting at acute angles to form wedges
Columnar	Divide mass into columns; three- to eight-sided, ideally hexagonal
Intense	Badly crushed and broken rock without system; various shapes and sizes of blocks

Source: Hunt (1984)

Figure B-4

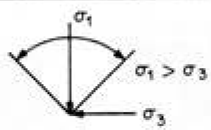
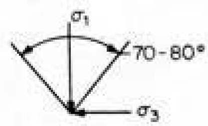
Geologic Nomenclature for Joints.

Surface	Roughness	Origin
Undulating	Rough or irregular Smooth Slickensided	Tension joints, sheeting, bedding Sheeting, nonplanar foliation, bedding Faulting or landsliding
Planar	Rough or irregular Smooth Slickensided	Tension joints, sheeting, bedding Shear joints, foliation, bedding Faulting and landsliding

Source: Hunt (1984)

Figure B-5

Classification of Joint Surface Roughness.

Characteristics	Shear joints	Displacement joints	Tension joints
Evenness	Very even	Even to uneven	Rarely even
Roughness	Smooth to mirror smooth	Smooth to rough	Rough
Degree of joint continuity	High	Medium	Low
Length of joint	Faults to very large joints	Very large joints to small joints	Large joints to small joints
Joint opening	Close	Variable	Wide
Fill material	Mylonite	Product of abrasion	
Traces of movement	Slickensides		
Fractures on molecular scale	Shearing of mesh	Fracture of crystallites	Fracture of crystallites
Orientation with respect to microstructure	Diagonal joints	Diagonal joints	Transverse joints = ac joints Longitudinal joints = bc joints Sedimentation joints = ab joints
Fracture angle 2α			
Friction angle (in unrestrained dilatation)			
Initial (peak)		30 to 55°	40 to 55°
Residual	About 15 to 30°	20 to 40°	30 to 45°

*From Fecker (1978).[30]

Source: Hunt (1984)

Figure B-6

Characteristics of Different Joint Sets in Hard Rocks.

Feature	Characteristics
Stratum discontinuity	Abrupt change in strata; discontinuous, omitted, or repeated
Slickensides	Polished and striated surfaces resulting from shearing forces; characteristic of weaker rocks.
Breccia	Angular to subangular fragments in a finely crushed matrix in the fault zone in strong rocks.
Gouge	Pulverized material along the fault zone; typically clayey; characteristic of stronger rocks.
Mineral alteration	Groundwater deposits minerals in the pervious fault zone, often substantially different from the local rock. Circulating waters can also remove materials. Radiometric dating of the altered minerals aids in dating the fault movement.
Groundwater levels	Clayey gouge causes a groundwater barrier and results in a water table of varying depths on each side of the fault. The difference in water levels can result in a marked difference in vegetation on either side of the fault, especially in an arid climate. Tree lines in arid climates often follow faults.
Foliation shear	Short faults caused by folding result in foliation shear in weaker layers in metamorphic rocks (typically mica, chlorite, talc, or graphite schist in a sequence of harder massive rocks) [Deere (1974)[14a]]. Shear zone thickness typically a few centimeters including the gouge and crushed rock. Adjacent rock is often heavily jointed, altered, and slightly sheared for a meter or so on each side. The zones can be continuous for several hundred meters and can be spaced through the rock mass.
Shale mylonite seam	A bedding shear zone caused by differential movement between beds of sedimentary rock during folding or during relief of lateral stress by valley cutting. Concentrated in the weaker beds such as shale, or along a thin seam of montmorillonite or lignite, and bounded by stronger beds such as sandstone or limestone. Sheared and crushed shale gouge is usually only a few centimeters thick but it can be continuous for many tens of meters [Deere (1974)[14a]]. Both foliation shear and mylonite, when present in slopes, represent potential failure surfaces.

Source: Hunt (1984)

Figure B-7

Internal Evidence of Faulting.

Feature	Characteristics	Fault type
Lineations	Strong rectilinear features of significant extent are indicative but not proof. Can also represent dikes, joints, foliations, bedding planes, etc. [Fig. 2.8].	All types
Landforms		
Scarps	Long, relatively smooth-faced, steep-sided cliffs.	Normal
Truncated ridges	Lateral displacement of ridges and other geomorphic features.	Wrench
Faceted spurs	Erosion-dissected slopes form a series of triangular-shaped faces on the foot wall.	Normal
Horst and graben	Block faulting. A sunken block caused by downfaulting or uplifting of adjacent areas forms a rift valley (graben). An uplifted block between two faults forms a horst. Soils forming in the valley are more recent than those on the uplands. Examples: Lake George, New York; Dead Sea; Gulf of Suez; Rhine Valley, West Germany; Great Rift Valley of Kenya; parts of Paraiba River, Sao Paulo, Brazil.	Normal
Drainage		
Rejuvenated streams	Direction of flow reversed by tilting.	Normal
Blocked or truncated	Flow path blocked by scarp and takes new direction.	Normal
Offset	Flow path offset laterally.	Wrench
Sag pond	Lakes formed by blocked drainage.	Normal
Secondary features	Practically disappear within less than 10 years in moist climates, but may last longer in dry [Oakeshott (1973)[13b]].	
Mole tracks	En-echelon mounds of heaved ground near base of thrust fault or along wrench fault.	Thrust, wrench
Step-scarps	En-echelon fractures form behind the scarp crest in a reverse fault (tension cracks).	Normal
Seismological	Alignment of epicenters.	All types

Source: Hunt (1984)

Figure B-8

Surface Evidence of Faulting.

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF ENVIRONMENTAL PROTECTION

STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.8 LABORATORY TESTS FOR SOIL

SECTION 3.8
LABORATORY TESTS FOR SOIL

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3.8 LABORATORY TESTS FOR SOIL

3.8-0 INTRODUCTION

The purpose of this section is to provide general guidelines for the selection of certain applicable laboratory tests on soil samples. These laboratory tests provide physical properties of soils, which may be necessary for geotechnical or hydrogeologic investigations, feasibility studies, and remedial design evaluations. The tests can be categorized in two general types: Index Properties Testing and Engineering Properties Testing. Index testing, such as grain size distribution, water content, specific gravity, and organic content provide the basic properties of a soil mass and are generally used for classification purposes. Some index properties are used to determine other index properties, such as porosity, as well as for correlation with engineering properties. Geotechnical properties such as compressibility, shear strength, permeability, and moisture/density relationships are necessary to predict the behavior and performance of soils used in earth construction. Typical applications for geotechnical laboratory testing include the following:

- Index properties and permeability testing are used in hydrogeologic investigations to help characterize ground water or contaminant flow behavior through various geologic media.

- Moisture density testing, permeability testing and Atterberg limit testing are used to establish the unique relationship between soil placement criteria and resulting permeability for each site considered. Examples of use are the design and construction of landfill soil liners and cover systems.

- Compressibility, permeability, and strength of soils and/or wastes are engineering property tests utilized for landfill designs. Highly compressible waste materials can result in surface subsidence, which damages cover systems. The permeability of the waste materials determines rates of waste consolidation and leachate generation. The properties of the waste materials determine how they can be graded, sloped, drained, and traveled on. Representative laboratory testing can only be performed on waste materials that could be considered homogenous in engineering analyses such as homogenous paper mill sludges or tannery waste. Representative laboratory testing cannot be performed on heterogeneous wastes with standard equipment currently used.

- Shear strength of soil materials must be determined to evaluate the stability of existing and new waste containment dikes. Consolidation tests are important if the soils underlying the dikes are soft and compressible. These tests are useful for evaluating liner integrity, leachate collection system and construction sequencing.

For each test method, there is a discussion of the significance and use of the test, physical properties obtained, field methods required for obtaining samples, sample size, preservation of samples, and special considerations, where it is relevant.

ASTM refers to the American Society for Testing and Materials. Geotechnical laboratory test procedures are described in the annual book of ASTM Standards, Section 4, Volume 04.08. COE EM refers to the Engineer Manual for Laboratory Soils Testing prepared by the U.S. Army Corps of Engineers, Waterways Experiment Station under direction from the Office, Chief of Engineers, May 1, 1980, Edition.

3.8-1 GRAIN-SIZE ANALYSIS

3.8-1.1 Standard Test Methods

The American Society of Testing Materials (ASTM) method numbers utilized are:

- C 117:Standard Test Method for Material Finer than 75 mm (200) Sieve and Mineral Aggregate by Washing
- C 136:Standard Test Method for Sieve Analysis for Fine and Coarse Aggregate
- D 1140:Standard Method for Amount of Material in Soils Finer than Sieve Number 200 (75 mm)
- D 421:Standard Practice Dry Preparation of Soil Samples for Particle Size Analysis and Determination of Soil Constraints
- D 422:Standard Method for Particle Size Analysis of Soils

3.8-1.2 Significance and Use

A grain-size analysis provides a distribution of soil particle sizes by weight. The grain-size distribution of medium- to coarse-grained soils (particles larger than 0.075 millimeter in diameter) is determined directly by mechanical analysis, while that of fine-grained soils (generally particles less than 0.075 millimeters in diameter) is determined indirectly by hydrometer analysis (sedimentation). Typical instances in which a grain-size distribution would be useful are in soil classification, rough estimations of the permeability of uniform, coarse-grained materials using published correlations, estimation of soil drainage characteristics, and evaluation of soil suitability for construction purposes.

3.8-1.3 Physical Parameters Obtained

The physical parameter obtained from grain size analysis is:

- Particle Size Distribution - a plot of the distribution of the particle size by weight on a logarithmic scale; coefficient of uniformity, percent fines, and maximum particle size.

3.8-1.4 Field Sampling Methods, Sample Size and Preservation

Samples for the grain-size analysis may be obtained using standard drilling and test pit sampling techniques, such as split-spoon sampling. Representative samples of coarser-grained soils (gravels) may not be obtained with the standard split-spoon sampler due to the standard inside diameter of the split spoon of 3.5 cm. Undisturbed samples are not necessary. Sample size is dependent on the maximum particle size of the material to be tested and is listed on Table 3.8-1.

Prior to testing, store samples in noncorrosible, airtight containers in accordance with ASTM D 4220-89 (Standard Practice for Preserving and Transporting Samples).

3.8-2 SPECIFIC GRAVITY OF SOIL

3.8-2.1 Standard Test Method

The ASTM method number utilized is:

- D 854:Standard Test Method for Specific Gravity of Soils

3.8-2.2 Significance and Use

The specific gravity of soil is defined as the ratio of a unit weight of a soil's solid particles to the unit weight of water. The specific gravity of the material is used, in conjunction with other index properties, for determination of the unit weight of a particular soil and for classification purposes. This index property is also used in the determination of other index and engineering properties of soil, including void ratio and porosity.

3.8-2.3 Physical Parameters Obtained

The physical parameter obtained by specificity is:

- G_s = Specific Gravity of Solids, no units

3.8-2.4 Field Sampling Methods, Sample Size, and Preservation

Samples for specific gravity determinations may be obtained using standard drilling and test pit sampling techniques. Collection of undisturbed samples is not required. Sample size is dependent on the apparatus used in the determination and ranges between 10 and 25 grams.

Prior to testing, store samples in noncorrodible, airtight containers in accordance with procedures outlined in ASTM D 4220-89.

3.8-2.5 Special Considerations

The term "solid particles" is typically assumed to mean naturally occurring mineral particles that are not soluble in water. The specific gravity of materials containing extraneous matter (such as contaminants, cement, or lime) and soils containing materials with a specific gravity of less than one, such as oil residue, typically require special treatment or a qualified definition of specific gravity.

3.8-3 ATTERBERG LIMITS

3.8-3.1 Standard Test Method

The ASTM method number utilized is:

- D 4318:Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

3.8-3.2 Significance and Use

Atterberg limits are index properties applicable to cohesive soils only (clays and silts) and are used to describe a soil's plasticity. Atterberg limits are used most commonly for soil classification purposes, although several empirical relationships between Atterberg limits and engineering properties have been developed.

By comparing the Atterberg limit values with the water content of the in-situ material, one can judge the workability and constructability of a particular soil. This relationship is important in the compaction of clay liners and cover systems for landfills.

3.8-3.3 Physical Parameters Obtained

The physical parameters obtained from Atterberg limits are as follows:

- LL = Liquid Limit - The water content, in percent, of a soil at the arbitrarily defined boundary between the liquid and plastic states.

- PL = Plastic Limit - The water content at which a soil can no longer be deformed by rolling into 3 mm (1/8-inch) diameter threads without crumbling.

- PI = Plastic Index - The range of water content for a soil where it behaves as a plastic material. Numerically, it is the difference between the liquid limit and plastic limit.

3.8-3.4 Field Sampling Methods, Sample Size, and Preservation

Samples for this test may be obtained using standard drilling and test pit sampling techniques. Undisturbed sampling techniques are not necessary. Obtain a sample sufficient to provide 150 to 200 grams of material, which is less than 0.425 mm in diameter.

Prior to testing, store samples in noncorrodible, airtight containers in accordance with procedures outlined in ASTM D 4220-89.

3.8-3.5 Special Consideration

The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on undried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behavior of soils in their natural moist state, do not permit samples to dry before testing, unless data on dried samples are specifically desired.

The composition and concentration of soluble salts, chemicals or contamination in a soil may affect the values of the liquid and plastic limits of soils as well as the water content values.

3.8-4 MOISTURE CONTENT

3.8-4.1 Standard Test Method

The ASTM method number utilized is:

- o D 2216:Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock

3.8-4.2 Significance and Use

The water content of a soil is the ratio of the weight of water of a given soil mass to the weight of solid particles. The water content of a soil is used in expressing the phase relationship of air, water, and solids in a given volume of material. The water content of cohesive soils is empirically correlated to compressibility, permeability, density, and workability.

3.8-4.3 Physical Parameters Obtained

The physical parameter obtained from a moisture content test is:

- o w = Water Content, expressed as a percent

3.8-4.4 Field Sampling Methods, Sample Size, and Preservation

The sample size for water content determination is dependent on the purpose of the test, the material being tested, and the type of sample (specimen from another test, bag, tube, or split barrel). In all cases, however, select a representative portion of the total sample. If a layered soil or more than one soil type is encountered, select an average portion, or individual portions of both, and note which portions were tested in the report of the results. For bulk samples, select the test specimen after it has been thoroughly mixed. The mass of moist material selected should be in accordance with Table 3.8-2.

For cohensionless soils, mix the material and then select a test specimen size from Table 3.8-2. For cohesive soils, the mass of the moist material should not be less than 25 grams or should be in accordance with Table 3.8-2.

Prior to testing, keep the samples in noncorrodible, airtight containers in accordance with procedures outlined in ASTM D 4220-89 at a temperature between 3 and 30 degrees Celsius and in an area that prevents direct contact with sunlight.

3.8-4.5 Special Considerations

This method does not give truly representative results for materials containing significant amounts of halloysite, montmorillonite or gypsum; highly organic soils; or materials in which the pore water contains dissolved solids (such as salt in the case of marine deposits). For material of the previously mentioned types, a modified method of testing or data calculation may be established to give results consistent with the purpose of the test.

3.8-5 ORGANIC CONTENT

3.8-5.1 Standard Test Method

The ASTM method number utilized is:

- D 2974:Standard Test Method for Moisture, Ash and Organic Matter of Peat and Other Organic Soils

3.8-5.2 Significance and Use

The organic content determination measures the percentage of moisture, ash, and organic matter contained in a given sample. The organic content of a soil is primarily used for classification purposes and can significantly affect other index and engineering properties of a soil. Materials with high organic contents typically have low shear strength and are very compressible. The organic content of a soil or waste material can have a significant impact on the cost of incineration processes or off-site disposal. It also is an influencing factor in the biotransformation of organic contaminants.

3.8-5.3 Physical Parameters Obtained

The physical parameter obtained by an organic content analysis is:

- Oc = Organic Content - the ratio of the weight of organics in a given soil mass to the total weight of the soil mass. Expressed as a percentage.

3.8-5.4 Field Sampling Methods, Sample Size, and Preservation

Samples for the organic content determination may be obtained using standard drilling and test pit sampling techniques. Undisturbed sampling techniques are not necessary. Minimum sample size should range between 50 and 100 grams.

Prior to testing, store samples in noncorrodible, airtight containers in accordance with procedures outlined in ASTM D 4220-89.

3.8-6 MOISTURE-DENSITY RELATIONSHIPS OF SOILS (LABORATORY COMPACTION TEST)

3.8-6.1 Standard Test Methods

The ASTM method numbers utilized are:

- D-698:Standard Test Method for Moisture-Density Relations of Soil Aggregate Mixture, Using 5.5 lbs. (2.49 kg) Rammer and 12 Inch (305 mm) Drop

- D-1557:Standard Test Method for Moisture-Density Relations Soil and Soil Aggregate Mixtures, Using 10 lbs. (4.54 kg) Rammer and 18 Inch (457 mm) Drop

3.8-6.2 Significance and Use

The purpose of a laboratory compaction test is to determine the moisture/ density relationship of a representative soil sample. This relationship is used as the standard for evaluating the effectiveness of compaction processes in the field. This test is generally not performed until specific materials for construction have been identified. The test is performed on fine-grained and coarse-grained soils. For design and construction of soil liners and cover systems, a series of laboratory permeability tests are often performed together with the laboratory compaction test to establish a relationship between moisture content, soil density, and permeability.

3.8-6.3 Physical Parameters Obtained

The physical parameters obtained from a laboratory compaction test are:

- ∂_d =dry density - weight per unit volume, dry; expressed as Mg/m^3.

- ∂_w =wet density - weight per unit volume, with water; expressed as Mg/m^3.

- o ∂_d max =maximum dry density - the maximum unit weight determined in the lab) produced on a particular soil under a particular compaction effort; this density is considered the maximum density that can be obtained in the field, using commonly used compaction equipment; expressed as Mg/m^3 (lbs/ft^2).

- o OMC =Optimum Moisture Content - moisture content (of a soil) corresponding to the maximum density; expressed as a percentage.

3.8-6.4 Field Sampling Methods, Sample Size, and Preservation

Due to the large sample size required, samples for moisture density testing are generally obtained using standard test pit techniques. Sample size is dependent on the method used and should range between 20 and 50 kilograms of material.

Samples stored prior to testing must be sealed to prevent moisture loss in accordance with D 4220-89.

3.8-7 STRENGTH TESTING OF SOILS

3.8-7.1 Standard Test Methods

The ASTM method numbers utilized are:

- o D 2166:Standard Test Method for Unconfined Compressive Strength of Cohesive Soils

- o D 2850:Standard Test Method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression

- o D 3080:Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

The methods utilized by the US Army Corps of Engineers, Engineer Manual for Laboratory Soils Testin (COE EM) are:

- o COE EM 1110-2-1906 (Appendix IX): Drained Direct Shear Test
- o COE EM 1110-2-1906 (Appendix X) : Triaxial Compression Tests
- o COE EM 1110-2-1906 (Appendix XI): Unconfined Compression Test

3.8-7.2 Significance and Use

Strength testing of soils is necessary for stability evaluations of earth embankments, excavations, and soils supporting structure foundations. For landfill projects, strength tests on homogeneous waste materials are useful for evaluation of waste handling, placement, configuration, and construction sequencing. Strength tests are often performed in preliminary stages of projects to evaluate conceptual remediation alternatives or preliminary design for waste containment schemes, closure evaluations, site clean-up schemes, and new landfills. For final design phases of such projects, strength testing is imperative.

Several different types of triaxial strength testing can be performed depending on the intended use of the soil and expected loading conditions. The selection and use of soil strength testing will depend on the project size and the size of the investigation. In general, a specific type of strength test will be selected for a particular soil or waste material depending on loading conditions that will be experienced during construction and operation. To assure that the type of strength test planned corresponds to the anticipated loading conditions, consult a geotechnical engineer.

3.8-7.3 Physical Parameters Obtained:

The physical parameters obtained by strength testing are:

- c =cohesion - the shear strength that exists in the absence of any normal stress on a failure plane; expressed in kPa.

- $q\mu$ = unconfined compressive strength; expressed in kPa.

- Φ =angle of internal friction; expressed in degrees.

3.8-7.4 Field Sampling Methods, Sample Size, and Preservation

Samples for strength testing may be obtained using drilling and test pit sampling techniques for disturbed and undisturbed sampling. Perform testing on disturbed samples if soils are to be used for construction purposes (i.e., reworked during construction). Perform testing on undisturbed samples if the native (in-situ soils) are to be loaded during construction (i.e. embankments or landfills are to be constructed over existing soils).

The most common means of undisturbed sampling is by thin-walled tube sampling methods outlined in Section 3.4 of these references. In order to minimize sample disturbance, thin walled sampling tubes should be no smaller than 7.62 cm. (3-inches) in diameter. It is important to minimize sample disturbance to obtain accurate strength test information. Disturbed (remolded) test specimens can also be made from samples obtained in standard drilling and test pit sampling techniques.

Seal samples to prevent moisture loss and handle carefully during shipment to avoid disturbance, in accordance with procedures outlined in ASTM D 4220-89.

3.8-8 CONSOLIDATION TEST

3.8-8.1 Standard Test Method

The ASTM method number utilized is:

- D 2435: Standard Test Method for One Dimensional Consolidation Properties of Soils

3.8-8.2 Significance and Use

Consolidation testing of soils will provide the parameters necessary to predict the rate and magnitude a soil will consolidate (settle) under the application of a load. The test is usually performed on fine-grained, compressible soils such as silts and clays. A typical instance in which the rate and magnitude of settlement would need to be determined is an evaluation of the impact of a landfill and its embankments upon underlying soils. If a particular waste can be considered to behave as a homogeneous mass, consolidation testing may be helpful to predict the amount of settling a landfill cap many undergo due to the overlying weight of the cap material. Consolidation properties are also necessary to predict the amount of leachate that may be generated from the landfill waste.

3.8-8.3 Physical Parameters Obtained

Some of the physical parameters obtained from the consolidation test are:

- c_v = Coefficient of Consolidation - used to determine the rate of consolidation of a soil; expressed as m^2/year.
- C_c and C_r = Compression Indices - used to determine the amount of settlement a soil will experience under application of a load; dimensionless.
- e_o = Initial or In-situ Void Ratio used in the calculation of settlement; dimensionless.

3.8-8.4 Field Sampling Methods, Sample Size, and Preservation

Samples for consolidation testing must be obtained using drilling and test pit sampling techniques for undisturbed sampling. The most common means of undisturbed sampling is by thin-walled tube sampling methods outlined in Section 3.4 of these references. In order to minimize the effects of sampling on the test results, thin-walled sampling tubes should be no smaller than 7.62 cm. (3-inches) in diameter. Alternative means of sampling shallow soils (usually less than 3 meters) would be by test pitting techniques outlined in Section 3.1 of these SRs.

Seal the samples to prevent moisture loss and handle carefully during shipment, following procedures outlined in ASTM D 4220-89.

3.8-9 PERMEABILITY OF SOILS

3.8-9.1 Standard Test Methods

The ASTM method number utilized is:

> D-2434: Standard Test Method for Granular Soils (Constant-Head Test)

The COE EM method number utilized is:

> COE EM 1110-2-1906 (Appendix VII): Method for Granular Soils and Cohesive Soils

3.8-9.2 Significance and Use

Permeability testing of soils will provide parameters necessary to predict the flow rate of a fluid through soils. Laboratory permeability tests can be performed on "undisturbed samples" or on samples recompacted in the lab to approximate in-situ conditions. Permeability tests are used extensively in hydrogeologic investigations to help predict the rate of groundwater flow or contaminant migration.

3.8-9.3 Physical Parameters Obtained

The physical parameter obtained in permeability testing is:

> K = coefficient of hydraulic conductivity; permeability;
> expressed as cm/sec.

3.8-9.4 Field Sampling Methods, Sample Size, and Preservation

Samples for permeability testing may be obtained using standard drilling and test pit sampling techniques for disturbed and undisturbed sampling. The sample size should range between 400 and 1600 grams.

Prior to testing, store samples in noncorrosive, airtight containers in accordance with ASTM D 4220-89.

3.8-9.5 Special Considerations

The test method and equipment apparatus used for permeability testing can vary considerably depending on the condition and character of the sample to be tested. Whether the sample is fine-grained or coarse-grained; very soft, undisturbed, remolded or compacted; saturated or non-saturated, will influence the type of apparatus and test method employed.

Maximum Particle Size		Minimum Weight of Samples	
((mm)	((inches)	(g)	((lbs.)
75.00	3.0	5000	11.00
50.00	2.0	4000	9.00
25.00	1.0	2000	4.50
12.50	0.5	1000	2.20
4.75	0.2	200	0.50
2.00	0.1	100	0.25

Table 3.8-1

Sample Size Needed to Analyze for Various Maximum Particle Sizes in Test for Grain-size Analysis.

Sieve Retaining More Than about 10% of Sample (mm)	Recommended Minimum Mass of Moist Specimen (grams)
2.00	100 to 200
4.75	300 to 500
19.00	500 to 1000
38.00	1500 to 3000
76.00	5000 to 10000

Table 3.8-2

Mass of Moist Specimen Recommended for Different Sieve Sizes.

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STANDARD REFERENCES FOR MONITORING WELLS

SECTION 3.9 PLUGGING BOREHOLES

SECTION 3.9
PLUGGING BOREHOLES

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3.9 PLUGGING BOREHOLES

3.9-1 PURPOSE

The purpose of plugging boreholes is to maintain the integrity of the natural subsurface conditions. Subsurface exploration activities of any kind introduce the potential to develop pathways for the movement of liquids and gases between geologic materials. Boreholes are the most common technique used for subsurface exploration associated with geotechnical investigations, soil and rock sampling, down-hole geophysical exploration, and the installation of piezometers and monitoring wells. The most common drilling techniques for making boreholes include, but are not limited to, uncased mud rotary, cased drive-and-wash and spun methods, and solid- and hollow-stem augers. In most cases, the concern is to prevent the migration of contaminants between geologic strata or from the surface to the subsurface environment. In addition to the potential migration of contaminants, boreholes may impact the natural water levels in both confined and unconfined aquifers. For these reasons, it is recommended that all boreholes that are not sealed as part of the installation of either piezometers or monitoring wells be plugged immediately after completion and utilization for their intended purpose. This should apply to uncontaminated as well as contaminated areas.

A brief description of the most common methods and materials used to plug boreholes are discussed in the following subsection. Some of the methods are also discussed in Section 3.3, Borings in Contaminated Areas, Section 4.3, Well Installation Procedures, and Section 4.6, Decommissioning of Monitoring Wells.

3.9-2 METHODOLOGY

The principle behind the methodology is simple and straightforward: that is, to plug borehole from bottom to top with a permanent, low permeability material. The most commonly used plugging material is described in this section. Because different equipment may be used to advance the borehole, this section will also describe a plugging methodology for the three most common drilling techniques: mud rotary, spun and drive-and-wash casing, and solid- and hollow-stem auger.

3.9-1.2 Plugging Material

It is recommended that the grout mixture used to plug all boreholes be composed, by weight, of 20 parts Portland cement to one part of bentonite, with a maximum of 8 gallons of water per 94-pound bag of cement. More bentonite may be required if the formation is very porous. This ratio of cement to bentonite should not exceed 6:1. Only clean water should be used when mixing grout slurries. It is important to always mix the bentonite with the water first, before adding cement. More details of grout material, mixtures, and mixing methods are described in Section 4.3-5.3.2 Grout Slurries. It should be noted that a neat cement is recommended for decommissioning abandoned wells when the riser and screen are left in place (Section 4.6).

3.9-2.2 Installation Techniques

The following sections briefly describe the plugging methods for mud rotary, cased boring, and solid- and hollow-stem auger techniques.

3.9-2.2.1 Mud Rotary Boreholes

When an uncased mud rotary borehole is completed, the plugging may be accomplished by pumping the selected grout mixture down the drill pipe while it is still in place with the rotary bit at the bottom of the hole. Because the grout mixture may plug the drill bit, it is recommended to use a separate tremie tube for this procedure. A tremie tube is a small diameter hollow plastic or metal tube. While grout is being pumped down the borehole, the drilling mud and formation water escape at the surface between the drill pipe and borehole wall (annular space). Grout should be pumped continuously until all the drilling mud and ground water has been forced out of the borehole. This is usually determined visually by watching the escaping fluid. When the hole has been completely filled with grout, the drill pipe can be removed. As the pipe is removed from the hole, the level of grout should be maintained at the ground surface. This can be accomplished by either pumping more grout down the drill pipe or by pumping grout directly into the annular space around the drill pipe. The latter is much easier and should be done with a short (i.e., 5 to 10 foot long) tremie tube. After the drill pipe has been completely removed, the grout level should be observed and periodically "topped off" with additional grout as settling and curing occurs.

3.9-2.2.2 Cased Boreholes

Cased borings are generally drilled with either spun or drive-and-wash techniques. When completed, even if they are above the water table, they generally have residual water from the washing activities in the casing. Plugging should be accomplished by pumping the selected grout mixture to the bottom of the borehole through a tremie tube. As the borehole fills, the residual water in the casing will be displaced and escape out the top of the casing. Grout should be pumped continuously until all the wash water has been forced out of the casing. This is usually determined visually by watching the escaping fluid. When the casing is full, the casing can be pulled from the borehole. As each section of casing is removed, the grout level should be maintained at the top. While the casing is being pulled, the tremie pipe can be shortened by 5- or 10-foot lengths.

3.9-2.2.3 Auger Boreholes

Auger borings are drilled using either a solid- or hollow-stem technique. Solid-stem augers should only be used under special conditions when it has been determined that plugging of the borehole will not be required. In order to plug a borehole made with a solid-stem auger, the auger must be totally removed from the ground prior to grouting. In unstable soil conditions, the borehole may collapse partially or completely before a tremie tube can be inserted. Every attempt to pump grout into the uncollapsed portion of the borehole must be made immediately after the solid stem auger has been removed. The procedure utilized to plug the borehole is the same as for the Hollow-stem auger, below, except there are no augers to be removed during the process.

Hollow-stem auger borings are plugged in much the same way as a cased boring. If the augers are below the water table, a tremie tube must be used to pump the grout to the bottom of the hole. The grout will displace and force the formation water out the top of the augers. The augers can be pulled and removed, one section at a time, while the level of grout is maintained at the top. If possible, it is advisable to pull the augers without rotating them. This will produce a smoother borehole wall and thus maintain a more uniform column of grout.

If the augers are above the water table, it is acceptable to pour grout into the hollow stem directly. Always keep the grout filled to the top as auger sections are pulled and removed.