Techniques of Water-Resource Investigations of the United States Geological Survey

Chapter F1

APPLICATION OF DRILLING, CORING, AND SAMPLING TECHNIQUES TO TEST HOLES AND WELLS

By Eugene Shuter and
Warren E. Teasdale

Book 2

COLLECTION OF ENVIRONMENTAL DATA

anywhere in the hole if the driller is equipped with the necessary tools for doing so. If this type of sampling is done, standard- rotary air-coring techniques using dry air, foam, or mist would be applicable.

SAMPLING TOOLS AND THEIR APPLICATION

A sample may be defined as a representative unit or part of the formation penetrated in the borehole, that is obtained for purposes of analyses and description. Samples taken can be either disturbed (grab samples, drill cuttings) or undisturbed (samples obtained under in-situ conditions), depending on the techniques with which they are obtained from the borehole. In general, the less sample disturbance required, the more costly the method for obtaining the sample.

Sampling of soil and rock involves many engineering techniques and a variety of specialized downhole tools. These tools are generally referred to as samplers or core barrels; many of them are discussed in the following section.

Applications of Denison Sampler and Core Barrel

The Denison sampler and core barrel can be used to obtain excellent quality, relatively undisturbed cores of unconsolidated materials or consolidated materials. It can provide adequate cores for any laboratory analysis of hydrologic conditions, and it can obtain uncontaminated samples for waste-disposal studies. These results are only possible if the proper techniques and care are used in its operation.

The Denison sampler and core barrel (fig. 31), unique in design and versatility, is one of the best tools available for taking relatively undisturbed cores of soft or unconsolidated material. This device, similar to that of any double- or triple-tube core barrel can also be used to take cores of consolidated material, including hard rock, by adding the optional bottom coring assembly. The bottom assembly consists of an inner-barrel extension, split-ring core catcher, and bottom-discharge coring bit set with either carbide- or diamond-cutting edge. The unique design characteristics of the Denison sampler and core barrel do not offer any advantages over most double-tube core barrels when taking cores of hard materials; however, it is excellent for sampling soft material. The Denison sampler and core barrel comes in two standard lengths: 2 ft and 5 ft. For sampling mostly soft materials, the 2-ft barrel will give the best results.

The Denison sampler and core barrel is used in the following manner: in the soft-formation sampling mode, a preselected-length, boron-tipped (hard-surfacing material) cutter shoe with saw-toothed edge is attached to the bottom of the outer barrel. Three different lengths of cutter shoes permit a lead extension of the inner barrel of from ½ in. to 3 in.; the length of the shoe selected depends on the hardness of the formation materials to be sampled (fig. 32). To obtain a sample, run the Denison sampler and core barrel into the hole and set it on the bottom; continually circulate a drilling fluid having a viscosity of about 50-s; and slowly rotate the Denison sampler and core barrel (not to exceed 100 r/min) while, at the same time, pushing the Denison sampler and core barrel downward at a steady rate. As the Denison sampler and core barrel is pushed downward, the cored sample is passed through the core retainer and into the thin-wall liners of the inner barrel. As the sample moves upward into the Denison sampler and core barrel, the drilling fluid remaining on top of the sample is vented to the low-pressure area on the outside of the core barrel through a disc valve, resulting in a minimum of resistance to the sample as it slides upward into the brass inner liner. After the full length of the sample has been cut, the downward push and rotation of the Denison sampler and core barrel is stopped, and the sample is withdrawn slowly from the hole. After the Denison sampler and core barrel has been removed from the hole, it is dismantled; the brass inner liner is removed and marked as to the top, bottom, depth, and any other necessary data; it is capped, and the ends are waxed, if moisture retention is important.

As previously mentioned, the Denison sampler and core barrel has three different lengths of cutting bits available that permit a ½-in. to 3-in. lead extension of the inner barrel. The variable length of the inner barrel ahead of the cutting bit provides a broad field of sampling application to the Denison sampler and core barrel; it is further described in

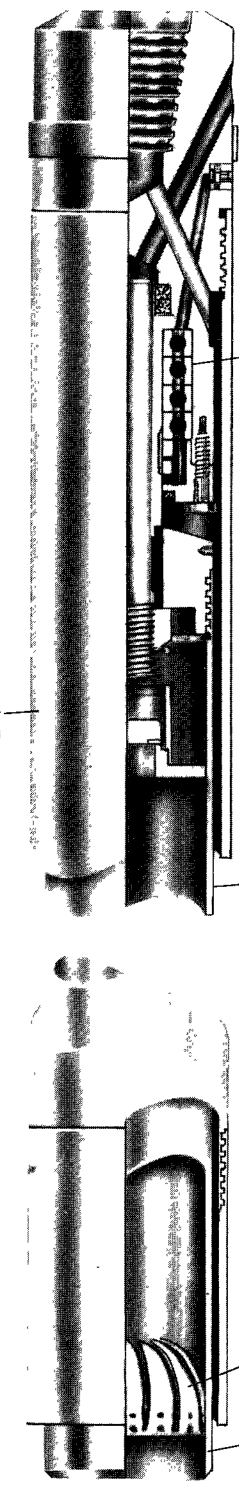


Figure 31.—Denison sampler and core barrel.

the following examples: in soft or loosely consolidated materials, a longer projection of the inner barrel ahead of the cutting bit is essential for best recovery, because the jetting or washing action of the drilling fluid would invade or wash away a loosely consolidated material if the discharge point of the drilling fluid was too close to that area of the material entering the inner barrel. In practice, use the longest inner-barrel extension that would still permit the downward movement of the Denison sampler and core barrel. In more consolidated material, a cutting bit close to the leading edge of the inner barrel may be essential to recover the core because the cored material is less compressible and not easily penetrated by the inner-barrel shoe. A cutting bit closer to the inner-barrel length is necessary to cut enough hole clearance for the downward progress of the Denison sampler and core barrel. Selection of the proper cutting bit to allow different lead lengths of the inner barrel must be learned by trial and error for the area and lithologic units that each user-operator is attempting to sample, but the overriding criterion for taking samples with the sampler is: use the longest inner-barrel extension possible to prevent invasion or fluid contamination of the sample. As much as 8,000 lb of downward thrust for a 4-in. O.D. Denison sampler and core barrel can be applied for penetration of the inner-barrel extension.

If sample materials are too dense or compact to be sampled by the previously described methods, then the Denison sampler and core barrel can be used as a standard core barrel by equipping it with the aforementioned optional bottom assembly for coring. The method of operation for coring hard materials with the Denison sampler and core barrel is no different than the methods of most double- or triple-tube core barrels. The Denison sampler and core barrel offers the advantage of conversion back to the soft-formation sampling mode, if the hard zones are only intermittent.

Removal of Sample-Retainer Liner from Inner Barrel

After the sample has been cut and retained in the brass inner liner, the Denison sampler and core barrel is slowly extracted from the hole and placed on a platform or set of sawhorses. Remove the core-barrel head and swivel assembly and inner barrel

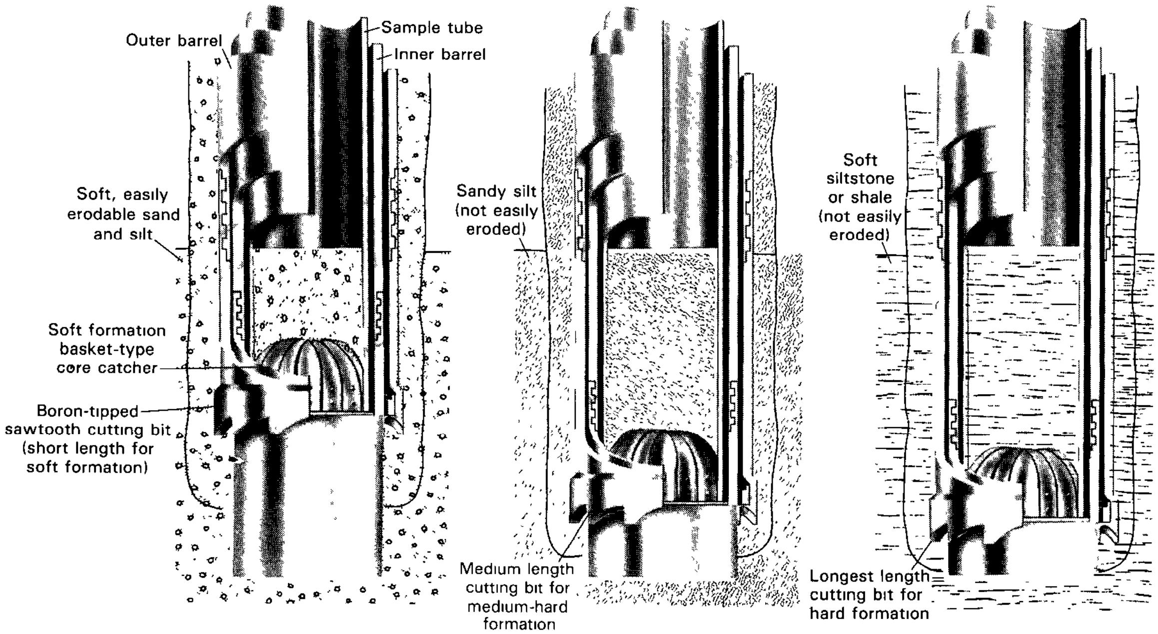


Figure 32.—Relationship of inner-barrel protrusion using different-length Denision-sampler cutting bits for drilling.

from the outer barrel. Strap the inner barrel into a pipe vise. Remove the inner-barrel lead shoe from the inner barrel; then extrude the brass inner liner. Under ideal conditions, the liner is withdrawn by taking hold of one end of the liner with a pair of vise grips or pliers while pushing on the other end with a short piece of the same-diameter brass liner. Occasionally, some fine grit gets in between the brass liner and the inner barrel, and this frictional locking of the inner liner makes it impossible to remove by hand. If this occurs, start the brass liner out of the inner barrel in the following manner. Place the inner barrel in a pipe vise, preferably mounted on the drill truck bed or bumper; place a short section of the same-diameter brass liner inside the inner barrel until it engages the shoulder of the brass liner. Then place the head of a mechanical or hydraulic jack against a block of wood that covers the open diameter of liner extension and place the base of the jack against an immovable backup; a slow, short-stroke operation of the jack will break the brass inner liner loose from the inner rrel and it can be readily removed. If the user anticipates a considerable amount of sampling with the Denison sampler and core barrel, it would be very advantageous to construct a simple type of extractor designed by the authors. The extractor (fig. 33) screws into the internal threads of the inner barrel, and turning the "T" handle the square-threaded push rod causes the sample-tube extractor ram to push the brass inner liner out of the inner barrel. We have never encountered any grit lock that could not be broken loose with this device. Note: Whatever system is used to start the brass inner liner out of the inner barrel, refrain from tapping or pounding on the sampler inner barrel, as not to damage the integrity of the sample.

Following are a few techniques that can result in good core recovery when using the Denison sampler and core barrel:

1. When pushing the inner barrel into the material being sampled, always rotate the outer barrel at a rate, less than 100 r/min. A fast rotation tends to set up vibrations that can destroy the integrity of a sample being pushed up into the inner barrel and inner liner.

2. Never use water as a drilling fluid (even though this is recommended in other literature), as there is far too great a chance for washing away the sample or invading ahead of the sample, resulting in a contaminated core. Use a lightweight but viscous drilling fluid having a minimum viscosity of 50-s.

3. When using the Denison sampler and core barrel as a sampler in soft formations, maintain a

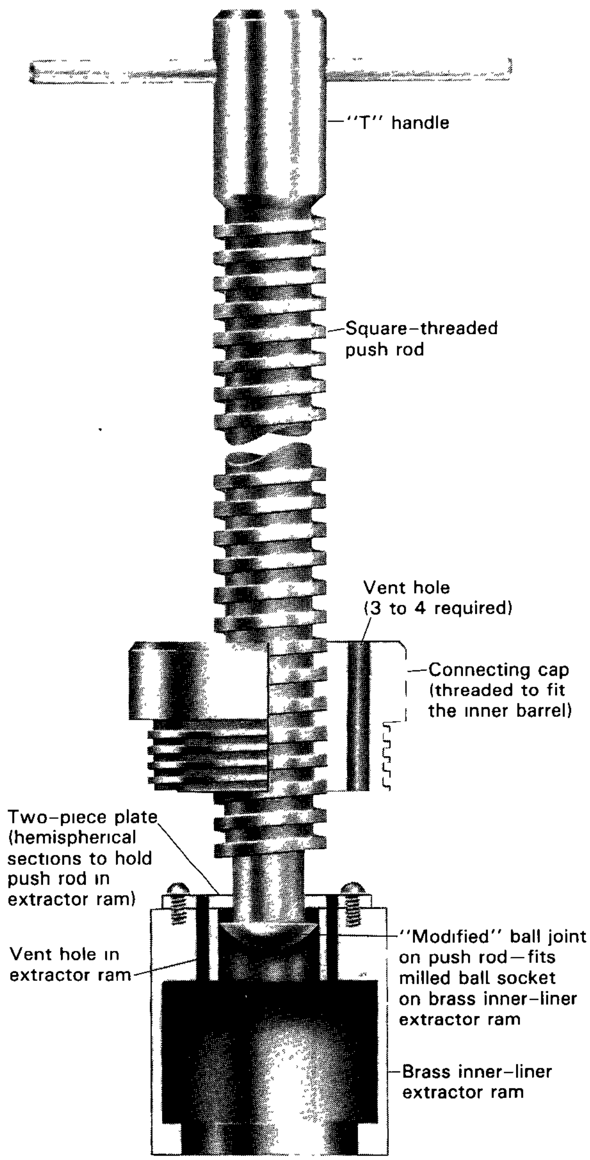


Figure 33.—Denison sampler and core-barrel brass inner-liner extruding assembly.

slow but steady rate of downward movement of the sampler. Do not progress the Denison sampler and core barrel faster than the drill fluid can carry the generated drill cuttings away from the cutting bit. If the sampler is pushed into the formation too fast, material that has not been moved up the hole will become jammed between the outer barrel and inner barrel, and it will cause the inner barrel to rotate with the outer barrel, shearing the bottom of the core off and disturbing any additional core that is pushed into the inner barrel. If the barrel locks together, return the Denison sampler and core barrel to the surface for cleaning and removal of core. Locking up the inner and outer barrel can be prevented by watching the drill-fluid pressure gage. For example: the sampler has been set on the bottom of the hole and the mud pump engaged; the pressure gage indicates a pressure of 50 lb/in.^{2} with a drilling-fluid discharge rate of 20–25 gal/min and coring of about 2 ft/min is begun, the cutting bit generates cuttings that must be removed from the hole and carried to the surface by the drilling fluid. This requires an additional 25 lb/in.^{2}. The pressure would then be about 75 lb/in.^{2}. As long as the pressure remains at about 75 lb/in.^{2}, coring is probably progressing satisfactorily. However, if the pressure approaches 100 lb/in.^{2} or more (caused by the cuttings not moving up the annulus fast enough or an invasion of sediment between the inner and outer barrel that is restricting flow), then the downward movement of the sampler should be slowed, not stopped, until the fluid pressure returns to about 75 lb/in.^{2}

4. As mentioned previously, the Denison sampler and core barrel comes in two standard lengths of 2 ft and 5 ft. If the material to be sampled is very soft, it is often better to take short coring runs (2 ft) so that there is no tendency to compress or distort the material in the inner liner. However, short coring runs can be accomplished using a 5-ft barrel as well as a 2-ft barrel, thereby still leaving the option of cutting a longer core if formations permit.

5. Shorter increments (standard is 5 ft) of the brass inner liners installed in the inner barrel may be preferred at times. This is possible but requires a particular note of caution. If five 1-ft brass inner liners, which are convenient for laboratory analysis, or two 2½-ft brass inner liners are preferred, the combination of lengths used must be cut full-length to ensure snug fit from shoulder to shoulder in the inner barrel; otherwise, grit lock between the brass inner liners and the inner barrel will occur at any separation, resulting in difficult brass inner-liner extraction.

Sampling Fluid Sands

Occasionally, the user of the Denison sampler and core barrel will encounter soft, fluid sands that will be lost through the slots of the basket retainer when the Denison sampler and core barrel is being removed from the hole. This loss of sample can usually be prevented by installing a sock of thin polyethylene sheeting around the basket retainer, before the retainer is installed in the lead shoe of the extension. The polyethylene sock should be long enough to cover the basket retainer and extend about 10 in. into the brass inner liner. The polyethylene should be slit longitudinally 1 in. apart several places about 4 in. from the top of the sock.

As the Denison sampler and core barrel penetrates the formation, the sand moves into the brass inner liners, past the basket retainer and polyethylene sock. When the sampling depth has been reached, downward movement and rotation of the Denison sampler and core barrel are stopped. Prior to removal of the Denison sampler and core barrel, allow a 2- or 3-min rest period so the cored fluid sands can settle and collapse the polyethylene sock over the fingers of the basket retainer. The Denison sampler and core barrel can then be withdrawn from the hole at a rate not exceeding 15 ft/min. A faster rate of withdrawal would cause undue suction on the bottom of the sample, resulting in its being lost in the hole.

The Denison sampler and core barrel is manufactured in four standard sizes: 3½-in. O.D., 4-in. O.D., 5½-in. O.D., and 7¾ in. O.D. Any of the four sizes recovers a relatively large sample in the inner nonrotating barrel and, because of these relatively large samples, usually causes less sample disturbance than is found in samples taken with smaller diameter sampling devices. Larger samples can be trimmed in the laboratory to minimize sample deformation caused by wall friction or slight drag of the core retainer springs on the sample. Sufficient sample volume exists to prepare several samples from any given horizontal strata.

Applications of Pitcher Sampler

The pitcher sampler can be used to obtain excellent-quality, relatively undisturbed cores of a variety of soil conditions. It can provide cores that are adequate for almost any laboratory analysis of hydrologic conditions as well as obtaining uncontaminated samples for waste-disposal studies. However, these results are only possible if the proper techniques and care are used in its operation.The pitcher sampler (fig. 34) was designed specifically to recover representative samples from formations that are too hard to be obtained using thin-walled Shelby samplers, or too brittle, soft, or water- sensitive to permit accurate recovery using conventional core-barrel-type samplers. It can provide uncontaminated samples of soft rock, sand, friable shales, and some clays that are too difficult to sample by other methods.

The pitcher sampler, like the Dension sampler and core barrel, offers the advantage of having a thin-walled Shelby tube extending below the point at which the drilling fluid is introduced, to remove drill cuttings from the hole. This feature prevents the drilling fluid from breaking through, eroding, or contaminating the sample, even in the softest materials. The mechanics of the inner-barrel extension of the Denison sampler and core barrel and the Shelby tube of the Pitcher sampler are quite different: the extension of the inner barrel of the Denison sampler and core barrel is predetermined by the selection of different-length cutting shoes installed on the outer barrel as explained beginning on page 63. Whereas the extension of the Shelby tube of the pitcher sampler is regulated by a high-tension spring within the upper core-barrel body (fig. 34), the Shelby tube of the pitcher sampler may extend as much as 6 in. ahead of the sawtooth bit and drill-fluid outlet (fig. 35A) when samples are taken of very soft or low-density formation. As the formation being sampled becomes harder and more difficult to penetrate, the upper housing of the inner assembly pushes up against the high-tension spring, which, in turn, exerts an ever-increasing thrust to the Shelby tube (fig. 35B).

The pitcher sampler is manufactured in several diameters ranging from 4½-in. O.D. to 7¾-in. O.D., which takes core samples from about 2¾ in. to 5 ⅞ in. in diameter. The standard pitcher sampler is the 4⅞-in. O.D., which takes a 3-in.-diameter sample. The pitcher sampler is also manufactured in two standard lengths, 5 ft and 3 ft. The 3-ft barrel is recommended to minimize disturbances of the material being pushed into the Shelby tube. In practice, the pitcher sampler is used in the following manner: the pitcher sampler is lowered into the hole on any of the standard drill rods. As the pitcher sampler is picked up and run into the hole, the 36-in., Shelby-tube liner will rest on the internal shoulder of the sawtooth bit and protrude about 30 in. below the sawtooth bit. This is a unique and advantageous feature of the pitcher sampler because it allows the drilling mud to be pumped directly through the Shelby tube and flush away any heavy mud or sediment debris that is in the bottom of the hole. As soon as the bottom end of the Shelby tube

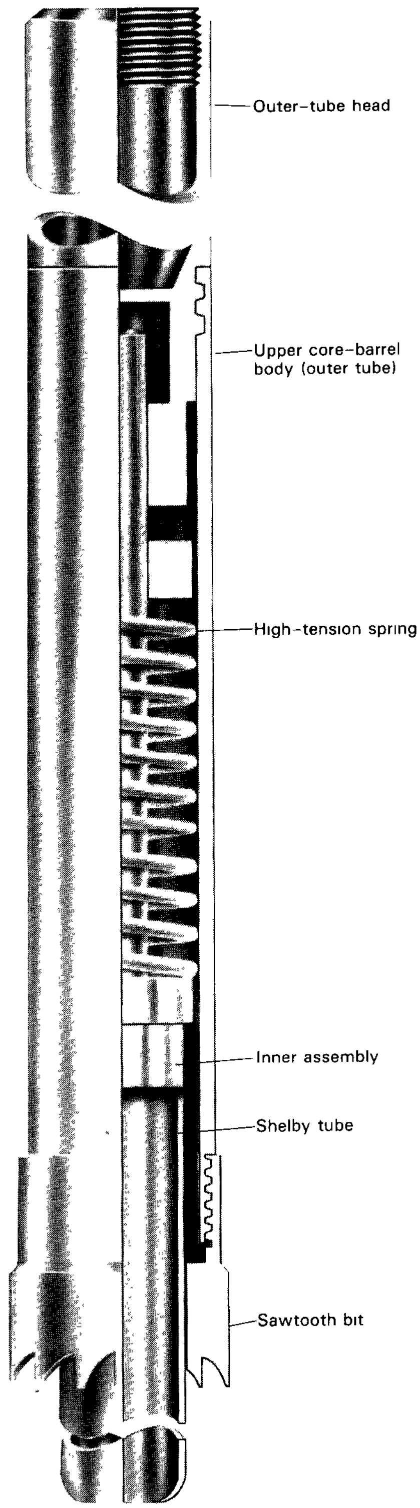


Figure 34.—Pitcher-sampler assembly.

meets any resistance of unsampled material, an internal sliding valve moves up, cutting off the supply of drilling mud to the Shelby tube and diverting it to the annular area between the Shelby tube and the outer tube. This fluid will then divert out the bottom of the sawtooth bit and transport the drill cuttings up the hole (fig. 35A and B). Drilling operations and sampling techniques are basically the same as those described for the Denison sampler and core barrel. Rotate the outer tube slowly to minimize any vibration that would disturb the cored material. Drilling-fluid discharge rate should be as low as possible but still carry the drilled cuttings up the hole. After the pitcher sampler has been pushed to full sample-penetration depth (3 ft) or to a point of refusal, the pitcher sampler is pulled out of the hole and the Shelby tube containing the sample is removed.

Removal of Shelby-Tube Sample Retainer

Removal of the Shelby-tube sample retainer from the pitcher sampler is a very simple operation. Unlike the Denison sampler and core barrel, which requires dismantling of the entire core barrel assembly, the Shelby-tube sample retainer is removed by taking out two allen screws. The Shelby tube containing the sampled material can then be prepared in the same manner as described on pages 73–74 for protecting Shelby-tube samples for storage or transport.

Applications of Solid- or Split-Barrel Samplers

The solid- or split-barrel samplers are simple but very useful tools for obtaining representative samples of unconsolidated formations. They can be used in any type of drill hole.

The tools are used widely in the soils-engineering field for SPT (standard penetration test); the ASTM (American Society for Testing and Materials) has published standards for the use of the sampler. The method is designated as: D1586–67 and is quoted here to (1) show potential users of the method for performing SPTs and (2) indicate that much of our discussion of the use of drive-core samplers does not

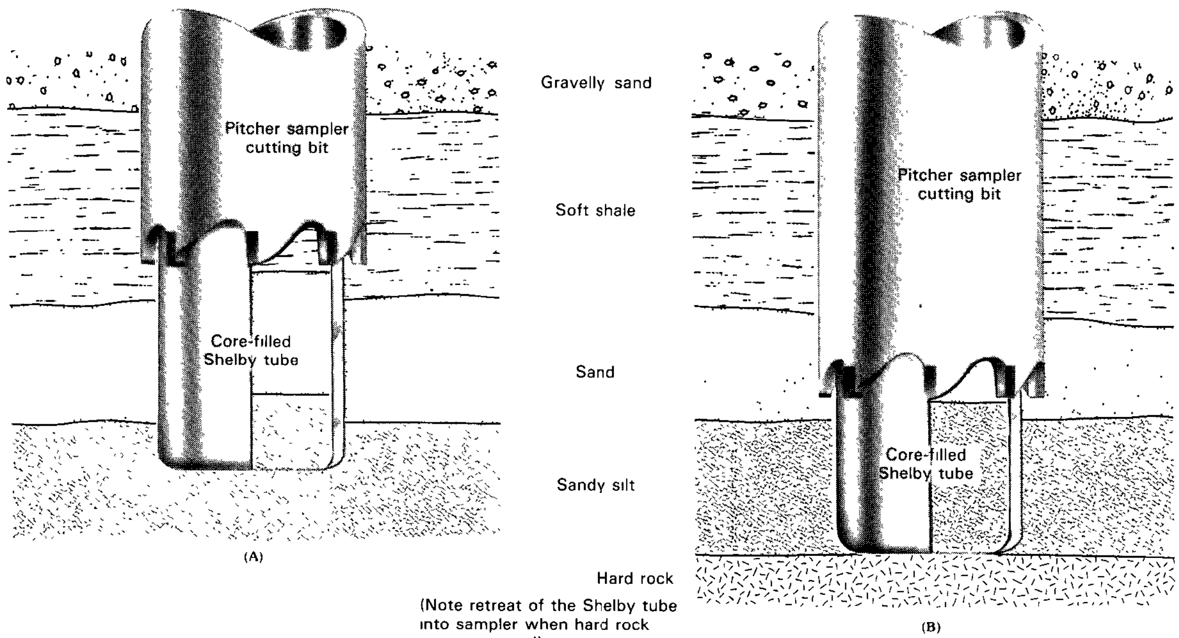


Figure 35.—Pitcher-sampler operation; *A*, soft formations, *B*, hard rock.

(nor is intended to) meet ASTM standards. The following is the standard set forth by the ASTM: Standard Method for Penetration Test and Split-Barrel Sampling of Soils

1. Scope

1.1 This method describes a procedure for using a split-barrel sampler to obtain representative samples of soil for identification purposes and other laboratory tests and to obtain a measure of the resistance of the soil to penetration of the sampler.

2. Apparatus

2.1 Drilling Equipment—Any drilling equipment shall be acceptable that provides a reasonably clean hole before insertion of the sampler to ensure that the penetration test is performed on undisturbed soil and that will permit the driving of the sampler to obtain the sample and pentration record in accordance with the procedure described in Section 3. To avoid "whips" under the blows of the hammer, it is recommended that the drill rod have a stiffness equal to or greater than the A-rod. An 'A' rod is a hollow drill rod or "steel" having an outside diameter of 1 ⅝ in. (41.2 mm) and an inside diameter of 1 ⅛ in. (28.5 mm), through which the rotary motion of drilling is transferred from the drilling motor to the cutting bit. A stiffer drill rod is suggested for holes deeper than 50 ft (15 m). The hole shall be limited in dia- meter to between 2¼ and 6 in. (57.2 and 152 mm).

2.2 Split-Barrel Sampler—The drive shoe shall be of hardened steel and shall be replaced or repaired when it becomes dented or distorted. The coupling head shall have four ½-in. (12.7 mm) (minimum diameter) vent ports and shall contain a ball check valve. If sizes other than the 2-in. (50.8 mm) sampler are permitted, the size shall be conspicuously noted on all penetration records.

2.3 Drive Weight Assembly—The assembly shall consist of a 140-lb (63.5-kg) weight, a driving head, and a guide permitting a free fall of 30 in. (0.76 m). Special precautions shall be taken to ensure that the energy of the falling weight is not reduced by friction between the drive weight and the guides.

2.4 Accessory Equipment—Labels, data sheets, sample jars, paraffin, and other necessary supplies should accompany the sampling equipment.

3. Procedure

3.1 Clear out the hole to sampling elevation using equipment that will ensure that the material to be sampled is not disturbed by the operation. In saturated sands and silts, withdraw the drill bit slowly to prevent loosening of the soil around the hole. Maintain the water level in the hole at or above ground-water level.

3.2 In no case shall a bottom-discharge bit be permitted. (Side- discharge bits are permissible). The process of jetting through an open-tube sampler and then sampling when the desired depth is reached shall not be permitted. Where casing is used, it may not be driven below sampling elevation. Record any loss of circulation or excess pressure in drilling fluid during advancing of holes.

3.3 With the sampler resting on the bottom of the hole, drive the sampler with blows from the 140-lb (63.5-kg) hammer falling 30 in. (0.76 m) until either 18 in. (0.4 m) have been penetrated or 100 blows have been applied.

3.4 Repeat this operation at intervals not longer than 5 ft (1.5 m) in homogeneous strata and at every change of strata.

3.5 Record the number of blows required to effect each 6 in. (0.15 m) of penetration or fractions thereof. The first 6 in. (0.15 m) is considered to be a seating drive. The number of blows required for the second and third 6 in. (0.15 m) of penetration added is termed the penetration resistance, N. If the sampler is driven less than 18 in. (0.45 m), the penetration resistance is that for the last 1 ft (0.30 m) of penetration (if less than 1 ft (0.30 m) is penetrated, the logs shall state the number of blows and the fraction of 1 ft (0.30 m) penetrated).

3.6 Bring the sampler to the surface and open. Describe carefully typical samples of soils recovered as to composition, structure, consistency, color, and condition; then put into jars without ramming. Seal them with wax or hermetically seal to prevent evaporation of the soil moisture. Affix labels to the jar or make notations on the covers (or both) bearing job designation, boring numer, sample number, depth penetration record, and length of recovery. Protect samples against extreme temperature changes.

4. Report

4.1 Data obtained in borings shall be recorded in the field and shall include the following:

- 4.1.1 Name and location of job,
- 4.1.2 Date of boring—start, finish,
- 4.1.3 Boring number and coordinate, if available,
- 4.1.4 Surface elevation, if available,
- 4.1.5 Sample number and depth,
- 4.1.6 Method of advancing sampler, penetration and recovery lengths,
- 4.1.7 Type and size of sampler,
- 4.1.8 Description of soil,
- 4.1.9 Thickness of layer,
- 4.1.10 Depth to water surface; to loss of water; to artesian head; time at which reading was made,
- 4.1.11 Type and make of machine,
- 4.1.12 Size of casing, depth of cased hole,
- 4.1.13 Number of blows per 6 in. (0.15 m).
- 4.1.14 Names of crewmen, and
- 4.1.15 Weather, remarks.

Deviations from ASTM Standards

Obviously the U.S. Geological Survey does not comply with the ASTM standards (use of different-size barrels, washing-in the sampler through caved material, using different drive rod, and so forth). These deviations are used to obtain representative samples of materials that will aid in the recovery of hydrogeologic data under less than ideal conditions. When possible, similar standards for collecting samples by the various available techniques are followed. However, the responsibility for collecting data to provide subsurface information needed to make critical decisions pertaining to water supply, contamination of water supplies resulting from solid-, chemical-, radioactive- (both solid and liquid) waste storage and disposal must be taken into account. To obtain the type of samples necessary to provide input of needed data for these studies, some accepted engineering standards must be modified or disregarded. Use whatever method is available for data collection, without undue concern about damaging sampling tools but with close attention to obtaining uncontaminated samples to provide vitally needed data.

Method for Drive Sampling

Although a specific description of drive sampling is provided in each of the drilling methods discussed in this manual, this general description is provided so the reader can refer to that particular section in the manual on the drilling method best suited to any particular sampling needs.pparatus

Apparatus

Solid- and split-barrel samplers are manufactured in a variety of diameters and lengths; our standard is

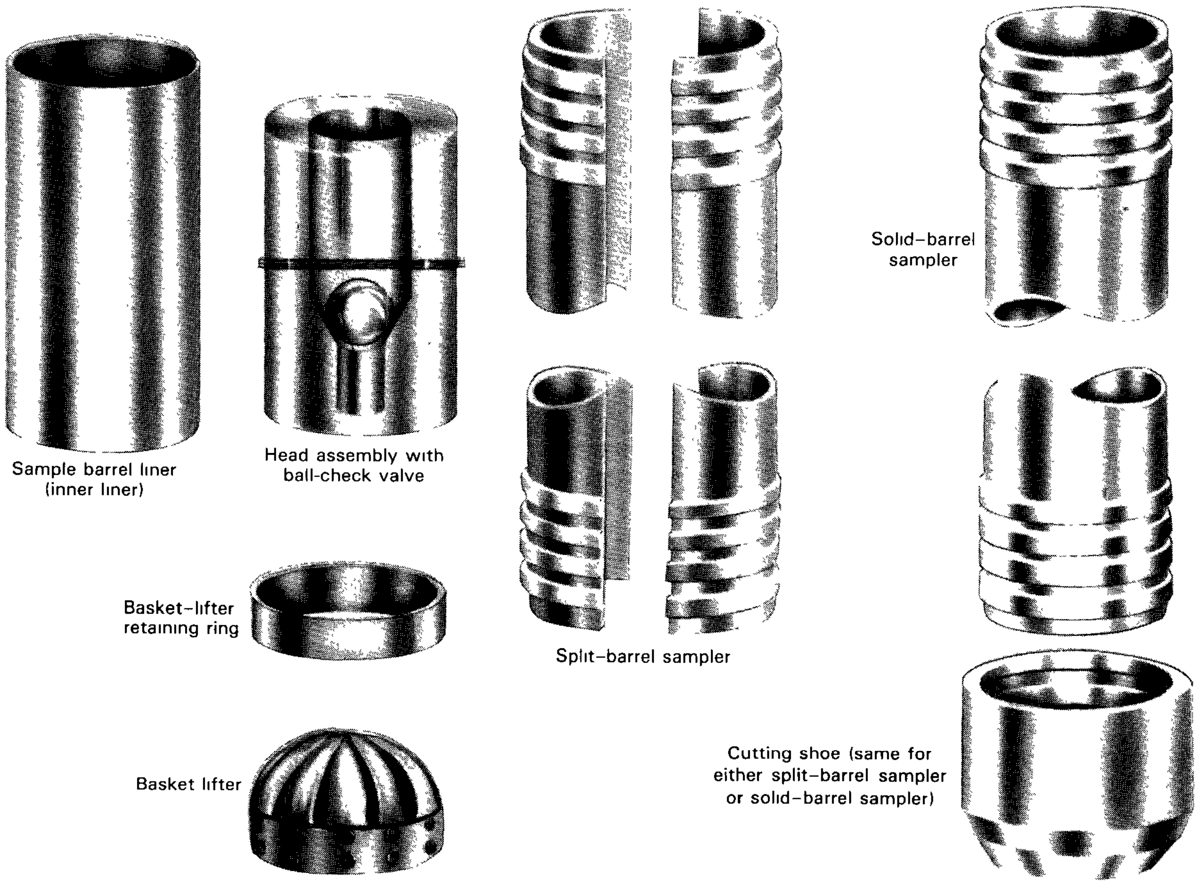


Figure 36.—Split-barrel sampler and a solid-barrel sampler with component parts.

a 3-in.-diameter, 18-in.-length sampler equipped with liners for retention and protection of the sample (fig. 36). The U.S. Geological Survey almost always uses N rod for drive rod instead of the A rod described in the ASTM standard because of needs to sample to depths of as much as several hundred feet rather than to the much shallower depths usually typical of soil-engineering studies. A 300-lb drive hammer rather then a 140-lb drive hammer is used to sample dense materials because much of the drive impact of the 140-lb hammer is lost in the whip and give of the lighter A rod, resulting in an insufficient blow to drive the sampler into dense material.

Procedure

Assume a clean-bottom auger-drilled hole that has had the cuttings removed or a rotary-drilled hole where cuttings have been flushed out and the hole spotted with a viscous, clean drilling mud to prevent downward penetration of fluid that would result in contamination of the drive sample. After the hole has been spotted with the drilling mud, follow the technique explained on pages 51 to 53 for driving the sample. The user must be aware that continued attempts to drive sample in a material that is very dense and hard (siltstone, sandstone, boulders, and so forth) will damage the sampler or break it off in the hole. A choice must be made concerning the ability of the sampler to absorb abuse versus the need for the sample.

Prior to obtaining a drive-core sample from a hole containing considerable cuttings or caved material, flush the material out and condition the hole with drilling mud in order to have a clean hole bottom for sampling. However, there are times when the sampler will have to be washed to the bottom of the hole because heavy cuttings settle out in the bottom of the hole or in a solid-stem auger-drilled hole bridging occurs due to improper drilling-mud control. This is accomplished in the following manner: remove the ball check from the sampler; mix a clean, lightweight drilling mud having a viscosity of about 50-s; connect the sampler to the N rod and lower it into the hole to a point about 3 in. above the bridged zone or the cuttings at the bottom of hole and circulate the drilling mud for several minutes to get the cuttings out of the hole or into suspension in the drilling mud at some point up the hole. If proper mud control is exercised in cleaning the hole, fluid invasion of the sample could be as little as 1 or 2 in., even in highly permeable sands. Note: Only a prepared drilling mud should be used for the cleanout procedure, because using water alone would cause considerable sample invasion and jetting damage to the proposed sampled interval. After washing the sampler to the bottom of the hole and flushing the hole is completed, the water swivel is removed from the N rod; the drive hammer is attached; and the sample is driven according to the sample-driving procedure.

After the drive-core sample has been driven to the prescribed or refusal depth, it is removed from the hole in one of the following ways: (1) dislodge the sampler from the formation by pulling it with the rig winch or hydraulics and (2) if the winch or hydraulics will not dislodge the sampler, the drive hammer is used in the reverse mode to jar up on it. The latter method should only be applied when absolutely necessary, because it adds to the disturbance of the sample. As soon as the sampler has been dislodged to a point that it can be retrieved with the rig winch, use the winch to pull the sampler and N rod out of the hole.

After removing the sampler from the hole and placing it in a pipe vise, the cutting-shoe head assembly and inner liners containing the sampled material are removed from the barrel. If the sampler is a solid-barrel type, the liners containing the sample must be extruded from the barrel (fig. 36). If the sampler is the split-barrel type, one-half of the split barrel is removed; the liners are marked at the top and bottom of the sample; a sharp knife is used to sever the sample at the liner joint. The liners are then individually removed, capped, taped on each end and properly marked with all pertinent data. Wrapping the sample liners in aluminum foil and dipping them in wax will help prevent desiccation. Any sample material remaining in the cutting shoe or any part of the sample not used for analysis can be used for visual description of the lithology. Note any pertinent data (ease or difficulty in driving the sample, number of hammer blows needed, and so forth) in the log book for sample evaluation. Note: With drive-core sampling experience, the user will learn through experimentation whether a basket-lifter retainer is needed in the bottom of the sample barrel or not to keep the sample from falling out when the sample barrel is dislodged. Many materials, particularly some sands and gravels, maintain enough friction to remain in the barrel without using a basket-lifter retainer. Coring without using a basket-lifter retainer, if possible, gains two advantages: (1) less disturbance of the sample occurs as it enters the barrel and (2) material in the bottom liner is not lost when the basket-lifter retainer is removed.

Applications of the Thin-Walled Tube Sampler

The thin-walled sampler utilizes a Shelby tube and is used primarily for the collection of undisturbed soil samples of low-density materials. The tool has limited sampling applications because of the fragile nature of the Shelby tube. Misuse will damage the sampler.

The sampler (fig. 37) is manufactured in a variety of diameters and lengths, but the Water Resources Division of the U.S. Geological Survey considers the 3-in.-diameter, 36-in.-length Shelby tube a standard. ASTM has established a standard method for sampling with the thin-walled tube sampler; this method, from ASTM D1587–83, is paraphrased here.

Standard Practice for Thin-Walled Tube Sampling of Soils

1. Scope

1.1 This method covers a procedure for using a thin-walled metal tube to recover relatively undisturbed soil samples suitable for laboratory tests. It is a guide to more complete specifications to meet the needs of a particular job.

1.2 In general, two types of samplers use thin-walled tubes for sampling, namely, open-tube samplers and piston samplers. In general, piston

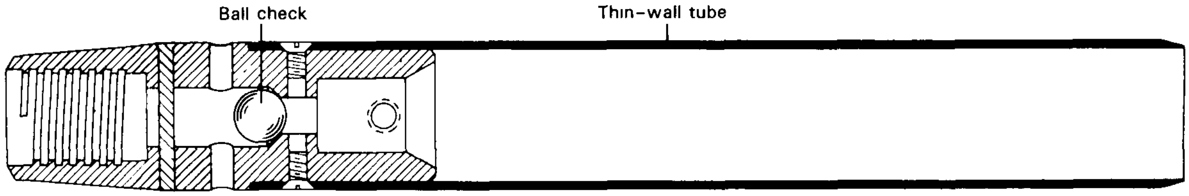


Figure 37.—Thin-walled tube sampler (Acker, 1974, reprinted by permission from Acker Drill Co., Inc.).

samplers are better and can be used in almost all soils. Since the thin-walled tube requirements are the same for both types of samplers, the method described applies equally to both.

2. Apparatus

2.1 Drilling Equipment—Any drilling equipment may be used that provides a reasonably clean hole before insertion of the thin-walled tube that does not disturb the soil to be sampled, and that can effect continuous and rapid penetration of the tube into the sampled soil.

2.2 Thin-Walled Tubes—Thin-walled tubes that are 2–5 in. (50.8-127 mm) in outside diameter and are made of any materials having adequate strength and resistance to corrosion will be satisfactory. Adequate resistance to corrosion can be provided by a suitable coating. Sizes other than these may be used, if specified.

2.2.1 Tubes shall be of such a length that 5–10 times the diameter is available for penetration into sands and 10–15 times the diameter is available for penetration into clays. Tubes shall be round and smooth, without bumps, dents, or scratches. They shall be clean and free from rust and dirt. Seamless or welded tubes are permissible, but welds must not project at the seam. The cutting edge shall be machined and shall be free of nicks. The inside clearance ratio shall be between 0.5–3 percent.

2.2.2 The coupling head shall contain a suitable check valve and a venting area to the outside equal to or greater than the area through the check valve.

2.3 Sealing Wax—Any wax shall be permitted for sealing that does not have appreciable shrinkage or does not permit evaporation from the sample. Microcrystalline waxes are preferable to paraffin. Thin disks of steel or brass that are slightly smaller than the inside diameter of the tube are desirable for plugging both ends before sealing with wax. Cheesecloth and tape are needed. Suitable expanding packers may be used.

2.4 Accessory Equipment—Labels, data sheets, shipping containers, and other necessary supplies.

3. Procedure

3.1 Clean out the hole to sampling elevation using whatever method is preferred that will ensure that the material to be sampled is not disturbed. In saturated sands and silts, withdraw the drill bit slowly to prevent loosening of the soil around the hole. Maintain the water level in the hole at or above ground-water level.

3.2 The use of bottom discharge bits shall not be allowed but any side discharge bit is permitted. The procedure of jetting through an open- tube sampler to clean out the hole shall not be allowed.

3.3 With the sampling tube resting on the bottom of the hole and the water level in the boring at the ground-water level or above, push the tube into the soil by a continuous and rapid motion, without impact or twisting. In no case shall the tube be pushed farther than the length provided for the soil sample. Allow about 3 in. (75 mm) in the tube for cuttings and sludge.

3.4 When the soils are so hard that a pushing motion will not penetrate the sampler sufficiently for recovery and where recovery by pushing in sands is poor, use a driving hammer to drive the sampler. In such a case, record the weight, height, and number of blows. Before pulling the tube, turn it at least two revolutions to shear the sample off at the bottom.

3.5 Repeat the sampling procedures described at intervals not longer than 5 ft (1.5 m) in homogeneous strata and at every change of strata.

4. Preparation for Shipment

4.1 Upon removal of the sampler tube, measure the length of sample in the tube and also the length penetrated. Remove disturbed material in the upper end of the tube before applying wax and measure the length of sample again. After removing at least 1 in. (25 mm) of soil from the lower end and after inserting an impervious disk, seal both ends of the tube with wax applied in a way that will prevent wax from entering the sample. Where tubes are to be shipped some distance, tape the ends to prevent breakage of the seals. Place cheesecloth around the ends after sealing and dip the ends several times in the melted wax.

4.2 Affix labels to the tubes giving job designation, sample location, boring number, sample number, depth, penetration, and recovery length. Record a careful description of the soil, noting composition, structure consistency, color, and degree of moisture. Mark the tube and boring numbers in duplicate.

4.3 Do not allow tubes to freeze, and store them in a cool place out of the sun at all times. Ship samples protected with suitable resilient packing material to reduce shock, vibration, and disturbance.

4.4 Using soil removed from the ends of the tube, make a careful description giving composition, condition, color, and, if possible, structure and consistency.

5. Report

5.1 Data obtained in borings shall be recorded in the field and shall include the following:

5.1.1 Name and location of job,
5.1.2 Date of boring—start, finish,
5.1.3 Boring number and coordinate, if available,
5.1.4 Surface elevation, if available,
5.1.5 Sample number and depth,
5.1.6 Method of advancing sampler, penetration and recovery lengths,
5.1.7 Type and size of sampler,
5.1.8 Description of soil,
5.1.9 Thickness of layer,
5.1.10 Depth to water surface; to loss of water; to artesian head; time at which reading was made,
5.1.11 Type and make of machine,
5.1.12 Size of casing, depth of cased hole,
5.1.13 Names of crewmen, and
5.1.14 Weather, remarks.

The procedure used by the Water Resources Division of the U.S. Geological Survey for collecting thin-walled tube sampler samples does not deviate much from the standard set forth by ASTM. Some further suggestions for taking undisturbed thin-walled tube sampler samples not covered in the ASTM procedure are the following:

1. The thin-walled tube sampler is very fragile, and considerable damage to the sampler and distortion of the sharpened cutting edge can result when attempting to sample gravelly materials. If damage occurs, particularly if a part of the cutting edge is turned in, the damage will contribute to disturbance of any additional sample entering the tube. Therefore, stop sampling when gravelly materials are encountered. However, if the user is interested only in representative or geochemical samples of the material, then the sample can be forced or driven beyond its normal capacity. The Shelby tube may be ruined for future sampling purposes but a representative sample can be obtained.

2. The thin-walled tube sampler has no retainers for holding the sample in. The sample is held in the tube by the swelling of cohesive, sticky soils as it expands in the sample tube as well as the ball-check valve creating a vacuum on the sample. In practice, the cutting edge of the tube is rolled inward to provide an inside clearance of about 1 percent of the diameter. It is then reamed to provide a sharp cutting edge. The 1 percent restriction helps to hold the sample in the tube. It is often beneficial to let the sampler remain in the hole for about 15 minutes, after it has been pushed into the formation. This allows the soil to swell and provides an additional friction hold.

3. If a thin-walled tube sampler is used to collect a sample under saturated conditions and the sample is to be used for chemical analyses determinations, the hole should first be spotted prior to sampling with a clean, viscous drilling mud. Water should not be used instead of the drilling mud for this purpose because it would flush the chemicals out of the sampled material during the sampling procedure. The clean, viscous mud will provide good hole control, prevent caving, and minimize fluid invasion in the sample.

Applications of the Retractable-Plug Sampler

The retractable-plug sampler (fig. 38) is a lightweight coring device ordinarily used for shallow exploration studies and usually hand driven using a 25-lb slip hammer. The small diameter and fragility of this sampler prohibits its use for sampling very dense formations or for sampling beyond a depth of about 50 ft. The small diameter of the cores impose limits to their usefulness for the purpose of quantitative hydrologic analyses.

However, the retractable-plug sampler can take clean representative samples that are adequate for less quantitative hydrologic analyses, as well as chemical and waste-constituent analyses. The retractable-plug sampler is discussed because of its unique design with a retractable penetrating plug to prevent any material from entering the sampler until the retractable plug has been removed. This feature makes the retractable-plug sampler an excellent tool for collecting uncontaminated cores in a known waste or contaminated environment, assuming of course that the lithology and depth requirements fit the limits of the sampler. The retractable-plug sampler also offers a means for taking uncontaminated horizontal samples below a shallow waste pit or trench, if an adjacent working pit is constructed.

The retractable-plug sampler consists of the following components: a cutting shoe, an outer-tube barrel that accepts six 1x6 in. brass inner liners, an inner retractable-plug assembly, and a mating inner-rod-to-outer-rod, fluted-thread assembly that permits locking of the retractable plug in either the penetration or coring position. In addition to these components of the retractable-plug sampler, additional 5-ft increments of both inner rods and outer tubes are needed to reach the intended sampling depth, a drive hammer, a special drive section of the outer tube (do not drive on threaded sections of the outer tube), and a small-diameter drive-sampler extractor jack similar to the one shown in figure 39. The actual coring procedure with the retractable- plug sampler is accomplished in the following manner:

1. Fill the outer-tube barrel with 1x6-in. brass inner liners and attach a cutting shoe on the bottom. Adjust retractable-plug section (with an inner rod attached) so that the cutting shoe is completely plugged (retractable plug in down or sample-penetration position). The sampler can now be driven to the desired depth of sampling by adding 5-ft lengths of outer tubes.

2. The retractable plug is removed so that the core can be taken by inserting enough inner rod to reach the inner-rod-to-outer-rod, fluted-thread section. Engage the threads by turning clockwise,

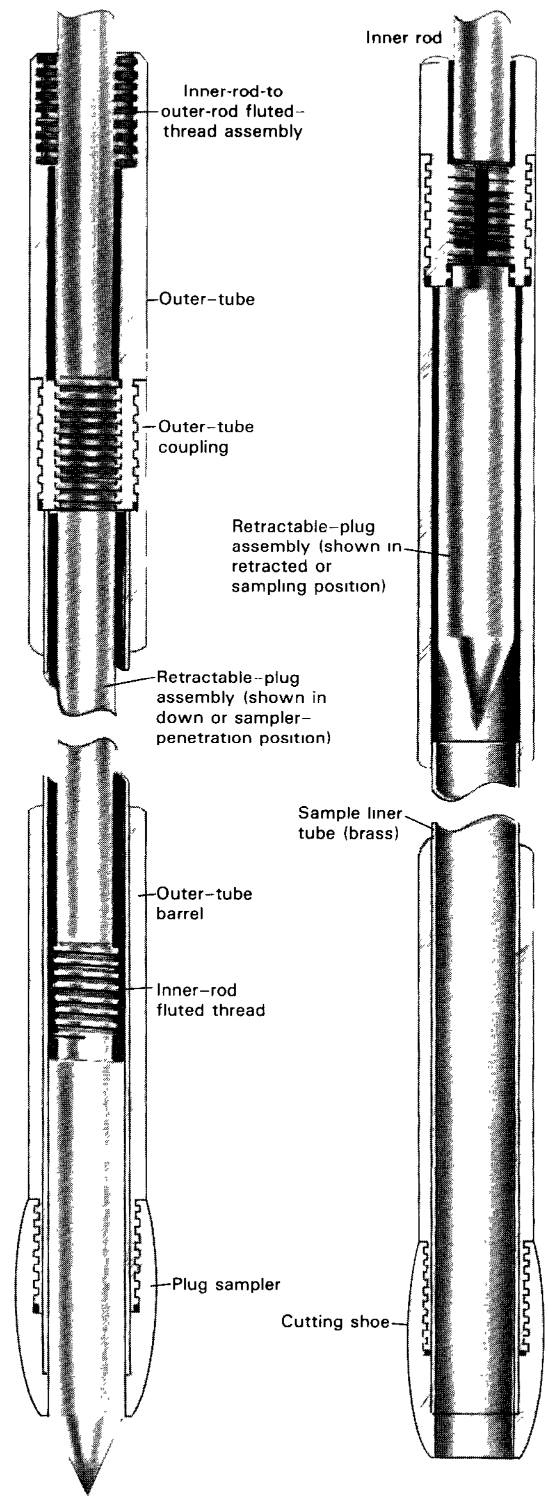


Figure 38.—Retractable-plug sampler.

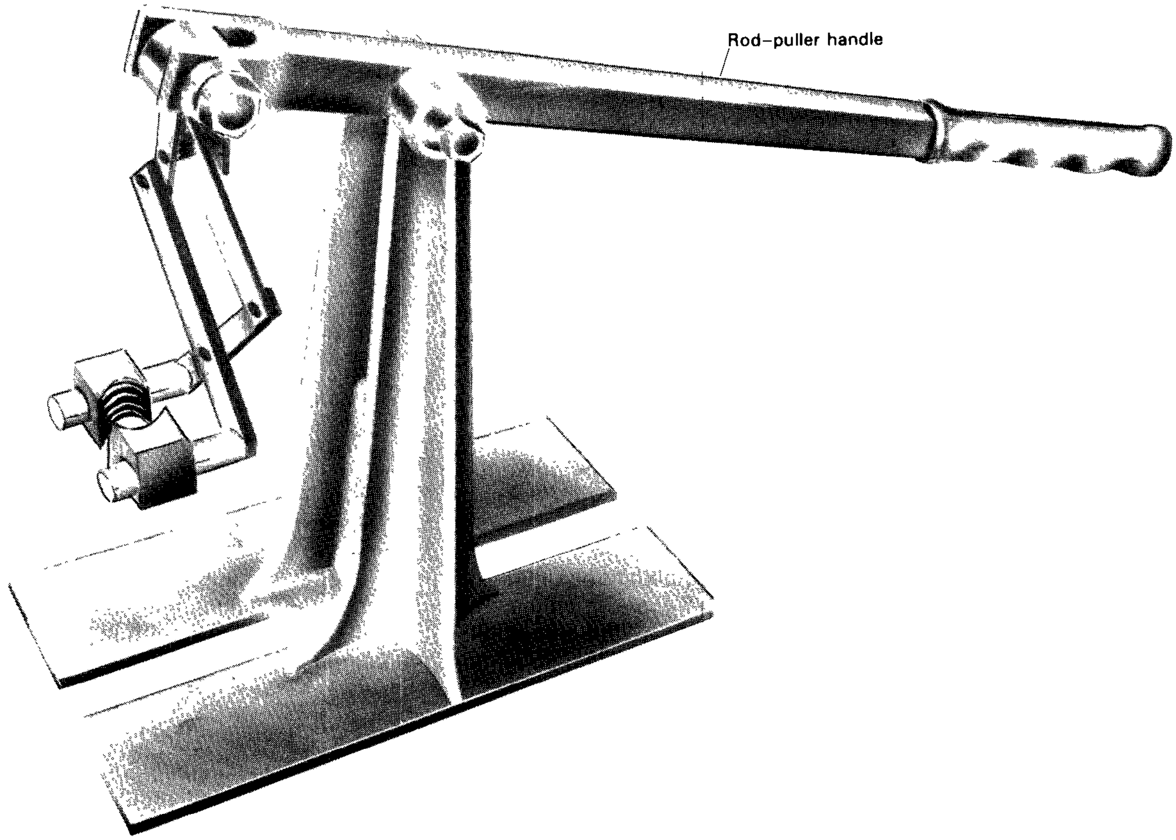


Figure 39.—Small-diameter drive-sampler extractor jack.

continue turning the inner rod (with small pipe wrench) until the upper fluted threads are free.

3. As soon as these threads are free, raise the inner rod with retractable- plug assembly attached until the bottom inner-rod fluted-thread section contacts the upper-thread housing; engage these threads about five or six turns by lifting up on the inner rod and turning it to the right (clockwise). Note: Do not make these threads up until they seat tightly, because the flutes in the threaded section are there to allow the upward escape of air (or fluid if it exists), when the core enters the barrel.

4. Remove the upper section of inner rod if it extrudes too far; attach the drive-head section of outer tube and use the slip hammer to drive the sampler about 2 ft.

5. After the sampler has been driven the 2 ft, remove the special drive section of the outer tube; reattach the top section of inner rod; and seal the sample in, by turning the inner rod clockwise, until the fluted-thread section is tightly seated. This creates a vacuum on the sample that holds it in the outer-tube barrel when the sampler is extracted, as well as keeping any possible fluid away from the sampled material. After a sample has been collected, prior to extraction, a pipe wrench is used to turn the outer tube two full turns clockwise to assure that the sample has been sheared at the bottom of the cutting shoe.

Extraction of the Sampler

Extract the retractable-plug sampler by one of the following methods:

1. Attach the small-diameter drive-sampler extractor jack (fig. 39) to the outer tube and thrust downward on the extractor-jack handle. Usually, after the sampler has been extracted 1 or 2 ft using the extractor jack, it can be pulled the rest of the way from the hole by hand.

2. If an extractor jack such as that described above will not pull the sampler, it can be extracted by fixing a fabricated rod-pulling clamp (fig. 40) to the

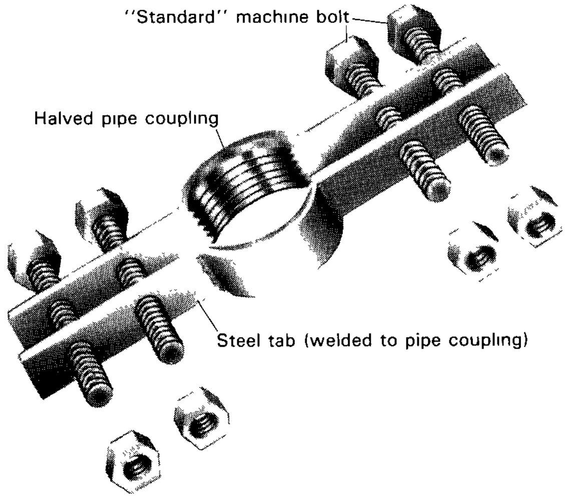


Figure 40.—Fabricated rod-pulling clamp.

outer tube about 1 ft above ground surface and (fig. 41) by using two hydraulic jacks (one under each flange of the clamp) to pull the sampler loose. Note: Do not use a single jack for this operation as it will bend the sampler outer tube. Use two jacks as described, and operate them simultaneously, in order to apply equal force to each flange of the clamp.

3. Some drive hammers used for driving the retractable-plug sampler are designed so that they can be used for driving the sampler upward to dislodge it. However, this is the least desirable method of extraction to use because a greater chance exists that vibration and shock will cause the sample to fall out of the outer-tube barrel.

After the sampler is dislodged, it is returned to the surface by alternately removing a 5-ft section of outer tube and inner rod. Prior to removal of the full sample-liner tubes from the outer-tube barrel, remove the cutting shoe and unscrew the outer-tube barrel from the retractable-plug assembly and remove it. The full sample-liner tubes can then be removed by one of the following methods:

1. Insert blank brass inner-liner tubes into the upper end of the outer-tube barrel and push the full sample liner tubes out of the bottom end of the outer-tube barrel. After the sample-filled inner-liner tube is extruded about 1 in., place a clean cap over the end of it and continue extruding it until the inner-liner tube is completely out of the outer-tube barrel; shear the end of the sample using a clean wire saw (ordinary cheese cutter is satisfactory) or a clean sharp knife. Cap the other end of the extruded liner. Tape both caps on with plastic, electrical tape and mark the sample properly with sample depth, hole number, top and bottom of sample, and any other pertinent data. Continue pushing additional blank inner liners into the outer-tube barrel until all of the sample-filled liners have been extruded, treating each individual sample as above.

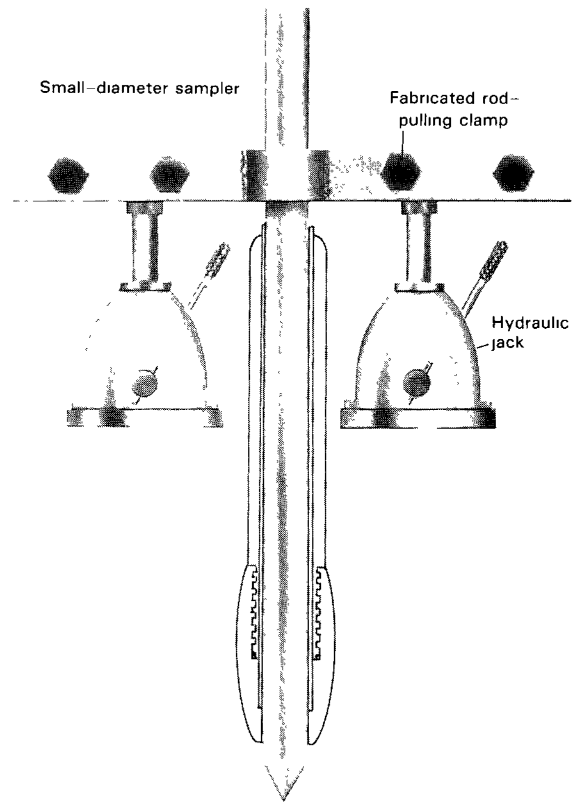


Figure 41.—Assembly for extraction of vertically or horizontally driven small-diameter sampler.

2. When sampling in saturated materials, some grit locking can occur between the inner-liner tubes and the outer-tube barrel, resulting in considerable difficulty in starting the inner-liner tubes out of the outer-tube barrel. For this reason, an inner-liner tube extractor assembly (fig. 42) designed by the authors should be used with the retractable-plug sampler. In operation, the sampler outer-tube barrel is locked to the extractor assembly by means of a chain-type pipe vise. A 1-in. plug that is swivel connected to a coarse-thread lead screw and fed through an internally threaded bracket welded to the channel-iron base of the extractor assembly butts against the inner-liner tube. Turning the handle

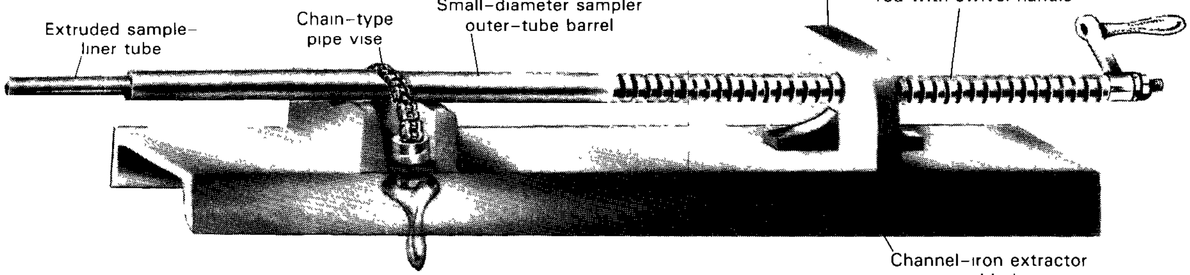


Figure 42.—Sample-liner tube extractor assembly.

clockwise forces the 1-in. plug against the inner-liner tubes, thereby breaking the grit lock and forcing the sample-filled inner liners out of the outer-tube barrel. Ordinarily, after two full inner-liner tubes have been extruded, the grit lock will no longer be a problem, and the remaining inner-liner tubes can be removed by hand. After the sample-filled liners have been removed and the outer-tube barrel is refilled with clean inner-liner tubes, the sampler is reassembled, and the sampling procedure is repeated.

Although the description of operation of the retractable-plug sampler emphasizes hand driving and removal, it is not intended to convey to the reader that the sampler cannot be used with power equipment, such as an auger-drilling rig, small drill rig, or even a tripod equipped with a cathead. Any power equipment makes it easier to collect samples, dislodge the sampler after sampling, and return it to the surface. However, this rather fragile sampling device cannot be treated like heavier duty drive-coring equipment. The retractable-plug sampler should not be driven with a drive hammer weighing more than 25 lb.

As mentioned previously this sampler offers a means for taking uncontaminated samples horizontally below a shallow waste pit or trench. This can be accomplished if an adjacent work pit is constructed to some depth greater than the waste pit to be sampled. The horizontal sample is obtained by driving the sampler as described for sampling in a vertical mode, the difference being that the sample is being driven horizontally. Dislodging the sampler for removal from the hole after sampling is somewhat different. The small-diameter drive-sampler extractor jack (fig. 24) is too heavy and awkward to position for use in horizontal extraction of the sampler. It can be extracted by using either extraction method 2 or 3, explained on page 223. If a considerable amount of horizontal sampling is anticipated, purchase (or have fabricated) a portable, double-acting hydraulic-jack apparatus. The ram must be well anchored, and it could provide the means for pushing the sampler into the material as well as dislodging it after collecting a sample.

If, for some reason, the work pit cannot be excavated to the necessary horizontal sampling depth adjacent to the waste-disposal pit to be sampled, samples can still be otained from beneath the waste-disposal pit in the following manner. Using a scale and a protractor, graphically construct a right triangle to determine the proper angle from the vertical and the necessary distance needed to drive the sampler to the predetermined sampling point below the bottom of the waste-disposal pit. Carefully begin driving the sampler from the predetermined angle and drive it the preselected distance below the bottom of the waste-disposal pit to collect the sample. Deviation of the sampler from the preselected angle usually does not exceed several degrees even if the sampler is driven a distance of about 50 ft.

Applications of the Stationary-Piston Sampler

The stationary-piston sampler (fig. 43) has been used very little for collecting samples for water-resource investigations because it is not capable of penetrating and sampling dense, coarse aquifer materials. However, the sampler offers the unique

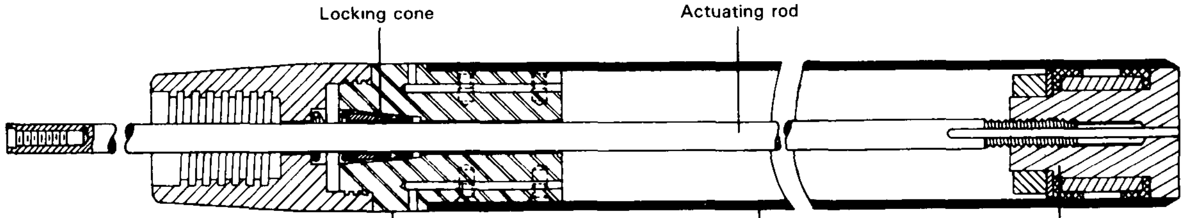


Figure 43.—Stationary-piston sampler (Acker, 1974, figure 77, reprinted by permission from Acker Drill Co., Inc.).

advantage of being completely sealed at the bottom, thus preventing any contamination of the sampler as it is lowered through fluid or cuttings in the hole. This feature warrants consideration of the stationary-piston sampler for use in known or suspected waste-contaminated environments, assuming that the formation to be sampled could be penetrated by the sampler.

In view of this potential, the following description in basic operation of the stationary-piston sampler (fig. 44) and the improved Lowe-Acker sampler (fig. 45) is provided (Acker, 1974, p. 69–71):

> The development of the Stationary Piston Sampler was a natural outgrowth of the use of the Thin-Wall Tube Sampler. As shown in figure 77, the construction of the Stationary Piston Sampler is similar to the Thin-Wall Tube Sampler except for the addition of a sealed piston and a locking cone in the head to prevent the piston from moving downward.
>
> By referring to figure 77, it can be readily seen that the Stationary Piston Sampler has two principal advantages: (1) It is fully sealed at the bottom so that it can be safely lowered through fluid and soft cuttings without fear of sample contamination; (2) by holding the piston stationary and pushing the sampler downward, the top of the sample is completely protected from any distorting pressure at the top. Thus, a much more effective vacuum seal is maintained than with the ball-check valve in the Thin-Wall Tube Sampler.
>
> Operation of the Stationary Piston Sampler: The hole is prepared in the same manner as it was for sampling with the Thin-Wall Tube Sampler. The Stationary Piston Sampler is placed on the bottom of the hole with the piston flush with the bottom end of the thin-wall sample tube. The actuating rod is held in place (see figure 78) and the sample tube is pushed past the stationary piston. The tube is then removed from the hole and separated from the sampler apparatus. The actuating rod (see figure 77) must be unscrewed a few turns, uncovering a vent hole to release the vacuum before the tube can be removed from the head. Once the tube has been removed, it is sealed and stored just like the thin wall tube sampler. In fact, once they are removed from the head, the thin wall tubes are identical and interchangeable).
>
> There are several variations of the standard Stationary Piston Sampler. The improved Lowe-Acker Stationary Piston-Plug Sampler shown in figure 79, is worthy of mention. This sampler represents an advance in both design and the use of improved materials. Standard size for this device is 3½ in. O.D. and is called the Modified 3½ in. Stationary Piston Plug Sampler.
>
> As the name implies, the improved sampler combines the features of the Plug-Type Sampler with the Stationary Piston Sampler so that the piston can be locked in the down location, it is possible to use the sampler without casing. Locking the piston in the top position ensures against movement after the sample is taken, thus insuring that the sample is not lost.
>
> This sampler also features a permanent steel barrel with plastic liner and a thin, elongated cutting shoe. The plastic liners that permanently retain the sample are tough, light, and inert. All in all, this is a more rugged, heavier-duty sampler than the thin-wall tube sampler or the standard stationary piston sampler. It is particularly useful in deeper sampling of heavy clays or where tidal or other conditions make it difficult to maintain casing.

SAMPLE CHARACTERISTICS

Undisturbed Samples

A considerable number of soil and rock samples collected each year by Water Resources Division personnel for hydrogeologic analyses and testing are

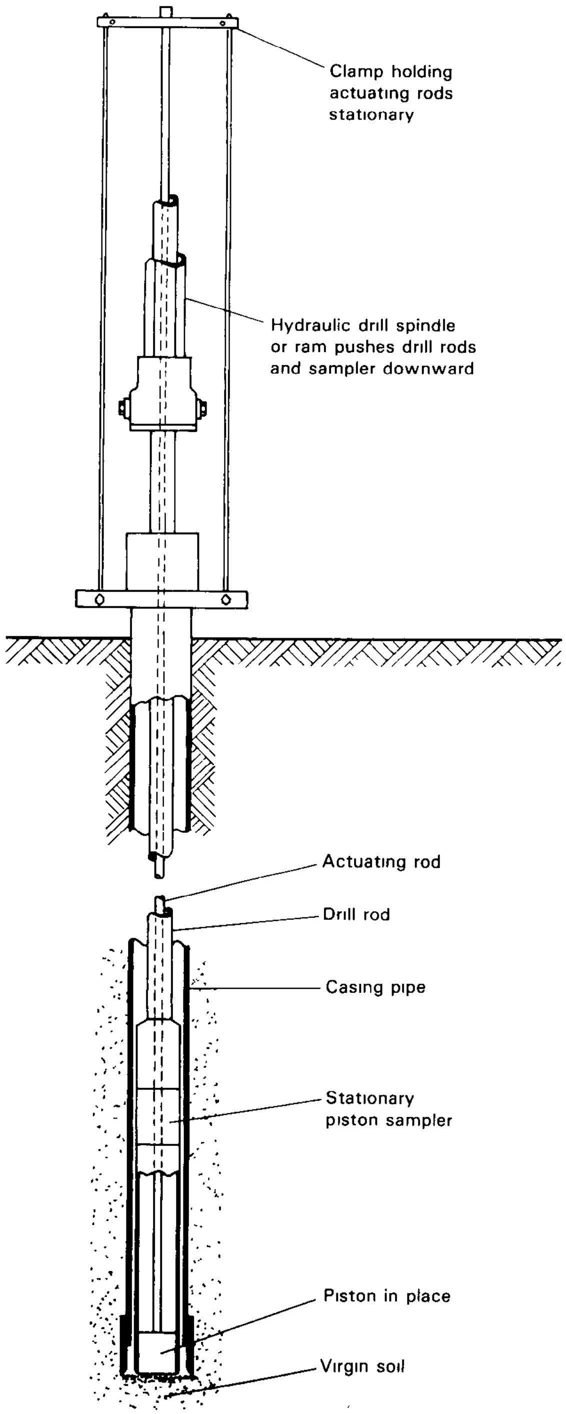


Figure 44.—Sampling operation using a stationary-piston sampler (Acker, 1974, figure 78, reprinted by permission from Acker Drill Co., Inc.).

found to be unsuitable for their intended uses. Causes of these deficiencies are often beyond the control of the sample collectors; however, in many instances, the failures result from an inadequate recognition of the relationship between sampling methods employed and the particular hydrologic tests required. The suggestions in this section provide information to enable onsite personnel to obtain samples with maximum efficiency and to better utilize laboratory-testing services. A considerable amount of the material in this section is from an unpublished manuscript, "Hydrologic Laboratory Note No. 7" (Edward A. Sammel, USGS, 1970).

Equipment

A prerequisite for undisturbed sampling in unconsolidatd materials is that the sample be collected and retained in a rigid tube in which the sample can also be shipped, stored, and subsequently mounted in a permeameter, if tests for hydraulic conductivity are desired. A thin-wall sampler, such as the Shelby tube, causes a minimum amount of disturbance, particularly in compressible sediments, and allows the sample to be tested in the sampling tube itself. However, for most sampling conditions, a thin-wall sampler will not support the stresses of hard driving, and other tools must be used. Double-tube samplers, in which the core is retained in an inner tube, represent a compromise between optimum sample conditions and the strength requirements imposed by most rock materials. Results obtained by using double-tube samplers are adequate for most purposes, if care is taken to minimize several problems discussed hereafter. Liners should be thin-wall, seamless tubing, with the ends smoothed, and should be cut perpendicular to the long axis of the tube. Because liners corrode rapidly during storage, the material should be corrosion resistant. Brass or corrosion-resistant steel have been preferred materials for liners, but their cost almost precludes their use on many projects. Tests of aluminum tubing have shown that it is relatively inexpensive and generally satisfactory, although some corrosion may occur during prolonged storage, and care must be taken to avoid flattening the tubes into oval cross sections.

Tubes of solid-fiberglass epoxy material were recently tested and found to have excellent properties of strength and rigidity. However, because they absorb and transmit significant amounts of water, they should not be used if determinations of moisture content are desired or if desiccation would impair the reliability of tests. Liners of laminated

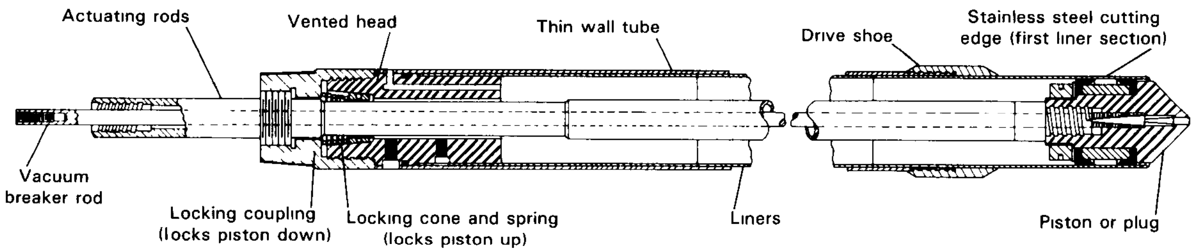


Figure 45.—Three and one-half-inch Lowe-Acker piston-plug sampler (Acker, 1974, figure 79, reprinted by permission from Acker Drill Co., Inc.).

plastic (polyethylene or nylon) are unsatisfactory because the laminae tend to separate, rigidity is low, and moisture transmission is relatively high.

The three principal sample characteristics that relate to geohydrologic tests are: (1) representativeness of the sample, (2) relative magnitude of effects caused by disturbance in the sample, and (3) accuracy of measurement.

Representativeness

The representativeness of a given sample is a function of variability in the sample in relation to the scale of variability in the formation from which the sample is taken. For example, a completely homogeneous, isotropic material requires only one sample, infinitely variable material requires an infinite number of samples. Statistical approaches are available for attacking this problem, but, because of its complexity, the problem is considered to be beyond the scope of this discussion. The two remaining considerations are discussed in the following paragraphs.

Compaction

Most coring operations result in some mechanical disturbance of the grain structure of the samples. Granular, noncohesive sediments usually tend to compact during sampling, as their grain structure collapses slightly from vibration of the drilling tool. Thick-wall samplers may increase the apparent volume of some sands as a result of displacement by the wall of the tube, but, regardless of whether the sand compacts or expands, grain structure is likely to be disturbed. Clays and fine silts are usually compressed by the pressures of sampling devices; changes in bulk volume of 15–20 percent are not uncommon.

Drive sampling usually causes greater compaction of samples than other methods of sampling, particularly in granular, noncohesive sediments. The amount of compaction may be directly related to the size of the core. Data suggest that the amount of compaction can probably be closely correlated to the number of hammer impacts and the total energy absorbed by the sample in the driving process. Although no quantitative data are available on this point, we suspecte that any drive sample requiring more than 20 or 25 blows per ft, using a 30-in. drop with a 140-lb hammer, will be significantly disturbed, probably throughout its entire volume. This observation may not apply to tough, cohesive materials, such as till or dry clay; but, in noncohesive materials, a relatively small amount of vibration may produce unacceptable samples.

Data collected from our own investigations, as well as from other sources, also show that the ratio of bit diameter to tube diameter is critical in obtaining undisturbed samples. Ratios of bit diameter to tube diameter ranging from 0.99 to 0.995 gave best results in drive samples. Wall thickness of the sample tube is critical; best results are obtained with wall thicknesses as small as 0.08 in. Wall thicknesses greater than 0.1 in. produce significantly greater compaction in both clays and sands.

Experience with drive samples has shown that the length of drive should never exceed 18 in. and, for best results, should not be more than about 12 in. It has been demonstrated that the upper 6 in. of sample is often significantly disturbed by an 18-in. drive. To minimize this problem, the USGS Water Resources Division uses sets of three 6-in. liners and one 18-in. sampler, and, in most instances, discards and reserves the upper 6-in. length for noncritical uses. This procedure also allows one to discard the upper part of any sample that has been contaminated by drilling fluids or filled by cave-in material.

The amount of compression that occurs during sampling of cohesive sediments is closely related to the diameter of the samples. Wall friction tends to drag the material down along the walls, and, as a consequence, a relatively large volume of material may be compressed and otherwise disturbed. In compressible clays and organic-rich sediments, a diameter of 2½ or 3 in. may be barely sufficient to minimize wall effects, whereas, for less compressible sediments, a 2-in. diameter may be adequate.

Expansion

Expansion of sediments as overburdened loads are removed cannot be eliminated by any means known at the present, and the effect is largely independent of sample size. Some recently tested clays and silts were estimated to have expanded by nearly 10 percent, with consequent increases in porosity and hydraulic conductivity. Apparent moisture contents were correspondingly low. We suggest, therefore, that if hydraulic conductivities, porosities, or moisture contents are desired from samples that tend to expand, the samples should be given a consolidation test to determine the relationship between porosity and applied load. The theory of consolidation allows a calculation of hydraulic conductivity from the consolidation curve, and, based on numerous experiments, hydraulic conductivities calculated in this way are apparently better related to in-situ conditions than are permeameter tests.

Wall Effects

The wall effects referred to are those resulting from the confinement of samples in smooth-wall tubes for permeameter measurements. Laboratory experiments have demonstrated that apparent hydraulic conductivities may be significantly affected by the higher velocities of flow that occur along the walls of permeameter tubes. The effects can be correlated with medium-particle diameters in the samples.

Practical means of coping with this effect in the laboratory do not exist; the best means of minimizing errors resulting from wall effects is to obtain samples of a size sufficient to make such errors insignificant. An adequate protection against wall effects in granular sediments is to use cores with diameters at least 25 times the diameter of the coarsest particle in the sample. For example, if the diameters of an appreciable portion of a sample are 2 mm, the core should be at least 50 mm in diameter (approximately 2 in.).

Accuracy of Measurements

Most laboratory tests, including those for hydraulic conductivity, are routinely accomplished with measurement precision that allows probable errors to be less than a few percent. Accuracy of the test result in relation to some true value is largely determined by characteristics of the sample. Measured porosities, for example, may easily differ by as much as 20 percent from in-situ values, with corresponding errors in calculated volumetric moisture contents. The effects of such changes on measured hydraulic conductivities are made complex by changes and shape factors; in general, no simple relationship exists between porosity and hydraulic conductivity in natural sediments. However, data from uniform granular media suggest that hydraulic conductivity is a logarithmic function of pore-size distribution; alterations in porosity are expected to cause relatively large differences in hydraulic conductivity. Similar effects are probably true for moisture tensions and specific yields, as well as some other parameters.

These problems are most clearly related to samples having too small diameters. In general, the length of the sample is not as critical a factor as the diameter is in causing erroneous and misleading test results. However, extremes in either case are not desirable. Six-in. samples are more than sufficient for routine hydrologic tests; shorter samples may be used for most purposes. Unless the representativeness of the sample is in question, little is gained by using samples longer than 6 in., while dangers of disturbance are greatly increased as length increases.

Contamination of Samples

A major problem associated with the rotary-drilling method for obtaining cores is sample contamination by drilling fluid. Unfortunately, the most serious problems of contamination occur in the permeable, granular materials, where drilling fluids are most essential to the drilling operation.

Drilling fluid may contaminate the sample by penetrating the undisturbed material beneath the hole as drilling progresses or by entering the sample liner with the sample. When drive sampling is done at the bottom of a hole drilled with fluid, the sampler penetrates a layer of drilling fluid before entering undisturbed material. Where such exposure to drilling fluids has occurred, it is often impossible to determine the exact depth of penetration of fluids into the sample; thus, cores may be useless for geohydrologic tests. These problems can be minimized if the suggestions on mud control explained previously are adhered to. If proper mud-control practices are not followed, then one of the dry-drilling methods, such as hollow-stem auger drilling and drive coring, should be used.

Disturbances Following Sampling

Many of the disturbances that impair the usefulness of samples occur during shipment or storage of the samples. Mechanical rearrangement of the grain structure by shock, vibration, or freezing are the most common of these disturbances. For example, a fine-grained core that appreciably dries in the liner may undergo essentially irreversible structural changes in the clay fraction, changes that destroy the reliability of measurements even when resaturated.

Some suggestions for preserving samples follow:

1. Sample liners should be fitted with tight plastic caps and sealed with plastic electrical tape immediately upon removal from the core barrel. For storage periods longer than a week or two and for samples in which moisture contents are extremely critical, the liner should be enclosed in plastic bags and coated with wax. Paraffin has a relatively high transmittance for water vapor; hence, it is not suitable for long-term protection. A number of tough, flexible waxes that do not transmit water are available from oil companies; one of these waxes should be used in preference to paraffin. An example of the type of wax to use for this purpose would be the ML-45 lemon wax available from Standard Oil Distributors.

During recent sampling operations to determine very small moisture contents in a thick, unsaturated zone, samples were weighed on-site on scales calibrated against laboratory scales and then reweighed in the laboratory to determine whether moisture loss or gain occurred. The precautions above were effective in detecting any change in moisture content, and the added caution of on-site weighing is likely unnecessary under most conditions.

2. Samples should be protected from extreme temperature changes that may place thermal stresses on moisture distribution. Samples should be protected from freezing, because freezing would result in mechanical stresses on the particle structure as well as redistribution of the moisture.

3. Samples should be protected from shock during shipment; they should be treated as fragile items.

4. On-site storage should be for minimum lengths of time. If sampling is done over an extended period, groups of samples should be shipped at short intervals to the laboratory where they can be stored in a constant-temperature, constant-humidity room. Samples that are thrown into the back of a vehicle and carried about during a summer field season are generally of little value for laboratory testing.

Disturbed Samples

Where economics or other considerations dictate, disturbed samples may be used for determinations of particle-size distribution, specific gravity, and lithologic or mineralogic analysis. In using disturbed materials, the following considerations should be kept in mind. (1) Material being returned to the surface by a power auger can rarely be relied upon to represent actual particle-size distribution in the sediments peneterated, especially when auger drilling below the water table. Loose, granular materials encountered in the hole will probably contribute excessively to the sample appearing at the surface; fine-grained materials may not be recovered. Segregation of particle sizes occurs rapidly as granular materials are vibrated, and, in most cases, coarser materials are continuously returned ahead of finer materials. Thus, in most instances, a sample returned to the surface will not represent a true integration of lithologic conditions through the entire depth of the hole, nor can it be considered representative of conditions at any given depth. (2) Drill cuttings from unconsolidated formations, using rotary or percussion methods, are also rarely found to be representative samples. Both the rapid settling of larger particles and the washing out of fines tend to distort the particle-size distribution of samples taken from drilling fluids. (3) Samples for use in repacked hydraulic-conductivity tests should contain the complete range of particle sizes of the in-situ material, particularly the smallest particles. Laboratory research on the problem of relating hydraulic conductivity to particle-size distribution has confirmed the hypothesis that hydraulic conductivity is most strongly correlated with particle sizes in the smallest 10 percent of the size range. Thus, if any appreciable amount of fine-grained material is lost during sampling, values of hydraulic conductivity may easily be in error by an order of magnitude or more. Repacked samples for hydraulic- conductivity determinations are of minimal value even if no better samples are available. However, if possible, such tests should be run only on relatively uniform granular material, containing less than 10 percent of materials finer than very fine sand. Materials having sorting coefficients greater than about 2 (containing more than about 10 percent of particles less than 0.125 mm) cannot be repacked to ensure a near reproduction of original bulk densities or the inter-granular geometrics.

These facts have been documented in tests conducted at the Idaho National Engineering Laboratory, Idaho, in which auger-drilled samples were compared with undisturbed samples of the same materials. Results of the tests confirm conclusions of personnel of the USGS Water Resources Division research project during several years of sampling with power augers.

Comparison between Undisturbed and Disturbed Samples

The most carefully obtained samples have been shown to be subject to disturbances that lead to uncertainties in tests performed on them. Why, then, incur the greatly increased costs in time and money that undisturbed samples require? The answer to this question cannot be given in general terms because it depends on whether or not potential gains appear to outweigh increased costs in any situation. In answering this question, realize that drill cuttings or auger-drilled samples are inadequate for many purposes, whereas carefully obtained undisturbed or representative samples provide the only possible basis for quantitative conclusions.

Experience has shown that, when good-quality samples are obtained, a relatively small number of them may provide a basis for extrapolation of data over a wide area. A particularly good example is the use of undisturbed samples to calibrate borehole-geophysical data. With present knowledge, data obtained by borehole-geophysical methods on moisture content, clay content, and porosities cannot be reliably quantitative, unless the results are calibrated against the best possible undisturbed samples from the formation. Once this calibration has been made for a given formation or area, geophysical- logging methods may provide quantitative data over a wide area at relatively low cost. In a somewhat similar manner, drill cuttings or auger-drilled samples may be calibrated against undisturbed samples, and in many cases it may then be possible to use readily available and relatively inexpensive data from the disturbed samples to evaluate aquifer characteristics over a wide area.

To summarize this discussion on sampling:

1. Undisturbed samples are essential for accurate laboratory determinations of hydraulic conductivity, porosity, moisture content, consolidation of clays, and the examination of sediments in thin sections after injection by plastics.

2. Sample-tube liners of rigid metal or plastic are a prerequisite for optimum sample conditions and for best results from certain hydrologic tests.

3. Some commercially available samplers are effective in providing adequate sample recovery with minimum disturbance, if certain precautions are observed in their use. Drive samplers may be used with caution in granular, noncohesive media to avoid compaction of the material. Coring by rotary-drilling methods offers some advantages over drive sampling but introduces the possibility of contaminating the sample with drilling fluids. The design of certain rotary samplers minimizes the problem of contamination by allowing the cutting shoe to precede the rotary bit. Piston-drive samplers are excellent for recovery of soft or compressible sediments.

4. The size of cores is critical in determining the reliability of geohydrologic tests; cores of too great length or too small diameter may be equally undependable for testing.

5. Much of the disturbance of samples from the standpoint of use in laboratory tests occurs following sampling, during storage, or during shipping. Disturbances may include desiccation and resulting compaction or mechanical rearrangement of the granular structure by shock or freezing.

6. Disturbed auger-drilled samples or drill cuttings are unreliable for geohydrologic tests because of the loss of fines, segregation of sizes, and the possibility of contamination. Disturbed samples should be repacked for tests of hydraulic conductivity only when the sample contains the complete range of particle sizes of the in-situ material.

7. Undisturbed samples of good quality are difficult to obtain and expensive to collect. Their use is justified whenever reliable data can be obtained in no other way and when results from a relatively few undisturbed samples can provide a quantitative basis for alternative methods, such as borehole geophysics, that can be applied at relatively low cost over wide areas.

WELL-DEVELOPMENT TECHNIQUES

Any drilling method is going to create changes in the aquifer materials immediately adjacent to the borehole wall, changes that will require well development to remove the introduced fines, to loosen or redistribute compacted granular materials, and to remove some of the normal fines of the aquifer materials surrounding the borehole. Well efficiency can be increased if permeability of the formation can be increased for a considerable distance surrounding the borehole. Remove enough of the fines in the vicinity of the borehole wall to complete a natural, coarse-grained sand pack around the screen that bridges and prevents fine sands from entering the well so that excessive wear of pump parts will not occur in the normal production process. An idealized illustration of this is shown in "Ground Water and Wells" (Universal Oil Products, 1966). Even if it were not possible to increase the efficiency of the well by removal of an appreciable amount of the fines in the formation surrounding the borehole wall, the problems induced by drilling the well must be corrected to have an observation or production well that is responsive to the aquifer in which the well is completed.

The processes that caused the problems of decreasing the permeability of the aquifer must be reversed. These primary deleterious processes are filter cake, invasion of mud and other fines, and redistribution of compacted materials. There are available methods to accomplish all of this, but the problem must be understood before it can be solved. As mentioned, all well-drilling methods result in some damage to the formation materials penetrated, although variable conditions can exist that would change the order. The standard drilling methods that cause the most damage to the aquifer and result in greater need for development are: (1) mud rotary, particularly when proper drilling-mud control is not practiced; (2) auger drilling because of rind and plastering effect; (3) cable tool, due to compaction from driving casing; (4) reverse rotary, if drilling mud has to be added to make up water to slow or stop fluid loss (this method can result in difficulties equal to mud rotary); and (5) air-rotary drilling.

Following is a review of these drilling methods and resulting problems.

1. When a well is drilled by the mud-rotary method, build a mud cake to stop fluid loss and help support the hole wall. Prior to forming this mud cake through the filtrate process, considerable invasion of clay, silt, and fine sands can invade permeable zones. The depth of invasion can be considerable, depending on drilling-mud control, hydrostatic head of the drill fluid, and permeability of the aquifer material. Development effort and stress on the aquifer are going to be needed to develop a mud-rotary drilled hole.

2. An auger-drilled hole can cause nearly as much damage to the well as mud-rotary drilling because of the plastering effects of finer grained materials on the wall of the hole. Two exceptions to this, however, are when the hole collapses and a screen can be washed into the caved materials opposite the aquifer and or when a well point can be driven into an aquifer at the bottom of the hole.

3. Cable-tool drilling is a cleaner method than either of the two drilling methods described previously, but some small amount of invasion occurs from the up-and-down surging motion of the bit. The greatest hole damage by the cable-tool method occurs by compaction of the materials as a result of driving the casing through unconsolidated

formations. Common practice is to install a screen in the aquifer by the pull-back method when drilling with cable tool—that is, the hole is drilled and the casing is driven into the aquifer; the hole is bailed clean of cuttings; the screen is run to the bottom; and the casing is pulled or jacked back exposing the screen to the aquifer material. The aquifer material must be restored to its original porosity and permeability if a properly responding well is to result. However, methods for development of a cable-tool drilled hole are almost always easier to apply than those used for developing a hole drilled by the mud-rotary method.

4. Reverse-rotary drilling does not damage and contaminate the aquifer as greatly as many other drilling methods do and, therefore, is considered to be a clean drilling method. For that reason, many people feel that no development of reverse-rotary holes is needed. However, this is a misconception because, even under ideal conditions, a small amount of invasion of solids and filter cake forms from the partially reused drilling fluid that contains suspended sediments. The hydrostatic head of the fluid in the hole almost always exceeds that in the formation. Therefore, some of this suspended sediment will invade permeable zones and form thin filter caking. A simple method, such as over-pumping the well, may be successful in development of the well in this instance. However, there are times when drilling muds, possibly even with lost circulation additives, must be used to prevent too much or even total water loss. If this is the case, then the reverse-rotary drilled hole must be treated and development procedures used similar to those applied to mud-rotary drilled wells.

5. Air-rotary-drilled holes are probably the cleanest of all methods, particularly if no mud additives are needed in drilling the hole. However, this does not mean that no invasion of fines into fractures or highly permeable granular material occurs because the cuttings have to be forced out of the hole. Also, invasion occurs if the hydrostatic head in the hole is greater than the hydrostatic head in the formation. Various methods of well development are performed to reverse contamination caused by drilling. Most of the useful methods of well development are covered in available literature; therefore, we comment only briefly on those. The development problems and techniques inherent in the development of small-diameter observation wells are discussed in more detail. A method of well development using inflatable packers also is described, because this method is not treated in the other literature.

Backwashing

We use the example of backwashing first because some of the ways it is applied demonstrate the worst techniques available for well development. A good example of a poor development technique would be the case where a small-diameter observation well with well point is installed in a mud-rotary drilled hole, a hose is attached to the top of the well casing, and water is pumped through the screen until the drilling mud has been displaced from the hole. This is a necessary first step prior to development; however, it accomplishes nothing in the process of development because a negative hydrostatic head has not been applied to the inside of the well to remove the filter cake. Unfortunately, this is the only development step taken in the installation of many observations wells, and it is valueless. The backwashing method may be successful only in an auger-drilled hole where the aquifer material has collapsed and a well point has been pushed or washed into the collapsed material. In this case, backwashing can wash the screen clear and lift the material in a suspended slurry; by gradually slowing the backwash discharge to zero, the coarser materials will settle back around the screen first. The backwashing method referred to as rawhiding has some merit (Universal Oil Products, 1966, p. 306–307).

Air Surging

Air surging is the most used method for development of wells, particularly for holes drilled by the rotary method and in situations where air-line submergence is possible (about 50 percent) to pump the well by the air-lift method. Both Universal Oil Products (1966, p. 303–305) and (Anderson, 1967, p. 120–121) provide excellent data on submergence ratios, required air volumes, and equipment required for using the air-lift system. Universal Oil Products (1966) also explained the technique of development by air. We believe the air-lift technique, when it can be used, is a very good method of development; however, any large amount of air introduced into the aquifer is harmful, and the back-blow process can, and usually does, force some air into the aquifer; so this process must be used with caution so as not to cause air locking of the aquifer. Entrapped air in the granular pore spaces can be as difficult to remove from the aquifer as fine materials are; too much air introduced into the aquifer can, at least temporarily, completely plug it.

Mechanical Surging

Mechanical surging or surge-block development of a wall is a method that applies a minimum of stress to the aquifer but is often adequate to develop wells that will produce a minimum of invasion or disturbance of the aquifer. This technique is commonly used as the only method for development of cable-tool drilled holes because of the easy up-and-down surging method obtainable through the spudding arm. The method also can be used on a rotary-type rig, but it requires considerable manipulation of the sandline winch by the operator, and it is usually not very successful in rotary-drilled holes where heavy filter caking and deep mud invasion have occurred. The method is well described by Universal Oil Products (1966, p. 299–303).

Overpumping

The overpumping method is simple and often is the only method used in development of reverse-rotary drilled holes. However, if the development pump does not have a much greater capacity than the intended production pump, enough fine sand may not be removed from the aquifer to properly develop it, resulting in later sand pumping and damage to the production pump. The reader is again referred to Universal Oil Products (1966, p. 305–306) for more details of this development method.

High-Velocity Jetting

High-velocity jetting is the best method available for destroying the integrity of the filter cake, particularly if the screen is close to the hole wall, and to stir up the material surrounding the screen. High-velocity jetting is also an excellent method of development in wells that can be completed in open hole without casing. In rock or consolidated lithologies, the only materials that have to be dislodged and removed from the well are the filter-cake membrane or rind left on the hole wall as a result of drilling and a possible small invasion of clay. The high-velocity jet will do an excellent job of flushing this filter cake off the hole wall. After the filter cake is disintegrated, it will remain in fluid suspension for a short period of time and can be pumped or bailed from the well. The method is described by Universal Oil Products (1966, p. 307–309); however, we emphasize some points made and add some suggestions that will improve the method:

1. It is suggested, where possible, to pump the well lightly at the same time that the high-velocity jet is working. This is not always practicable, but should be done where the size of the well, the available equipment, and the position of the static-water level in the well permit. Pumping of the well (preferably by air) should be done whenever possible, and not "lightly." The greatest stress that can be applied to the aquifer while using the high-velocity jetting technique will bring more fine materials into the well, doing a better job of development, and, at the same time, the heavy pumping will remove most of the fine materials from the hole.

2. The jetting tool (Universal Oil Products, 1966, fig. 288) must fit as closely as possible in the screen section being jetted. Do not use a 6-in.-diameter jetting tool in an 8- or 10-in. screen, because if the jetting tool is centered in the hole, the 1 or 2 in. of water surrounding the tool will greatly slow the velocity rate of the jet. Because most drill holes are not vertical, the tool probably will be dragging on one side of the hole, resulting in good energy application to one side of the screen and poor energy application to the other side, from the velocity lost through 2–4 in. of water. The result would be partial development of the formation, and this result only can be overcome by fitting the tool to the screen diameter.

3. When a two- or four-nozzle high-velocity jetting tool is used and is slowly turned and raised in the screen in an attempt to cover all areas of the screen, it is unlikely that the entire screen area has been covered. We prefer to use a well-development jetting tool (fig. 46) of a design that provides better coverage of the screen area. Four horizontal slots are cut through the jetting tool to a length of ½in.

The wedge shape of the water jet provides about one-half coverage of a 6-in. screen, resulting in a minimum turning of the pipe. However, this tool requires more pump capacity to operate it than the one illustrated by Universal Oil Products (1966). The standard jetting tool with four 3/16-in. nozzles requires about 48 gal/min for velocities of 150 ft/min, while the slotted jetting tool (shown in fig. 46) requires about 115 gal/min to obtain the same velocity.

Chemical Treatment

Many polyphosphates (deflocculents), such as sodium hexametaphosphate, sodium pyrophosphate, and sodium tripolyphosphate can be added to the water in the well at a rate of about 5 lb of additive to 100 gal of water to help break down the gel properties of the drilling mud and disperse the clay particles by separating them from the sand particles in the aquifer. These additives should be pumped into the well and agitated, particularly if the annular area of a gravel pack is filled by some surging or agitation with a bailer. Some combination polyphosphate-light acid products are on the market, such as Coty Chemical Corporation, Dry Acid, and Johnson, Nu Well, that have helped remove clays and drill muds from wells; they are safe to transport and handle. Coty Chemical Corporation recommends "the use of ½ to ¾ pounds of 'Dry Acid' per gallon of water in the hole." Dry Acid should remain in the hole for at least 24 hours and should be agitated with a bailer every few hours. After the solution has been in the hole the prescribed amount of time, it should then be removed from the hole and normal development methods used to complete the well.

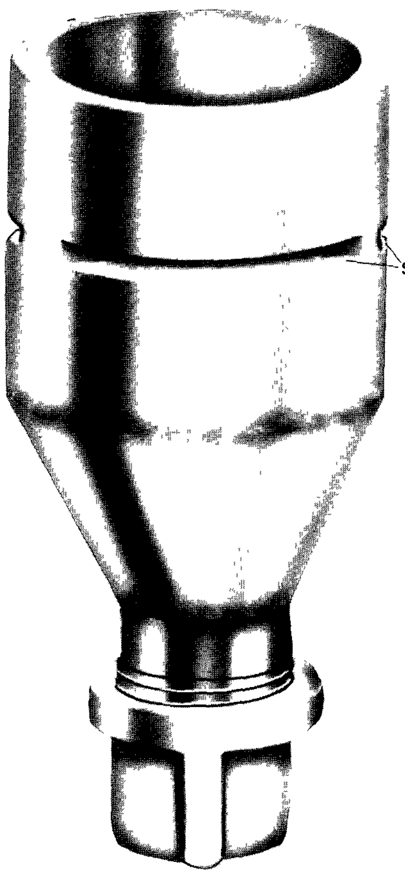
"Nu Well" by Johnson is a pelletized chemical treatment primarily used for removing deposits of calcium and magnesium from encrusted water-well screens. The amount of Nu Well to be placed in the well for satisfactory results is about 30 percent or more of the weight of water contained in the well screen. Allow about 2–4 hr for the pellets to dissolve; then surge the solution to spread the solution's coverage in the well and hasten breakup of the encrusting material. After agitating, best results are obtained when the solution is allowed to remain in the well overnight. The Nu Well contains a pH indicator that changes from a dark purple or red color to an orange or yellow color after reacting with the incrustant. When the orange or yellow color is evident in the well fluid, it denotes the change from a strong acid solution to a weak solution. When this occurs, agitate and pump or bail the solution from the well and dispose of the used Nu Well in a safe place. After removal, normal development methods can be resumed to complete the well.

Development of Selected Well-Screen Intervals

Even when all available well-development methods previously described are used according to recommended procedures wells are not entirely developed to their greatest potential. This is particularly true in wells screened in thick, high-yielding aquifers where enough stress cannot be applied to the aquifer to pull the fines in. If spinner- or tracejector-flow tests, conducted while the well is pumping indicate that certain areas of the aquifer are not producing, these zones can be developed by the straddle packer and swabbing technique. However, this method of well development is complex and expensive. This method is often used by Water Resources Division in hydrologic testing of open holes, but it is almost never used as a development procedure in screened wells or perforated-casing holes.

As an example, assume development of a preselected 20-ft interval of an 8-in.-diameter screen:

1. Two air-inflatable packers are coupled together with a 20-ft section of slotted screen straddled between them (fig. 47). The slotted screen should have a diameter slightly larger than the diameter of the deflated packers, and the slot size of the screen should be larger than that of the aquifer screen so that all fine materials removed from the aquifer can readily pass through the packer screen.
2. Nylaflow tubing (¼-in. I.D.) is coupled to the inflation fittings of each of the packers. The straddle tool is then run into the hole on pieces of 4-in. flush-joint casing, and the Nylaflow tubing is taped to the casing at about every 20 ft interval.
3. When the desired depth for well development is reached, the flush-joint casing is set on the well casing by means of a tubing clamp, and the upper end of the packer pipe is affixed with a tee fitting for later discharge of water when swabbing. The packers are then ready to be inflated. To determine the inflation pressure, compute the pressure needed to overcome the static water-level head above the



Cut-away view of jetting tool

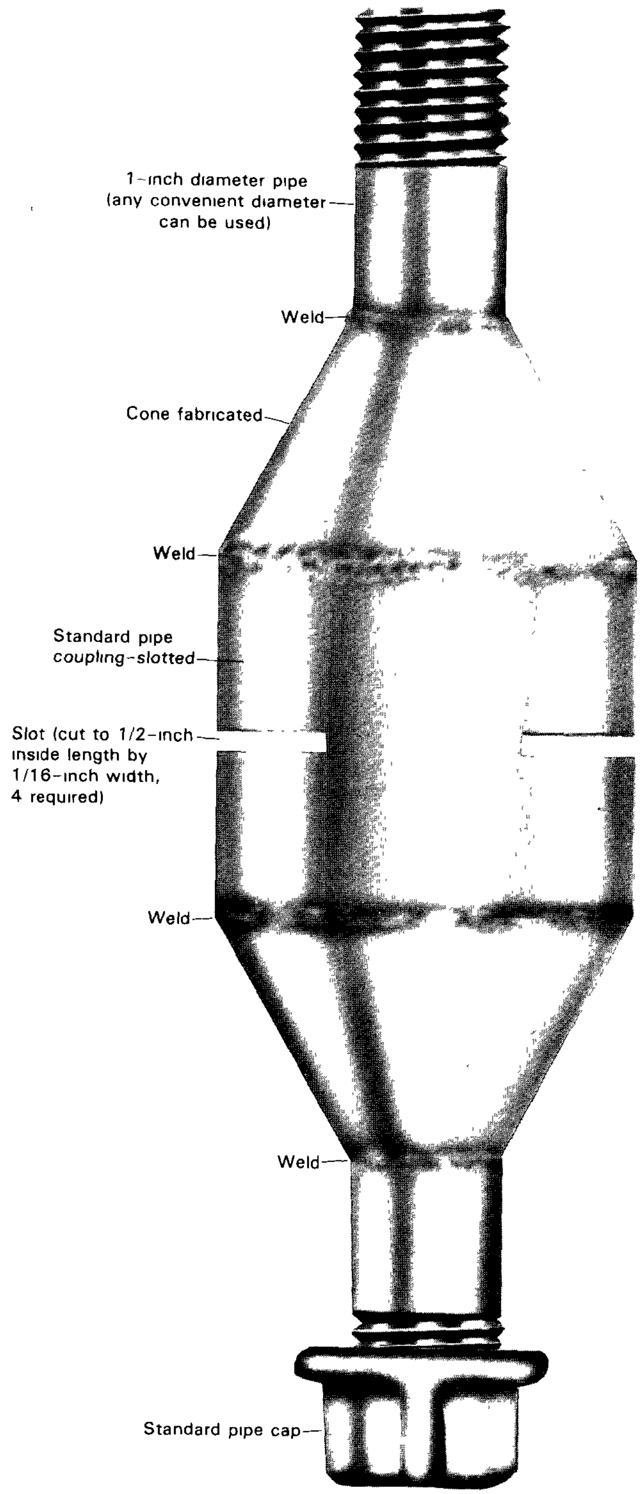


Figure 46.—Fabricated high-velocity well-development jetting tool.

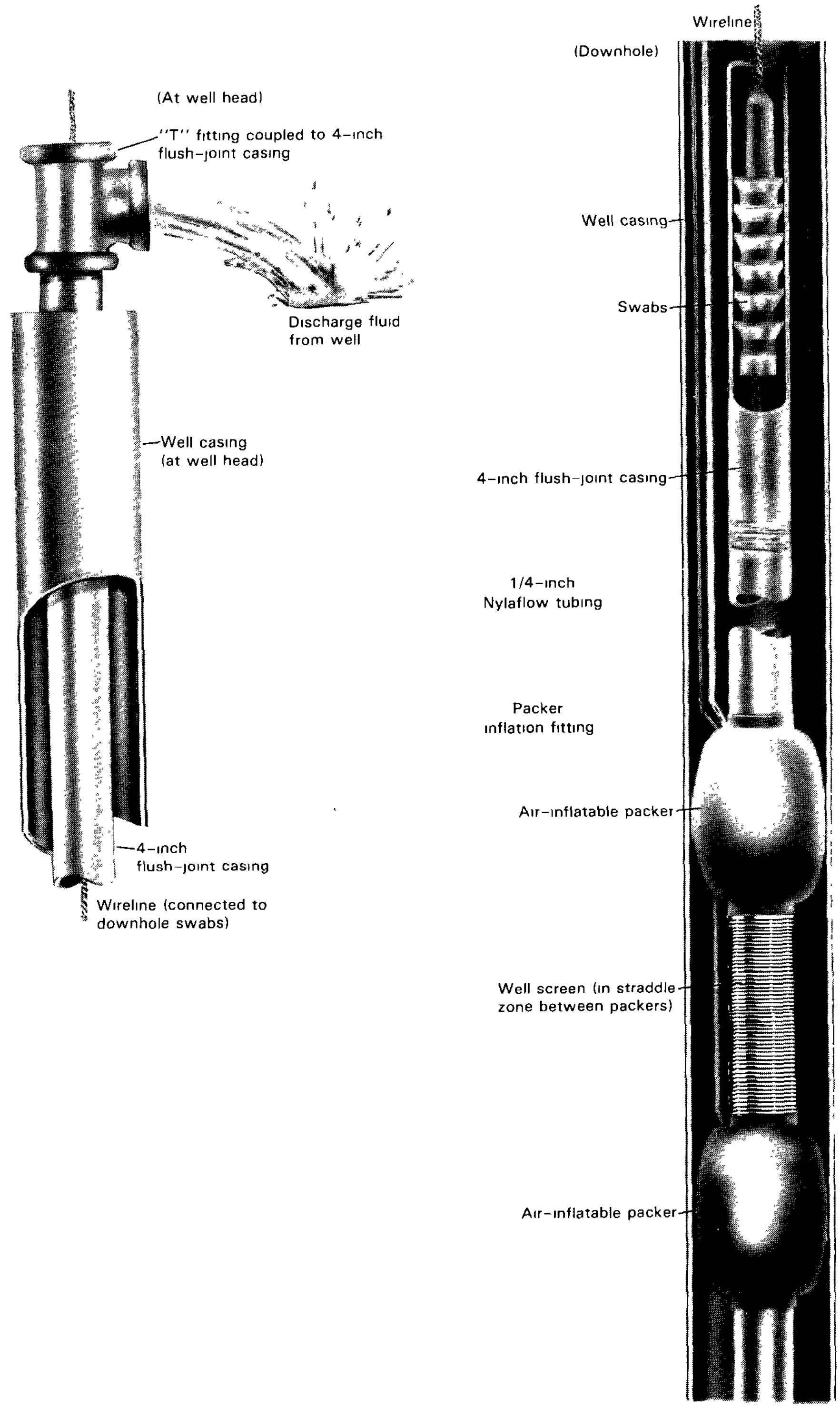


Figure 47.—Straddle packer and well-swabbing equipment used for well development.

packers; to this amount add 50 lb/in.^{2} to inflate the packers to the screen; and apply about 75–100 lb/in.^{2} more pressure against the screen. For example, if the packers are to be set 300 ft below the static-water level use 130 lb/in.^{2} to overcome the water-level head plus 50 lb/in.^{2} to inflate the packers to the screen plus 75 lb/in.^{2} more pressure against the screen, or a total of 255 lb/in.^{2} inflation pressure.

4. After setting the straddled packers in the hole and inflating them, the swab (we prefer the Mission cup type) is run in on a sandline to a depth of 50–75 ft below the water level. Initially, the swab is raised out of the hole at a rate of about 100 ft/min so that the swab cups open and trap all the water above the swab. The swab is brought all the way to the surface, discharging the water out the tee. As soon as the swab has dumped the load of water, it is immediately lowered back down the hole and the depth at which it enters the water (easily detected by slacking the line or sound) is noted. If the water level has not recovered to the initial static-water level in this short time, swabbing is continued using about 50-ft intervals and the recovery rate is observed. If the recovery rate does not increase, the swab should be lowered about 100 ft below the water level and pulled at a faster rate (200 ft/min). This procedure will produce a discharge rate of about 125 gal/min and will likely impart an instantaneous head difference of about 100 ft (plus the vacuum applied from the swab) to the borehole wall thereby breaking down any filter cake and pulling the fine materials into the swab casing. Note: If discharge of sand at the fluid effluent pipe tee indicates that a considerable amount of sand has entered the swabbing casing, halt swabbing temporarily and run in a wash pipe or small bailer to clean out the sand, since large amounts of sand above the swab cups can sandlock them in the casing. After removing the sand, additional swabbing of the well should be performed.

This method of well development is very effective and can be conducted at any desired intervals. Note: When working at considerable depths below static-water level, never attempt to lower the swabs too deep below the water level and pull an instantaneous 500- to 600-ft column of water. This practice can damage the packers and may even damage the screen. After zone development has been completed, the packers are deflated and returned to the surface or reset at a different depth and another zone developed by the same process.

Development of Gravel-Packed Wells

A common erroneous assumption among drillers is that little or no development is needed in wells constructed by the gravel-packed method. Actually, if the well was drilled by the mud-rotary method and the screened zone is underreamed to a larger diameter to accommodate a larger gravel envelope (which is a common procedure for gravel-packed constructed wells), then development of the aquifer through the gravel packing will be much more difficult than development of a natural-packed well. Gravel packing of wells generates difficulties in aquifer development, and the method should be used only when proper screens cannot be selected to prevent sand pumping (Universal Oil Products, 1966, p. 310–311).

An example of the difficulty encountered in the development of a gravel-packed well follows: Two wells were constructed in the same aquifer, consisting of relatively fine, slightly cemented sand. One well was completed with 105 ft of 8-in.-diameter stainless-steel slotted screen installed in a close-tolerance, mud-rotary drilled hole. The other well was completed using 125 ft of a shutter-type screen installed in an underreamed 36-in. hole and was gravel packed. After five days of development, using the high-velocity jetting method to remove the drilling mud and other fine materials from the well, the specific capacity (gallons per minute per foot of drawdown) of the natural-pack well was 17.4 gal/min/ft, a good specific capacity for fine sand. On the other hand, after 30 days of development of the gravel-packed well by the surging and backwashing method, the specific capacity only reached 1.3 gal/min/ft of drawdown, a very poor specific capacity for fine sand. This low specific capacity probably was a result of having under-reamed to a diameter larger than desirable.

An energy means, such as surging, high-velocity jetting, and pumping, must be present in the bore-hole to create a positive head in the formation and a negative head in the well to break down the filter cake on the wall of the hole and remove fine materials, to develop an aquifer to its full potential. The following example indicates the impossibility of accomplishing this in a gravel-packed well. High-velocity jetting, which was very successful for developing the natural-pack well, was valueless in the development of the gravel pack, because the thick gravel envelope absorbed all the energy imparted by the high-velocity jetting tool; and all that was accomplished in the well was the creation of a greater positive-hydrostatic head against the filter cake. Mechanical surging and backwashing will only result in water moving up and down in the permeable gravel pack section of the hole, resulting in little or no negative head energy being imparted to the filter cake. Since the filter cake is a rubbery membrane having little or no permeability and very little supportive strength, except when the hydrostatic head is greater in the hole than in the formation, it can only be destroyed if the hydrostatic heads are reversed. However, the gravel pack gives internal support also, and it cannot be removed by stressing the aquifer. If gravel packing has to be done in the well, the gravel envelope should be kept as thin as possible so that the various development techniques employed have a chance of breaking down the filter cake and developing the formation.

DEVELOPMENT OF SMALL-DIAMETER WELLS

Development principles of all wells are the same. However, small-diameter observation wells, because of the small diameter and the fact that many of these wells penetrate the aquifer to a shallow depth, pose particular problems that require different development techniques than those used for development of large-diameter wells. As part of an observation-well maintenance program, the wells should be slug tested or pumped periodically to confirm that they are open and responsive to the aquifer.

An observation well should be developed immediately after its installation. Too often, as an expediency when a large number of observation wells are installed on a particular project, the decision is made to delay the development of the wells until a later time. This always results in more development effort, and, in most cases, later development is impossible to accomplish.

Air Development

In the first example, assume a 2-in.-diameter well with a 2- or 3-ft well point or screen at the bottom is to be developed, and, upon sounding the well, no appreciable amount of fine sediments has been found in the bottom of it. Also, enough water was in the well pipe to allow the proper submergence of an air line for development of the well by the air-lifting method. A fabricated air nozzle (as shown in fig. 48) is connected to the bottom of ½-in. pipe and then lowered into the well until the proper submergence depth is reached. The upper end of the pipe or tubing is connected to a compressor, and enough air is slowly provided to pump water out of the pipe. If the water level is pumped down to a level where only air is blowing out of the pipe, lower the air line further into the well pipe until the well again produces water. Lowering the air line can be continued, but it should not be lowered into the well screen, which might allow air to be introduced into the aquifer. If the air pumping has created enough static-head difference to begin well development by causing fine sediments to enter through the well screen, it will be evident from the amount of turbidity in the discharge water. Continue to pump until the water clears. If development is successful, an appreciable increase in discharge will be noticeable. Occasionally, use of this method of development can cause a considerable amount of fine sand to enter the well; if the fine sand cannot be lifted out in the ascending column of water, it must be removed by other means, or it will resettle in the well and again plug the screen. If the above occurs, the air jet should not be lowered into the screen to blow it out. Instead, the air line is removed from the hole; the ¼-in. pipe plug is unscrewed from the jetting tool and replaced with a ¼- by 2-in. nipple. The ½-in. pipe is then lowered back into the hole to a point just above the fill in; it is connected to the water pump; and the sand is jetted out of the well. Some of the water will come out of the small jets in the jetting tool, but the largest volume of water will pass through the ¼-in. pipe, permitting flushing out of the fine materials. After the fines have been flushed out of the well pipe, the screen should be cleaned by jetting while the tool is still at the bottom of the well. To accomplish this, the bottom of the jetting tool must first be sealed again by dropping a 7⁄16-in. or ⅜-in. steel ball bearing down the ½-in. jetting pipe and letting it seat on the ¼-in. pipe nipple. Or a 3⁄16 by 1- or 2-in. bolt can be used instead of a ball bearing; the bolt is dropped down the pipe, thread end first, and the head of the bolt will seat on the ¼-in. pipe. The jetting tool can be used nowas a high-velocity jetting tool to clean the

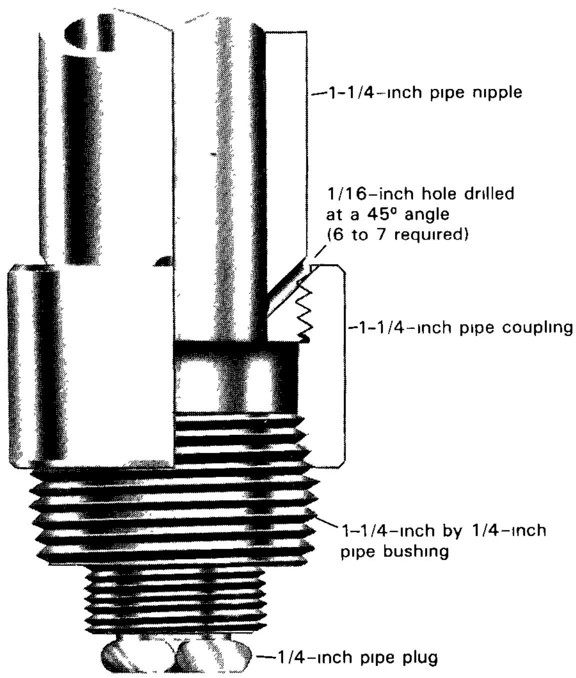


Figure 48.—Fabricated air nozzle for development of small-diameter wells by the air-lifting method.

screen. After jetting, the ½-in. line is pulled back up the hole some distance, the compressor reconnected, and additional air pumping performed as necessary to complete the well-development process.

Sometimes, observation wells penetrate the aquifer to such a shallow depth that the method of air pumping previously described cannot effectively be accomplished. However, there is an air-development method that may provide adequate results for such wells. For example, assume an observation well has a static-water level of 50 ft, and only 10 ft of water in the well is above the screen. This well cannot be pumped in the manner previously described; however, air can be used to blow water out of the well by the following method. The air line with the jetting tool attached (with the ¼-in. pipe plug in place in the jetting tool) is lowered into the well to a point about 5 ft below the surface of the water, and the compressor line is attached to the air line. A rapid, large, upward surge of air will blow the water out of the well. After the water has been blown out of the well, the process is repeated after waiting several minutes. The amount of the second discharge of water should be observed and compared to the first amount discharged from the well. If little or no water discharges on the second surge, the air line is lowered another few feet in the well but not so far down that the air jets are discharging inside the screen. This procedure including the resting and resurging is repeated. If dirty water starts to be discharged from the well and as much water discharge is observed in the second surge as occurred in the first surge, the well is developing, but do not continue to surge air at this same depth. As the well starts to make water, the air pressure must be increased to lift the heavier water column, and this may result in back pressuring of air through the screen and into the aquifer. The air line is raised in the well and the blowing-out procedure is continued.

If this method does not develop the well, because of the very low stress that can be applied to the aquifer, the high-velocity jetting method should be used to clean the screen and one of the suggested polyphosphates or low-acid combinations added to the well. If the screen or formation is so plugged that it will not take the additives, they may be forced out into the formation by filling the well pipe with water or even connecting a pump to the pipe and back-washing them into the formation.

High-Velocity Jetting

Some observation wells, because of too large a screen-size selection, may contain a considerable amount of materials that entered the pipe through the screen when the well was installed. If the well was not developed at the time that it was installed, the materials gradually settle out and create a completely sealed and nonresponsive observation well. To develop a well where this has occurred, remove the sediments from the inside of the pipe using the jetting-washout method. After the sediments have been washed out of the well, the ball bearing or the bolt is dropped into the fabricated air nozzle and high-velocity jetting is performed through the screen, for cleaning of the screen and agitation of the materials around the screen. This process may provide adequate development; if it does not, then one or more of the following techniques can be used.

Swabbing

Swabbing of small-diameter wells as a development method is probably the most positive development technique available, particularly if it is performed at the time of installation and if the well penetrates at least 30 ft into the aquifer. Small-diameter swabs of the Mission type can be obtained in sizes of 1¼ in., 1½ in., and 2 in.; these will accommodate the range of most small-diameter observation wells. The swabbing technique for small-diameter wells is the same as that described beginning on page 88, except packers are not used. Certain precautions must be used in swabbing development of small-diameter wells:

1. Swab cups are manufactured to operate in flush-joint tubing. Although they will operate in standard coupled steel or plastic pipe, the user must ensure against two things that will either prevent them from being lowered through the pipe or will tear the cups up when the swab is pulled: (1) if a steel pipe is used, each end of the pipe must be reamed to remove any sharp cutting edges, (2) if plastic pipe of the cement-joint type is used, cement should be applied sparingly at the coupling so that excess cement does not form a ring or blockage inside the pipe.

2. If plastic pipe (and particularly plastic screens) are used in construction of the observation well, pulling too much water out with the swabs at one time may cause the screen to implode. This is particularly important when the well begins to develop, because water may not be entering the screen fast enough to equalize the head. Swabbing should begin by pulling no more than a 50-ft head. Then, if the well increases in yield and hydrostatic-head equalization is not a problem, the swabbing head can be increased to apply more stress on the aquifer.

SELECTED REFERENCES

Acker, W.L., II, 1974, Basic procedures for soil sampling and core drilling: Scranton, Pa., Acker Drill Co., Inc., 246 p.

American Association of Oil Well Drilling Contractors, 1969, Principles of drilling fluid control, American Petroleum Institute and University of Texas, eds.: Dallas, Tex., 215 p.

American Society for Testing and Materials, 1977, Standard method for penetration test and split-barrel sampling of soils, *in* Natural building stones; soil and rock; peats, mosses, and humus: Annual book of American Society for Testing and Materials standards, pt. 19, D 1586–67, p. 224–226.

——— 1977, Standard method for thin-walled tube sampling of soils, *in* Natural building stones; soil and rock; peats, mosses, and humus: Annual book of American Society for Testing and Materials standards, pt. 19, D 1587–74, p. 227–229.

Anderson, K.E., 1971, Water well handbook, 2nd ed.: St. Louis, Mo., Missouri Water Well and Pump Contractors Association, Inc., 281 p.

Angel, R.R., 1957, Volume requirements for air and gas drilling: Society of Petroleum Engineers, American Institute of Mining, Metallurgical, and Petroleum Engineers, Transactions, v. 210, p. 325–330.

Barraclough, J.T., Robertson, J. B., and Janzer, V. J., 1975, Hydrology of the solid-waste burial ground, as related to the potential migration of radionuclides: U.S. Geological Survey Open-File Report 76–471, 183 p.

Brantly, J.E., 1961, Rotary drilling handbook 6th ed.: New York, Palmer Publications, 825 p.

Brown, B.D., 1959, Cementing water wells: Public Works, v. 90, no. 9, p. 99–100.

Burgus, W.H., and Maestas, S.E., 1975, The 1975 Radioactive Waste Management Complex core-drilling program: U.S. Energy Research and Development Administration: U.S. Department of Commerce, National Technical Information Service, Report IDO 10065, 36 p.

Campbell, M.D., and Lehr, J.H., 1973, Water well technology: New York, McGraw-Hill, 681 p.

Church, M., 1960, Mud pressure aids cable tool drilling: Johnson Driller's Journal, v. 32, no. 3, p. 4–5.

Cummings, J.D., and Wicklund, A.P., 1968, Diamond drill handbook: Toronto, Ontario, Canada, J.K. Smit and Sons Diamond Products Ltd, 547 p.

Doll, H.G., 1955, Filtrate invasion in highly permeable sands: Petroleum Engineer, v. 27, no. 1, p. B53-B66.

Gordon, R.W., 1958, Water well drilling with cable tools: Milwaukee, Wis., Bucyrus-Erie Co., 230 p.

Green, B.Q., 1959, New tests show which lost-circulation materials to use and how to use them: Oil and Gas Journal, March, p. 110–115, 170–173.

Haden, E.L., and Welch, G.R., 1961, Techniques for preventing sticking of drill pipe: American Petroleum Institute Drilling and Production Practices, p. 36–411.

Halliburton Services, 1969, Halliburton cementing tables: Duncan, Okla., 75 p.

Hudeck, R.R., 1969, How to select and use drill bits profitably: World Oil, v. 169, no. 4, p. 73–77.

Hughes Tool Co., 1966, Rotary drilling bits: Houston, Tex., 37 p.

Johnson Driller's Journal, 1961, Jet development does the work: v. 33, no. 6, p. 1–5.

Keys, W.S., and MacCary, L.M., 1971, Application of borehole geophysics to Water-resources Investigations, Chapter E1, Book 2, 133 p.

Lummus, J.L., 1965, Chemical removal of drilled solids: Drilling Contractor, March-April, p. 50–67.

Mesaros, J., 1957, The application of flow properties to drilling problems: American Petroleum Institute Drilling and Production Practices, Bulletin 243, p. 83–93.

Moehrl, K. E., 1964, Well grouting and well protection: American Water Well Association Journal, v. 56, no. 4, p. 423–431.

Moore, P.L., 1966, Drilling for the man on the rig: Oil and Gas Journal, Technical manual reprint, 72 p.

National Lead Corp., 1966, What's new with mud?: Baroid Division Special Report, 35 p.

National Water Well Association, 1971, Water well driller's beginning training manual: Columbus, Ohio, 84 p.

______ 1976, Manual of water well construction practices: U.S. Environmental Protection Agency, U.S. Department of Commerce, National Technical Information Service, Report EPA-570/9–75-001, 155 p.

Oregon Well Contractors Association, 1968, Manual of water-well construction practices: Portland, Ore., 85 p.

Peterson, J.S., and others, 1955, Effect of well screens on flow into wells: American Society of Civil Engineers, Transactions, v. 120, p. 562–584.

Teasdale, W.E., 1980, Test drilling is basalts, Lalamilo Area, South Kohala District, Hawaii: U.S. Geological Survey Open-File Report 80–1299, 25 p.

Teasdale, W.E., and Pemberton, R. R., 1984, Wireline-rotary air coring of the Bandelier Tuff, Los Alamos, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 84–4176, 9 p.

Universal Oil Products, 1966, Ground water and wells: St. Paul, Minn., Edward E. Johnson, 440 p.

Watt, H.B., and Akin, T.B., 1967, Tricore, a continuous sidewall core cutter: Society of Professional Well Log Analysts, 8th Annual Logging Symposium, Denver, Colo., Transactions, p. 211–219.

GLOSSARY

(Commonly used drilling and sampling terms)

Annulus The annulus or annular space is the space between the outside diameter of the drill rods, drill pipe, or casing and the wall of the borehole.

Box Female end of threaded drill-tool joint; see pin.

Casing A pipe used to case a drill hole; special seamless tubing in which drill rods rotate; used to hold back overburden or to line cavernous drill holes.

Core The cylinder of hard rock or unconsolidated material produced by the hollow, coring-type bit.

Dead-sticking Process of moving a string of drilling tools up or down in a borehole without rotating them.

Derrick The mast on a drilling rig used for supporting the tackle for drilling, hoisting, and lowering the drilling tools.

Drawworks A power-driven winch or system of winches, usually equipped with clutch and brake (might also be hydraulically controlled system) for raising or lowering a drilling string.

Drill bit The steel tool attached to the bottom end of the drill pipe which performs the actual drilling. Made in a variety of sizes, types, and shapes depending upon the type of lithology to be drilled, the method of drilling, and the depth and size of the hole.

Drill collar A heavy steel tool that is attached at the lower end of a string of drill pipe and just above the bit to provide weight and stability to the drill tools for rotary drilling or coring.

Drill jars A tool composed of two connected links having vertical play between them. Used to apply a sudden upward impact or shock to a string of drill tools stuck in the hole.

Drill pipe See drill rod.

Drill rod Special pipe, hollow flush-jointed or coupled rods joined and threaded at each end, used to transmit rotation from the rig rotating mechanism (rotary table); thrust or weight to the bit; conveys drilling fluid or air to remove cuttings from the hole and cool and lubricate the bit.

Drill stem A steel tool that is attached below the drill jars in a string of drilling tools to provide weight to the tool string.

Fish Debris in a borehole, such as broken bits, drill rod, core barrels, and tools which might have broken off or fallen into the hole.

Fishing The attempt to recover debris from the borehole.

Fishing tools Special tools (overshot, spear, junk basket, magnet) used to recover debris from a hole.

Fluid Liquid or gas medium used for clearing cuttings from the borehole being drilled; stabilizes borehole wall; cools and lubricates bit and drill tools.

Flush-coupled casing Seamless tubing having a box end and a pin end instead of using a coupling. Has the same outside diameter throughout. Flush-coupled casing is thinner walled than flush-joint casing.

Flush-joint casing Seamless tubing having a box end and a pin end instead of using a coupling. Has the same inside diameter throughout. A special type of flush-joint casing is used for wireline coring.

Grab samples Random lithologic samples taken as the borehole is being drilled or auger drilled. The samples are disturbed and usually contain a mixture of the materials being penetrated by the bit and transported to the surface in the drilling fluid or transported up the auger flights in an auger-drilled hole.

High-yield bentonite A bentonite that will give a specific viscosity to the largest volume of water. The yield test relates the solid content to the viscosity of a clay-water mixture.

Hole conditioning The process of circulating a drilling fluid in a borehole to remove drill cuttings, stabilize the borehole wall with a filter cake (rind), and prepare the hole for geophysical logging. Conditioning is usually performed after drilling or coring has been completed in the borehole.

Kelly A formed or machined section of hollow drill steel which is connected directly to the swivel at the top and the drill rod below. Flutes, flats, or splines of the kelly engage the rotary table to transmit rotation to the kelly which is, in turn, transmitted to the drill rods and bit.

Overshot assembly Wire-line-core barrel inner-barrel retrieval assembly. Lowered through the wire-line-drill rods on a wire line by means of a wire-line winch.

Packer An inflatable cylinder of reinforced rubber and metal used to seal a well or borehole for hydraulic testing, grouting, or well-development purposes.

Pin Male end of threaded drill-tool joint; see box.

Rope socket A tool by which a connection is made between the drilling line and the drill stem used on a cable-tool drilling rig.

Shale shaker A screened, vibratory drilling-mud cleaning device used to separate drilled cuttings out of the uphole flow of cuttings-laden drilling mud before the mud is recirculated back downhole.

Spot To selectively place a quantity of drilling fluid at a particular depth in a borehole to control caving or fluid entry in that portion of the borehole, usually to facilitate lithologic sampling of that zone.

Spudding in The starting of a hole.

Sub A substitute or adaptor used to connect from one size or type of threaded drill rod or tool connection to another.

Swivel A connection from a stationary hose into a rotating member, such as a kelly or drill rod, to allow passage of a drilling fluid or air and the free rotation of the rods.

Tremie (pipe) A small-diameter pipe with a funnel like top through which grout is poured into a borehole.

Wire-line-core barrel A core barrel in which the inner-barrel assembly and contained core may be retrieved to the surface by means of a wire-line with overshot assembly without removing the drill rods from the borehole.

☆ U.S GOVERNMENT PRINTING OFFICE· 1989—673-047/86,044 REGION NO. 8