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# Recommended Practices for Core Analysis

RECOMMENDED PRACTICE 40  
SECOND EDITION, FEBRUARY 1998





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# Recommended Practices for Core Analysis

**Exploration and Production Department**

RECOMMENDED PRACTICE 40  
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## SCOPE

These recommended practices for core analysis replace API RP 40, *Recommended Practice for Core Analysis Procedure*, 1960, and API RP 27, *Recommended Practice for Determining Permeability of Porous Media*, 1952, (reissued 1956). In the first section of the new recommended practices, Planning a Coring Program, key factors to be taken into consideration in obtaining core samples are explained and advantages of different coring procedures are given. The second section, Wellsite Core Handling Procedures and Preservation, addresses documentation of coring conditions and how cores should be handled once they reach the surface, including marking and preservation. The third section, Core Screening and Core Preparation, describes how the condition and nature of core samples can be documented through core gamma logs and various imaging techniques, and how samples should be selected and prepared for basic testing. Also covered in the third section are methods of preserving samples prior to testing, and procedures for cleaning and drying samples. The fourth section, Fluid Saturation, explains how fluid saturations can be determined on different types of samples and the limitations of the various techniques. The fifth section, Porosity Determination, defines different types of porosity and explains the measurements. The sixth section, Permeability Determination, explains the theory and methods for measurement of permeability of porous media to a single phase. Relative permeability measurements to two or three phases are not covered in this document. The seventh section, Supplementary Tests, covers determination of grain size, brine salinity, oil gravity, and acid solubility. The eighth and final section, Reporting, supplies forms to assist in recording the details of core handling and testing methodology that could be critical in interpreting basic core analysis data.

Core analysis, like other technical areas, is continually evolving so that both methodology and costs are changing. The recommended practices provided here represent a snap shot in time of the consensus advice of a large international committee.

Geologic materials come in a vast range of chemical compositions and physical states. For unusual samples or extraordinarily accurate data, it may be necessary to develop special procedures.

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## **SECTION 1—PLANNING A CORING PROGRAM**



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# Recommended Practices for Core Analysis

## 1 Planning a Coring Program

### 1.1 GENERAL

#### 1.1.1 Scope

This section addresses the complexities of planning a coring program, the decisions to be made, and the factors that influence the choices.

#### 1.1.2 Principle

A coring program is similar to many engineering projects. It begins with the premise that an investment will reap a reward. It progresses through a phase of exploring alternate sources of information; well tests, logs, previous cores, and cuttings or sidewall cores.

Planning begins by listing the objectives of the coring program. This is best done by a team of petrophysical, reservoir, geological, drilling, and production personnel. When discussing objectives, every expenditure must ultimately lead to producing more oil or gas at a lower unit cost. Constraints in budget, location, and timing will be placed on the program. Hole size, hole angle, temperature, pressure, and rock type will influence the selection of the coring tools. Planning becomes an interactive process where consensus is built and a detailed program formulated.

The keys to a successful coring operation are planning and communication.

#### 1.1.3 Objective

The objective of every coring operation is to gather information that leads to more efficient oil or gas production. Some specific tasks might include the:

- a. Geologic objectives:
  1. Lithologic information:
    - (a) Rock type.
    - (b) Depositional environment.
    - (c) Pore type.
    - (d) Mineralogy/geochemistry.
  2. Geologic maps.
  3. Fracture orientation.
- b. Petrophysical and reservoir engineering:
  1. Permeability information:
    - (a) Permeability/porosity correlation.
    - (b) Relative permeability.
  2. Capillary pressure data.
  3. Data for refining log calculations:
    - (a) Electrical properties.
    - (b) Grain density.
    - (c) Core gamma log.
    - (d) Mineralogy and cation exchange capacity.

4. Enhanced oil recovery studies.
5. Reserves estimate:
  - (a) Porosity.
  - (b) Fluid saturations.
- c. Drilling and completions:
  1. Fluid/formation compatibility studies.
  2. Grain size data for gravel pack design.
  3. Rock mechanics data.

#### 1.1.4 Coring Fluids

**1.1.4.1** The selection of a coring fluid should be based on four points:

- a. Safety.
- b. The primary objective of the coring program.
- c. Environmental concerns.
- d. Cost.

**1.1.4.2** Safety takes precedence over all other factors. The drilling fluid must be designed to hold the expected formation pressures as well as clean, lubricate, and stabilize the borehole. The objectives of the coring program should influence the selection of the coring/drilling fluid. All coring fluids should be designed to have low static API filter loss and very low dynamic spurt loss to minimize core flushing.

**1.1.4.3** Environmental concerns should also be considered and budgeted for. This may mean using a more expensive drilling fluid system to meet environmental objectives, or providing additional drilling fluid handling equipment to ensure containment.

**1.1.4.4** Cost is important; still, it is a good practice to review the cost of the entire core analysis program and the expected benefits from it while pricing drilling fluid systems. Savings on drilling fluids may increase the cost of the core analyses, and put the accuracy of the core studies at risk.

**1.1.4.5** The question of which drilling fluid is best for coring cannot be answered directly. Water-based, oil-based, foam, and air/mist drilling fluids have all been used to successfully cut cores. The best recommendation is to follow the criteria given above. Evaluating the needs of the drilling and core analysis program will lead to an appropriate selection.

## 1.2 CORING EQUIPMENT

### 1.2.1 Scope

This section presents an overview of coring tools, including guidelines for selecting coring tools for specific applications. Details of particular coring systems, and job specific coring recommendations should be obtained from appropriate service companies.

### 1.2.2 Principle

Coring equipment is designed to retrieve rock samples from deep in the earth for geologic and engineering studies. The tools do an excellent job of recovering core material, and specialized equipment has been developed to trap reservoir fluids and even seal in bottom-hole pressure.

### 1.2.3 Apparatus

With several notable exceptions coring systems consist of an inner core barrel suspended by a swivel assembly within an outer core barrel that is attached to the drill string. A coring bit is attached to the bottom of the outer barrel and a core catcher is fitted to the bottom of the inner core barrel. Drilling fluid is pumped down the drill string, through the swivel assembly, through the annulus between the inner and outer core barrels, and out the core bit.

## 1.3 CONVENTIONAL CORING SYSTEMS

### 1.3.1 Conventional Core Barrel

Conventional coring tools are available to cut cores with outer diameters from 1.75 to 5.25 inches (44.5 to 133.4 millimeters). Core length can run from 1.5 feet (.46 meter) for short radius horizontal well applications to over 400 feet (121.9 meters) for thick, uniform, consolidated formations. Hole size, hole angle, rock strength, and lithology will control the diameter and length of core that may be cut in one trip. The final selection of a particular system will depend upon the formation, location, and objectives of the coring program. Table 1-1 summarizes the conventional coring options available.

### 1.3.2 Heavy-Duty Conventional Core Barrels

Special heavy-duty coring tools have been developed to core harder than normal formations, and cut extended length cores. Heavy duty threads allow more torque to be applied to

the bit, and improve the margin of safety against tool failure. Designed to cut cores up to 5.25 inches (133.4 millimeters) in diameter, these tools are especially attractive in situations where rig time is the largest coring expense. Heavy-duty coring systems are used to best advantage when coring longer lengths of homogeneous formations or when anticipating higher than normal torque loads.

The marine core barrel was the precursor to today's generation of heavy-duty core barrels. Developed to be stronger than existing coring systems, the tool was developed for use in offshore applications. The marine core barrel does increase the margin of safety against tool failure, but is restricted to cutting a 3-inch (76.2-millimeter) diameter core.

### 1.3.3 Core Barrel Liners

The use of a core barrel liner in a steel inner core barrel has two primary functions: to improve core quality by physically supporting the core material during handling and to serve as a core preservation system. PVC and ABS plastic, fiberglass, and aluminum have all been used as inner core barrel liners. The liners slip inside a conventional inner core barrel and are held in place by the core-catcher assembly and friction. Liners are typically 30 feet (9.14 meters) long. They may be cut shorter for special applications, but their maximum length is rarely more than 30 feet (9.14 meters) due to manufacturing and material handling limitations.

Liners are most often specified when coring unconsolidated or fractured formations. They are also appropriate when cutting hard rock in remote and offshore locations when immediate core preservation is required. Plastic liners are suitable up to temperatures of 180°F (82.2°C). Fiberglass liners may be used up to 250°F (121°C); 350°F (176.7°C) if special high temperature resin is used. Aluminum is generally recommended when temperatures in excess of 250°F (121°C) are expected. The disadvantage of core barrel liners is that

Table 1-1—Conventional Coring Systems

| Inner Barrel                  | Core Length                         | Special Features                                                                                                                                                                              |
|-------------------------------|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Mild steel                    | 30 to 120 ft. (9.14 to 36.58 m)     | Ready-made core preservation system. High temperature applications.                                                                                                                           |
| Mild steel                    | 1.5 ft. (.46 m)                     | Designed for short-radius coring.                                                                                                                                                             |
| High strength steel           | 120 to >400 ft. (36.38 to >121.9 m) | Stronger barrel, includes additional inner and outer core barrel stabilization.                                                                                                               |
| Fiberglass                    | 30 to 90 ft. (9.14 to 27.43 m)      | Ready-made core preservation system. Used for consolidated and unconsolidated formations. Maximum operating temperatures: normal resin 250°F (121°C), high temperature resin 350°F (176.7°C). |
| Aluminum                      | 30 to 90 ft. (9.14 to 27.43 m)      | Ready-made core preservation system. High temperature applications, maximum 350°F (176.7°C).                                                                                                  |
| Steel with a plastic liner    | 30 ft. (9.14 m)                     | Ready-made core preservation system. Maximum temperature of 180°F (82.2°C). Reduces core diameter by 1/2 in. (12.7 mm).                                                                       |
| Steel with a fiberglass liner | 30 ft. (9.14 m)                     | Ready-made core preservation system. Maximum temperature of 250°F (121°C). Reduces core diameter by 1/2 in. (12.7 mm).                                                                        |
| Steel with an aluminum liner  | 30 ft. (9.14 m)                     | Ready-made core preservation system. Maximum temperature of 350°F (176.7°C). Reduces core diameter by 1/2 in. (12.7 mm).                                                                      |

they reduce the effective diameter of the inner core barrel by approximately 0.5 inch (12.7 millimeters).

### 1.3.4 Disposable Inner Core Barrels

Disposable inner core barrels serve the same general purposes as core barrel liners. They improve core quality by physically supporting the core material during handling and serve as a core preservation system. In addition, the outside diameter of the core is not reduced, as it would be with an inner barrel liner. Disposable inner core barrels are available in aluminum, fiberglass, and mild steel, and are manufactured in a variety of sizes to fit most conventional coring systems. In addition, the fiberglass inner core barrel has a low coefficient of friction that allows the core to slide more easily into the core barrel, thereby reducing the risk of core jamming.

### 1.3.5 Coring High Angle or Horizontal Well

Medium radius [290 to 700 feet (88.4 to 213.4 meters) radius] and extended length wells can be cored with conventional core barrels powered from the rotary table or by a downhole motor. Most cores will be cut without using a downhole motor, but cases will arise where the use of a mud motor is justified. Using a downhole motor enables coring to proceed without rotating the drill string. Typically a 30-foot (9.14-meter) long conventional core barrel would be placed ahead of the downhole mud motor. Mud motors produce high torque at low rotating speed for optimum coring power. Core barrel length and core diameter may be varied to accommodate drilling constraints. The inner core barrel is stabilized by fitting it with special roller bearing or bushing assemblies to centralize the inner core barrel. A special drop ball sub may be placed between the motor and core barrel to allow drilling fluid to flow through the inner core barrel, cleaning it of debris before coring. Activating the sub diverts the drilling fluid flow between the inner and outer core barrel for coring.

In some instances during coring it may be necessary to keep very tight control on the angle of the well. Coring without the downhole motor may improve well-angle control.

## 1.4 SPECIAL CORING SYSTEMS

### 1.4.1 General

Special coring systems have evolved to fill specific coring needs. Pressure-retained and sponge core barrels arose from a need for better oil saturation data. The rubber-sleeve and full-closure coring systems were developed specifically to improve the quality of cores cut from unconsolidated formations. Other special coring systems have equally unique capabilities, making them all useful to the engineers and geologists employing them. Table 1-2 summarizes some of the available special coring options.

### 1.4.2 Pressure-Retained Coring

Pressure-retaining core barrels are designed to retrieve cores maintained at reservoir pressure conditions. Accepted as the best method for obtaining core-based oil saturation data, pressure-retained cores also capture reservoir gases. The tool is especially useful when studying the feasibility of enhanced recovery projects and estimating the methane content of coal.

Pressure-retained core barrels are available in two sizes: 6-inch (152.4-millimeter) and 8-inch (203.2-millimeter) outside diameter that cut cores 2.50- and 3.75-inch (63.5- and 95.3-millimeter) outside diameter, respectively. The 6-inch (152.4-millimeter) outside diameter barrel cuts up to 20 feet (6.1 meters) of 2.5-inch (63.5-millimeter) diameter core while holding a maximum of 10,000 psi (69 MPa) pressure. The 8-inch (203.2-millimeter) outside diameter barrel cuts 10 feet (3.05 meters) of 3.75-inch (95.3-millimeter) diameter core while retaining a maximum of 5,000 psi (34.5 MPa) internal pressure. The maximum recommended operating temperature is 180°F (82°C).

Pressure core barrels are sophisticated tools requiring an on-site facility to service the barrel and handle the pressurized cores. Core handling procedures may be found in 2.2.5.

Table 1-2—Special Coring Systems

| Coring System                | Maximum Core Dimensions                                                                                               | Special Applications                                                       |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Pressure-retained            | 3.75 in. x 10 ft. (5000 psi) [95.3 mm x 3.05 m (34.5 MPa)]<br>2.5 in. x 20 ft. (10000 psi) [63.5 mm x 6.1 m (69 MPa)] | Pressure-retained analyses, fluid saturations, gas volume and composition. |
| Sponge-lined                 | 3.5 in. x 30 ft. (88.9 mm x 9.1 m)                                                                                    | Fluid saturations.                                                         |
| Full-closure                 | 4.0 in. x 60 ft. (101.6 mm x 18.3 m)                                                                                  | Recovering unconsolidated formations.                                      |
| Rubber-sleeve                | 3.0 in. x 20 ft. (76.2 mm x 6.1 m)                                                                                    | Recovering unconsolidated, fractured, or conglomeritic formations.         |
| Wireline retrievable         | 2.75 in. x 30 ft. (69.9 mm x 9.1 m)                                                                                   | Coring is possible without tripping pipe.                                  |
| Wireline percussion sidewall | 1 in. x 1.75 in. (25.4 mm x 44.5 mm)                                                                                  | Samples obtained after drilling and logging.                               |
| Wireline drilled sidewall    | .94 in. x 1.75 in. (23.9 mm x 44.5 mm)                                                                                | Samples obtained after drilling and logging.                               |
| Sidewall corer               | 2.5 in. x 10 ft. (63.5 mm x 3.05 m)                                                                                   | Core obtained after drilling and logging.                                  |

### 1.4.3 Sponge-Lined Coring System

The sponge-lined coring system was developed to improve the accuracy of core-based oil saturation data. A sponge coring system does not trap reservoir gases, instead it traps oil expelled as the core is brought to the surface. The saturation information is very useful when evaluating enhanced oil recovery projects.

A sponge coring system has the advantage of being less expensive to operate than a pressure-retained coring system, while providing an opportunity to improve the accuracy of the core based oil saturation data. The sponge is stable to a temperature of 350°F (176.7°C). The sponge coring system is limited to cutting a maximum of 30 feet (9.14 meters) of 3.5-inch (88.9-millimeter) diameter core per trip.

### 1.4.4 Full-Closure Coring Systems

Full-closure coring systems were developed to improve the recovery of unconsolidated formations. These systems use core barrel liners or disposable inner core barrels, and a special core catching system to retrieve the troublesome rocks.

Full-closure coring technology allows the inner core barrel to slip gently over soft core with a minimum of disturbance, and then seal the core within the core barrel. This is done by using a full-closure core catcher assembly that allows unobstructed entry of the core into the inner core barrel, and then after coring seals off the bottom of the inner barrel. Full-closure coring systems are currently limited to cutting either 3.5-inch (88.9-millimeter) or 4-inch (101.6-millimeter) diameter cores. The recommended core length is 30 feet (9.14 meters). The smooth bore and the absence of an exposed core catcher may result in lost core if the tool is lifted off bottom before activating the full-closure core catcher.

### 1.4.5 Rubber-Sleeve Core Barrel

The rubber-sleeve coring system was the first system developed to improve the chances for recovering unconsolidated sands, conglomerates, and hard fractured formations. The rubber-sleeve barrel is unique in that the top of the inner barrel does not move relative to the core during coring. The outer barrel is drilled down around a column of rock that is progressively encased in a rubber sleeve. The rubber sleeve is smaller than the diameter of the core; it stretches tightly around the core, wrapping it securely and protecting it from the scouring action of the drilling fluid. The core is supported by the rubber sleeve thus, aiding in the recovery of soft formations that would not support their own weight.

There is only one size of rubber-sleeve core barrel, that cuts 20 feet (6.1 meters) of 3-inch (76.2-millimeter) diameter core per trip. The rubber sleeve itself is limited to temperatures no higher than 200°F (93°C). The tool is not recommended for use in holes with more than 45 degrees of inclination. In addition, coring must be stopped approxi-

mately every two feet to allow the tool to be reset; this might lead to core jamming in fractured formations. The system works best from fixed drilling structures, yet it can be operated from floating rigs if rig movement is minimal.

### 1.4.6 Wireline-Retrieval Core Barrel

Wireline-retrieval coring tools are operationally similar to conventional coring systems except they are designed for the inner core barrel to be pulled to the surface by a wireline. This speeds the coring operation by eliminating the need to trip the entire drill string for each core. A new section of inner core barrel is pumped down the drill string and latched into place for additional coring, or a drill plug is pumped down to facilitate drilling ahead.

Wireline-retrieval coring tools are usually smaller and lighter than conventional coring systems. This is an asset when they must be transported to remote locations or by helicopter. Unfortunately, the core diameters are limited since the entire inner core barrel assembly must pass through the drill string. Also, care must be taken to prevent “swabbing” oil or gas into the wellbore as the inner barrel is recovered.

## 1.5 WIRELINE SIDEWALL CORING

### 1.5.1 General

Wireline sidewall coring systems were developed to obtain core samples from a wellbore after it has been drilled and logged, and before casing is run. These tools may be positioned in zones of interest using data from gamma or spontaneous potential logs as guides. The samples provide small pieces of formation material, suitable for geologic and engineering studies.

### 1.5.2 Percussion Sidewall Coring

Most wireline sidewall cores are obtained by percussion sidewall coring systems. These tools shoot hollow, retrievable, cylindrical bullets into the wall of an uncased hole. The tool (gun) is lowered to the desired depth on a wireline, and then fired by electrical impulses controlled from the surface. The bullets remain connected to the gun by wires, and movement of the gun pulls the bullets, containing the samples, from the hole wall. Up to 66 samples, 1 inch (25.4 millimeters) in diameter by 1¾ inches (44.5 millimeters) in length, may be taken during one downhole trip. Different bullet “core barrel” designs are available for unconsolidated, soft, and medium-to-hard formations. It is wise to have more than one type of core barrel on location until acceptable core recovery can be shown.

The advantages of percussion sidewall coring are speed, low cost, and the ability to sample zones of interest after open hole logs have been run. The disadvantage is that the bullet usually alters the formation, shattering harder rock or compressing softer sediments. This reduces the quantitative value of the sidewall core analysis data. Percussion sidewall coring

recovery tends to be low in very hard or fractured rock, and in very permeable unconsolidated sand.

### 1.5.3 Drilled Sidewall Coring

The rotary or drilled sidewall coring tool was developed to recover wireline sidewall core samples without the shattering impact of the percussion system. Suitable for hard-to-friable rock, the rotary sidewall coring tool uses a diamond-tipped drill to cut individual samples. Leverage applied to the drill snaps the sample from the sidewall. The drill and sample are retracted into the body of the tool where the sample is deposited. The tool is moved to a new location after depositing each sample. A maximum of 30 samples,  $1\frac{5}{16}$ -inch (23.9 millimeter) diameter by  $1\frac{3}{4}$ -inch (44.5-millimeter) length, may be taken during one trip.

An advantage of the rotary sidewall coring system is that it produces samples of hard rock suitable for quantitative core analysis. Disadvantages are that it is more expensive than percussion sidewall coring in terms of rig time costs, and sample recovery tends to be low in unconsolidated formations.

### 1.5.4 Sidewall Coring Systems

Some new sidewall coring systems are coming on the market, and they merit discussion for two reasons. First, they are designed to acquire a larger, more-continuous core sample from a drilled and logged wellbore than is possible with existing sidewall coring tools. Secondly, the emergence of new tools confirms there is still room for improvement in the area of acquiring high quality, low cost core samples.

The first system is similar to a conventional core barrel. The sidewall coring system is designed to cut up to 10 feet (3.05 meters) of  $2\frac{1}{2}$ -inch (63.5-millimeter) diameter core. The tool is attached to a conventional drill string and lowered to the zone of interest. There an integral arm pushes the core barrel against one side of the wellbore. From then on the tool is operated as a conventional core barrel. The second system uses a removable whipstock to direct a conventional core barrel out into the formation. Both systems address the need to acquire quality core samples after logging.

## 1.6 ORIENTED CORING

### 1.6.1 General

Oriented cores are used to orient fractures, stress fields, and permeability trends. Exploration, production, and drilling operations use the information to explore for fractured reservoirs, design waterfloods, and plan horizontal wells.

Oriented cores are typically cut using a conventional core barrel fitted with a special scribe shoe, and a device for recording the orientation of the primary scribe knife relative to magnetic north. Laboratory methods used to orient cores are correlation of the core with borehole imaging logs and the paleomagnetic method. Table 1-3 lists methods commonly used to orient cores.

Table 1-3—Core Orientation Methods

| Method               | Location   | Comments                                             |
|----------------------|------------|------------------------------------------------------|
| Multishot survey     | Well       | Must stop drilling to take reading.                  |
| Electronic survey    | Well       | Records orientation versus time.                     |
| Paleomagnetic method | Laboratory | Orients one continuous interval.                     |
| Log correlations     | Laboratory | Requires correlatable features in core and wellbore. |

## 1.7 CORING BITS

### 1.7.1 General

Coring bits are a basic part of the coring system. Unfortunately for the experts and novices alike, coring bits come in a bewildering array of styles. Fortunately, general bit/formation guidelines are available from manufacturers to aid in selection of the proper bit. With a little background information, it is possible to make informed decisions on cutter types, bit profile, and hydraulic considerations for the range of anticipated coring conditions. Final bit selection should be guided by the goals of the coring program, coupled with a confirmation that the bit has proven itself in the field for similar applications.

The hardness (compressive strength), abrasivity, and variability of the rocks to be cored will have the greatest influence on cutter selection. General guidelines suggest use of smaller, more impact-resistant cutters as the formations get harder.

Low-invasion, face-discharge core bits designed for unconsolidated-to-medium strength formations can be used in harder or more abrasive rocks, but bit life may be drastically reduced.

The information presented in Table 1-4 provides an overview of the types of coring bits that are available. Specific details on coring bits and recommendations for particular applications should be obtained from service companies.

### 1.7.2 Natural Diamond Bits

Natural diamond core bits are used when the formation is too hard (high compressive strength) and/or abrasive for other type cutting elements. Large natural diamonds can be surface-set in a tungsten carbide matrix, or fine diamond chips can be dispersed in matrix to form what is called an impregnated diamond bit. Impregnated natural diamond bits are for ultra-hard formation applications.

### 1.7.3 Polycrystalline Diamond Compact—PDC

Polycrystalline diamond compact (PDC) cutters are man-made diamond materials that consist of a layer of micron sized diamond grit sintered together and bonded to tungsten carbide studs. The thickness of the polycrystalline diamond layer is only 0.020 to 0.060 inches (.51 to 1.52 millimeters). PDC bits are used to efficiently core formations ranging from

Table 1-4—General Coring Bit Guide

| Rock Properties                          | Rock Type                      | Core Bit                                     |
|------------------------------------------|--------------------------------|----------------------------------------------|
| Ultra-hard, abrasive rock                | Quartzite, Igneous Rocks       | Impregnated natural diamond.                 |
| Hard, abrasive rock                      | Sandstone, Shale, Siltstone    | Natural diamonds surface set or TSP cutters. |
| Hard, non-abrasive rock                  | Limestone, Dolomite, Anhydrite | TSP cutters.                                 |
| Medium to hard rock with abrasive layers | Sandstone, Limestone, Shale    | TSP or surface set natural diamonds.         |
| Soft to medium strength rock             | Sandstone, Chalk, Shale        | PDC cutters, low fluid invasion design.      |
| Soft rocks, no sticky layers             | Salt, Anhydrite, Shale         | PDC or roller cone cutters.                  |
| Soft, sticky rock                        | Gumbo Clay                     | PDC cutters, face discharge.                 |

very soft to medium hard. The bits are designed to cut by shearing resulting in a rapid rate of penetration. Due to the geometry of the PDC cutter, they are susceptible to impact damage, and therefore, are not recommended for very hard, highly fractured, or cherty formations.

### 1.7.4 Thermally Stable Diamond—TSP

Thermally stable (diamond) product, TSP, is similar to PDC in that it is also a man-made diamond material. The main difference in the TSP material is that it has a higher range of thermal stability due to the leaching of the metal catalyst used in the sintering process of manufacture. These cutters are suitable for formations generally considered too hard and/or abrasive for PDC cutters. They are not recommended for soft formations.

### 1.7.5 Roller Cone

The roller cone core bit uses four rotating cones set with tungsten carbide inserts or hard-faced milled-tooth cutters for coring purposes. The cutters in the cones roll and impact the hole bottom and fail the formation in compression by a chipping action. Due to the slow cutting action (chipping-compressive failure) and the number of moving parts, roller cone core bits are not commonly used.

## 1.8 FLUID DISCHARGE CHARACTERISTIC OF CORE BITS

### 1.8.1 Throat Discharge

Throat discharge core bits are designed to have 100 percent of the fluid pass between the core shoe and the inside diameter of the core bit (the “throat”). Throat discharge bits are designed to clean the inside diameter of the core bit, removing cuttings from this area to ensure a very smooth entry of the core into the core barrel. The cleaning action reduces the tendency of hard and/or brittle formations to jam.

### 1.8.2 Face Discharge

Face discharge core bits are designed to divert some fluid that would normally pass through the throat of the bit to the face of the bit. This cleans the face of the bit and reduces the

amount of fluid scouring the core as it enters the core barrel. Face discharge bits are recommended for use in soft and friable formations.

### 1.8.3 Low-Invasion Profile

The low-invasion profile coring bits are designed to maximize penetration rate, and minimize drilling fluid filtrate invasion into the core. The design incorporates face discharge ports, a reduced number of cutters, and a diminished clearance between the inner core barrel and the bit face. Use of low-invasion profile core bits is recommended for soft to medium strength formations. Harder formations would slow the rate of penetration and possibly damage the cutters.

## 1.9 CORE CATCHERS

### 1.9.1 General

The single most critical part of every coring system is the core catcher that holds the core in the barrel as it is brought to the surface. Table 1-5 lists the core catchers available and suggests those most appropriate for specific rock types.

Many situations call for combining two or more catchers to ensure success. Sequences of friable sand interbedded with shale might require both slip and flapper type catchers. Full-closure catchers, run primarily to ensure success when coring unconsolidated sand, also incorporate split-ring or slip-type catchers to improve core recovery in case coring ends in hard rock.

Table 1-5—Core Catchers

| Type               | Recommended Usage                                                                      |
|--------------------|----------------------------------------------------------------------------------------|
| Split-ring, spring | Consolidated formations.                                                               |
| Collet             | Where formation characteristics are unknown.                                           |
| Slip               | Consolidated formations, normally run with flapper catcher or with orientation knives. |
| Dog or flapper     | Consolidated, fractured, and unconsolidated formations where geology is unknown.       |
| Basket             | Unconsolidated formations, normally run with another core catcher type.                |
| Full closure       | Friable to unconsolidated formations to provide positive full closure.                 |



## **SECTION 2—WELLSITE CORE HANDLING PROCEDURES AND PRESERVATION**



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## Recommended Practices For Core Analysis

### 2 Wellsite Core Handling Procedures and Preservation

#### 2.1 GENERAL

**2.1.1** The recommendations included in this document may involve the use of hazardous materials, operations, and equipment. This document does not address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

**2.1.2** Wellsite core handling procedures and preservation should follow the best possible practices because the value of all core analysis is limited by this initial operation. The objectives of a core handling program are as follows:

- a. Obtain rock material that is representative of the formation.
- b. Minimize physical alteration of the rock material during core handling and storage.

The major problems confronting those handling and preserving reservoir rocks for core analysis are as follows:

- a. Selection of a nonreactive preservation material and a method to prevent fluid loss or the adsorption of contaminants.
- b. Application of appropriate core handling and preservation methods based upon rock type, degree of consolidation, and fluid type.

Different rock types may require additional precautions in obtaining representative core data (see 2.4). All core material should be preserved at the wellsite as soon as possible after retrieval to minimize exposure to atmospheric conditions.

**2.1.3** The terminology that has evolved to describe the state of core preservation is important historically, but may be confusing because it is sometimes not used consistently. For example, the term “native state” has been often used to designate core drilled with oil-based mud or lease crude for the purpose of making accurate water saturation measurements. Similarly, “fresh state” has often been used to imply that core was drilled with bland, water-based drilling fluid and preserved at the wellsite to limit evaporative losses. This term has also been used to include cores cut with oil-based mud. In the interests of consistency, the following terminology is recommended:

**2.1.3.1 fresh core:** Any newly recovered core material preserved as quickly as possible at the wellsite to prevent evaporative losses and exposure to oxygen. The fluid type used for coring should be noted, e.g., fresh state (oil-based drilling fluid), fresh state (water-based drilling fluid).

**2.1.3.2 preserved core:** Similar to fresh core, but some period of storage is implied. Preserved core is protected from alteration by any of a number of techniques (see 2.5).

**2.1.3.3 cleaned core:** Core from which the fluids have been removed by solvents. The cleaning process (sequence of solvents, temperature, etc.) should be specified.

**2.1.3.4 restored-state core:** Core that has been cleaned, then reexposed to reservoir fluids with the intention of reestablishing the reservoir wettability condition. This is often the only alternative available, but there is no guarantee that reservoir wettability is restored. The conditions of exposure to the crude oil, especially initial water saturation, temperature and time, can all affect the ultimate wettability.

**2.1.3.5 pressure-retained core:** material that has been kept, so far as possible, at the pressure of the reservoir in order to avoid change in the fluid saturations during the recovery process.

None of these terms alone adequately describes the state of the core; a full description of drilling mud, handling, preservation, and subsequent treatment is required.

**2.1.4** For testing, the core must be sampled. In order to obtain a representative core analysis from the formation(s) of interest, it is recommended that the entire core be sampled. The entire core section should be retained. Wellsite core sampling can be important for a variety of reasons (see 2.3.1). If sampling of the core is required, it should be performed with an awareness that the sampling procedure may impact future core analysis efforts and results. Wellsite sampling must be minimal to maintain the integrity of the core. Samples for lithology description, for example, can be taken from small broken pieces of core without damaging any of the intact rock. If intact, measurable lengths of core are removed, a note or block should be left in their place describing the sample length, lithology, the reason for removal, and any other pertinent information. If samples are required from within an intact core segment, a non-percussive sampling method should be employed. The objective of a standard core-sampling procedure is to obtain samples under a uniform procedure so that the results will be independent of human bias. The selection of samples is fairly simple for uniform formations. However, where a formation contains widely varying lithology and heterogeneous porosity types (such as conglomerates, cherts, vugular or fractured reservoirs, and inter-laminated shales and sands), the proper selection of representative samples requires greater care. A qualified person (engineer, geologist, etc.) should follow an established sampling procedure to minimize statistical bias.

**2.1.5** The prescribed core handling and preservation procedures are applicable to all conventionally cored rock material. Many of the same practices apply to sidewall cores and drill cuttings. These recommended procedures have been selected as those which will yield core materials for the most reliable and representative core analysis. The success of any given technique is directly related to the rock properties of the core. Handling procedures should also be based on the technology used to retrieve the rock material and the objectives of the coring program. A review of core preservation materials is also presented. Each coring job and reservoir should be carefully examined prior to the design of a wellsite handling and preservation program.

## 2.2 CORE HANDLING PROCEDURES

### 2.2.1 General

Several methods are available for core acquisition. Conventional, full-diameter, continuous coring techniques can be divided into two groups; those that employ a standard reusable steel inner barrel, and those that utilize disposable inner barrels or liners. Other coring methods such as the sidewall devices and wireline-retrieved coring apparatus obtain rock material using special equipment. Special coring processes, including pressure-retained and sponge methods, are available to obtain core and fluid analysis results more representative of in situ conditions.

Consolidated core material obtained with a standard reusable inner barrel should be removed from the barrel as soon as possible after reaching the surface to minimize drilling fluid imbibition. Among the possible undesirable effects of fluid imbibition are as follows:

- a. Changes in fluid saturations, geochemical and gas solution equilibrium.
- b. Changes in wettability.
- c. Mobilization of interstitial clays and fine-grained minerals.
- d. Clay swelling and associated degradation of mechanical properties.

Any delay in removal of the core from the barrel should be reported. Various rock types and coring methods require varying levels of attention and can be broken into two major categories:

- a. Basic handling—This category requires minimum training and/or experience and includes:
  1. Standard reusable steel inner barrel used to obtain core on fairly homogeneous consolidated rock.
  2. Wireline sidewall core acquisition from percussion or rotary coring.
- b. Special handling—This category requires extensive training and/or equipment and includes:

1. Disposable inner barrels and oriented core barrels used to obtain core from fractured or unconsolidated rock that may require mechanical stabilization (Skopec, et al., 1992).
2. Pressure-retained core barrel to maintain core at reservoir pressure to minimize fluid expansion from pressure reduction and fluid expulsion as the core is brought to the surface (Sattler, et al., 1988).
3. Aluminum core barrel with sponge liner inside a standard steel inner barrel to trap fluids during expansion from pressure reduction as the core is brought to the surface (Park, 1983).

The use of any core inner barrel liner reduces the diameter of the resultant core.

### 2.2.2 Removal of the Core From a Standard Reusable Steel Inner Barrel

The core should be removed from the inner core barrel in a horizontal position whenever possible. Care should be exercised to minimize the mechanical shock during extraction. The core should be allowed to slide out of the core barrel by slightly elevating the top end of the core barrel. If the core will not slide a rod may be used to push the core from the barrel. It may be necessary to gently tap the core barrel with a hammer to initiate movement of the core. However, do not hammer the core barrel in a manner that imparts severe mechanical shock to the core. In all physical manipulations, attempt to expose the core to the minimum mechanical stress. If the core cannot be removed by the foregoing method, it should be pumped out of the barrel with a fluid. If this is necessary, a suitable piston arrangement should be used that will prevent fluids from directly contacting and contaminating the core. The coring fluid should be used if pumping directly with fluids is necessary. The use of fresh water or other fluids foreign to the core should be avoided. If water is forced past the piston and contacts the core, erroneously high water saturation values may be obtained in subsequent core analysis as any excessive pressuring of the barrel may cause fluid to penetrate the core. Any difficulty or irregularity encountered while removing the core from the barrel should be noted, e.g., pressure used if pumped out with fluid, loss of core material, etc.

### 2.2.3 Labeling and Logging of the Core

The core should be laid out and boxed on the rig floor if space is available. Alternatively, the pipe rack can be used for this purpose. The labeling and logging of the core should not interfere with the drilling and/or coring operation. If the decision is made to handle the core on the rig floor, place appropriately marked trays, boxes, or troughs near the core barrel. If the core is to be laid out on the catwalk, prepare a cleared area and place the core between two lengths of drill pipe.

Care must be taken to maintain the orientation, and to preserve the correct sequence of the core pieces. The key point is

that the core must be labeled and marked in such a way that the entire cored interval can be reassembled at some future time. The core should be protected from temperature extremes, moisture, and dehydration, i.e., direct sunlight, hot engines, rain, strong wind, and low relative humidity. Core preservation materials and equipment should be close to the core handling area to facilitate a rapid operation. Accurate measurements of recovery must be made and recorded. Any recovery in excess of the core cut should be reported, as well as nonrecovery. Assign nonrecovery and overrecovery to the bottom of each core, unless some special observation indicates that an exception should be made. All such exceptions should be noted. The following data and observations may be helpful in determining the origin of overrecovery and nonrecovery:

- Drilling parameters—drilling time, torque, rate of penetration, pump pressure, etc.
- General conditions of the core—continuity, broken sections, induced fractures, etc.
- Condition of the bottomhole coring assembly.

Label the core depths from top to bottom and assign overrecovery and underrecovery to the bottom. The top of the next core should be given the drilled depth. This means that in the case of overrecovery there will be the same depth in two cores. However, these cores will be distinguishable from each other because of their core numbers. Core depths must be adjusted to log depths before correlations can be made between log properties and core properties and between cored and uncored wells. Core-to-log adjustment can be made using detailed core descriptions or core scans.

It is recommended that all core barrels be laid down on the catwalk or rig floor before removal of core. The following guidelines are appropriate for laying out and marking the core:

- The bottom of the core comes out of the barrel first and the first piece of core should be placed at the bottom of tray, box, or trough, with each succeeding piece being placed closer to the top.
- Caution must be exercised in maintaining the proper sequence and core orientation to ensure that individual core segments are not out of place or turned upside down. Any portion of the core that is badly broken should be put in thick plastic bags and placed in its proper position.
- Fit the core together so that the irregular ends match, then measure total recovery.
- Do not wash the core (see 2.4, 3.5, and 3.6). If excess drilling fluid is on the core surface, it may be wiped off with a clean drilling fluid saturated cloth and wrung out as often as needed.
- With red and black indelible markers, taped together, stripe the core from top to bottom with parallel lines (see Figure 2-1). The red line should be on the right as the individual performing the marking is facing from the bottom of the core towards the top. Arrows pointing toward the top of the core should be used to avoid confusion.
- With an indelible marker or paint stick, starting from the top, draw a line across the core at each foot and label each line with appropriate depth.
- To obtain reliable core analysis, speed is essential in removing, laying out, labeling, and preserving the core to minimize any alteration due to exposure (see 2.5).
- The core should be preserved (see 2.5) and placed in numbered containers for transportation to the laboratory. It is recommended that the entire core interval be preserved at the wellsite, with sampling being reserved for the controlled conditions at the laboratory.

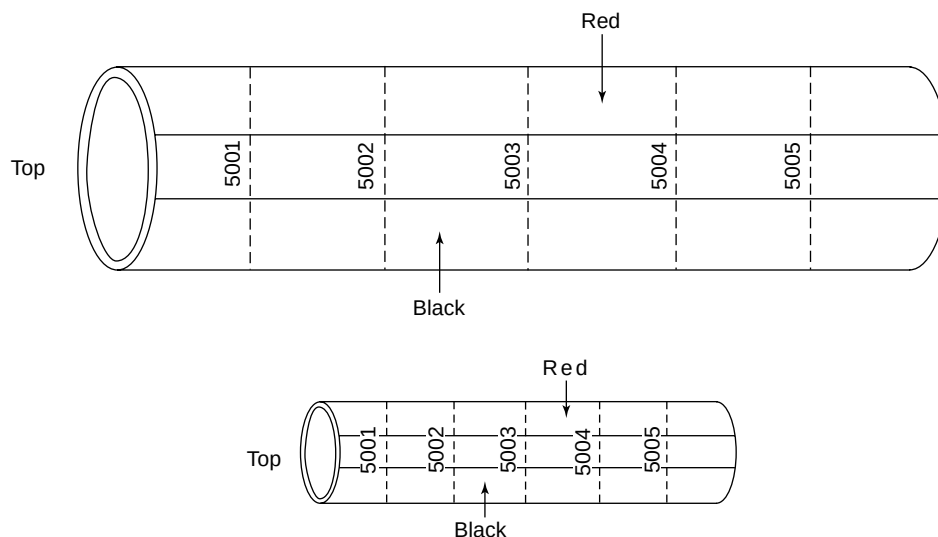


Figure 2-1—Core Marking

Even a few minutes exposure, depending on atmospheric conditions, can cause a significant loss of both water and light hydrocarbon fractions from cores. If the core is accidentally washed with water, allowed to remain in the core barrel, or let stand before preservation, then this information should be noted.

## 2.2.4 Handling Liners and Disposable Inner Barrels

Inner core barrel liners and disposable inner barrels improve the recovery of poorly consolidated or fractured formations. They are made of plastic, fiberglass, or aluminum and are rated to various temperatures. When coring unconsolidated or poorly consolidated formations, select the liner or disposable barrel to withstand the circulating temperature. Hard beds such as shale are best cored using either fiberglass or aluminum to prevent jamming and consequently poor core recovery. Certain coring fluid additives such as caustic react with aluminum barrels causing release of aluminum ions, that may react with the core to alter its surface properties.

When coring a poorly consolidated formation, to avoid rock compaction it is advisable to cut short lengths, 30 feet or less depending upon the rock strength. In long lengths, the lower section of core may be over compacted and damaged by the weight of the overlying material. Damaged core is of limited use for core analysis. When coring fractured formations, short core lengths may also be beneficial to decrease the risk of jamming.

The core barrel should be brought to the surface smoothly. During the last five hundred feet the core should be surfaced slowly to minimize gas expansion that can severely damage unconsolidated core if the pressure is reduced too quickly. Where gas expansion damage is expected, a perforated liner or a perforated disposable inner barrel can be used to provide a means for gas escape. All perforations must be sealed if the liner or disposable inner barrel is used as a core preservation container. Alternatively, the entire perforated section can be placed in plastic bags to prevent fluid loss.

A core-filled liner can be lowered to the catwalk, within the metal inner core barrel, using a system of pulleys anchored to the end of the catwalk. The barrel should not be banged on the rig and should be lowered gently onto the catwalk. Core-filled inner barrels flex, particularly those made of fiberglass or plastic, and should be supported by a splint. The splint should be attached to the inner barrel while it is hanging in the derrick.

- a. Wedge the core barrel to prevent rotation and remove the core catcher. Transfer the core catcher material to a suitable length of liner or disposable inner barrel. The core catcher material is generally too disturbed to be used for quantitative core analysis.
- b. A catwalk extension can be used to remove the entire core-filled liner from the inner barrel without flexing.

1. If the entire liner is removed or if handling a disposable inner barrel, feel inside and locate the top of the core. Cut the liner at this point. Label the core with orientation lines (red on the right and black on the left), depths, and other identification (see 2.2.3). Label depths every foot starting from the top.

2. (Preferred Method) If there is no room to remove the entire liner, pull out a little over 3 feet (0.91 meter) at a time using adequate support to prevent it from flexing. Label each 3-foot (0.91-meter) length with orientation lines and with a number to represent its position in the sequence of cut lengths. Label depths on the 3-foot (0.91-meter) lengths once the entire recovered interval is processed and the top of the core is located.

- c. Cut the liners and core into 3-foot (0.91-meter) lengths using an air or electric powered circular saw. Fiberglass and aluminum liners should be cut using a mounted circular saw. Be careful to avoid vibration and rotation of the core. Clamps on the core barrel should be used with caution to avoid damaging the rock. Alternatively, the entire 30-foot (9.1-meter) length of core can be capped and shipped with a splint attached to the liner or inner barrel to prevent it from flexing. The core can then be cut in the laboratory to any specified length. This minimizes the handling of the core at the wellsite; however, preservation, sampling, and shipping procedures become more difficult.

- d. Physically stabilize the 3-foot (0.91-meter) lengths using a nonreactive casting material (e.g., epoxy) to fill the annular space between the core and liner. Alternatively, the annulus can be filled with a nonreactive fluid in order to prevent evaporation. As a minimum precaution, the 3-foot (0.91-meter) lengths should be sealed with standard end caps.

- e. Transfer the lengths to labeled boxes and cushion them for the trip to the laboratory. Use screws to attach wood lids to wood core boxes to avoid core damage caused by hammering.

## 2.2.5 Pressure-Retained Core

Pressure retaining core barrels are designed to obtain the best possible in situ fluid saturation. This method of coring offers an alternative to the conventional core barrel that loses pressure upon its retrieval to the surface. To enable the fluid saturations to be measured in the laboratory, the core must go through extensive handling. The core barrel assembly is placed in a special core service unit and the drilling fluid is flushed from the annulus between the inner and outer barrel using a nonreactive fluid while maintaining proper back pressure on the entire system. The entire core barrel assembly is then placed in a freezer box filled with dry ice (see 2.5.2.2).

To this point in the handling of a pressure-retained core, the work should be performed by trained service company personnel to their specifications.



The following procedures performed on frozen cores should be supervised by the operating company:

- a. Remove the pressure-retained inner barrel from the ice, place in a safety shroud, and cut to the desired lengths.
- b. Place each section back on ice, as it is cut. Take care to ensure that sections are laid down in such a way that top and bottom and position in the core section can be clearly identified. (see 2.2.3).
- c. Raise one end of the core section at a time and place core cap with label on each end, securing with a hose clamp (see 2.2.4).
- d. The labels should be marked with the company's name, recovered pressure, legal location, depth range of core, and processed core depth.
- e. Place processed core sections in insulated shipping boxes and pack with dry ice. Mark the box with core numbers and depths along with company, location, and shipping information. If insulated shipping boxes are in transit for more than 24 hours, additional dry ice may be required.

## 2.2.6 Sponge Core

The sponge coring assembly is designed to improve the measurement of reservoir fluid saturations. As the core is brought to the surface, fluid that would otherwise be lost by expulsion because of pressure reduction is trapped by an absorbent polyurethane sponge surrounding the core. The coring assembly consists of 6 pre-cut 5-foot (1.52-meter) lengths of aluminum liner run within a standard steel inner barrel. The sponge core is, for the most part, then handled according to procedures established in 2.2.4. In most cases, the liner must be pumped from the coring assembly. The pre-cut liner is stored and preserved in PVC shipping tubes filled with a suitable nonreactive fluid. The PVC shipping tube is sealed with one rigid and one rubber gas expansion end cap. For orientation purposes, each sponge liner section is beveled on one end.

Once the sponge core arrives at the laboratory, it is milled open and both the core and sponge are extracted of all reservoir fluids (see 4.3.4).

## 2.2.7 Wireline Sidewall Coring

Wireline sidewall cores are extracted from the formation by a variety of means. Percussion sidewall coring involves the use of an explosive charge that propels a hollow projectile into the formation. Because of the forces produced by the entry of the percussion core bullet into the formation, compaction, fracturing, and rearrangement of rock grains occur; great care must be exercised when handling this core material.

Alternatively, wireline sidewall cores may be mechanically drilled from the formation with a rotary bit. Damage is minimized with this technique; however, this method is not feasible in all types of rock. If the sample breaks during removal

from the coring tool, it should be pieced together and any damage should be noted. Other sidewall sampling devices involving the use of pressure-actuated coring receptacle samplers are also available.

When using sidewall coring techniques, fragile samples should be placed in plastic or glass jars with metal lids. Paper or other materials capable of absorbing liquids should not be placed in jars to act as sample cushioning material. Heat-sealable plastic laminates are an acceptable preservation technique for the drilled sidewall samples. All samples should be stabilized and cushioned during transport to the laboratory (see 2.5.2.1) and be accurately labeled (see 2.2.3).

## 2.2.8 Wireline-Retrieved Continuous Coring

In wireline-retrieved continuous (WRC) coring operations, the core barrel is recovered while the drill string remains in the borehole. Trip time is reduced and consequently the method can be less expensive than conventional coring. Typically, long vertical intervals are cored continuously, and certain wells may be cored from surface to total depth.

### 2.2.8.1 Depth Marking of WRC Cores

Good communication between the wellsite core retrieval personnel and the driller is necessary for accurate depth marking of WRC core. In conventional coring, the driller provides the top and bottom depths of the cored interval. This may cause some confusion in assigning core depths, because conventional cores are referenced from the top of the cored interval. Because WRC coring is continuous, it is best to use the bottom of the previous coring run as the top of the subsequent run. Monitoring for possible fillup between runs is suggested to minimize errors from this cause. Maintaining sound core accounting procedures in the form of a realtime spreadsheet should minimize the potential for errors in determining the top of the next interval. The spreadsheet information should include core run number, top of cored interval, bottom of cored interval, percent recovery, and a column noting the point from which core marking started.

All WRC core should be marked and labeled in accordance with 2.2.3, except assignment of depth should be modified in accordance with the following procedures. The conventional procedures for assigning core depths are not always appropriate for WRC core. In WRC coring, core dropped in one coring run may be retrieved in the next coring run, so the true depth of the current core may be in the previously cored interval. The retrieval of "dropped core" also means that the volume of overrecovered core is larger than is commonly encountered in conventional coring. Given the larger volumes of core involved, it is more important to use a core marking procedure that avoids assigning the same depth to more than one piece of core. If overrecovery occurs, the core depth marking can start with the bottom of the core, with the depth of that piece of the core being assigned the bottom reported

by the driller. Core marking should then move from bottom to top. If 100 percent or greater recovery was also obtained in the previous coring run, depth assignments should follow conventional procedures, with the depth marking beginning at the top.

For underrecovery, the following equation should be used to account for missing core:

$$\begin{aligned}\text{Missing core} &= \text{Depth Drilled} - \text{Core Length} \\ &= [CDD - PDD] - [CBL + PC - VOID]\end{aligned}\quad (1)$$

Where:

- MC* = missing core length, feet (meters).
- CDD* = current driller's depth, feet (meters).
- PDD* = previous driller's depth, feet (meters).
- CBL* = core barrel length, feet (meters).
- PC* = protruding core, feet (meters).
- VOID* = void in core barrel, feet (meters).

In underrecovery, the core depths should be labeled from top to bottom, assigning underrecovery to the bottom of the cored interval.

### 2.2.8.2 Alternate Method for Depth Marking of WRC Cores

An alternate to the method discussed in 2.2.8.1 is to assign depths in the same manner as conventional cores (see 2.2.3). As for conventional cores, there may be underrecovery or overrecovery. Starting at the top, mark the core with depth marks every foot through to the end of the core. No attempt should be made to resolve underrecovery or overrecovery intervals before core-to-log adjustment. If depths are consistently marked from the top of each core run and each core run has a unique number, there may be the same "depth" in two consecutive cores, but they will be distinguished by their core run number. If an attempt is made to adjust for overrecovery at the wellsite, this can result in tremendous confusion with cores relabeled multiple times.

### 2.2.8.3 Washing of WRC Cores

As for conventional coring, care should be exercised to avoid damaging the rock; e.g., by washing it with inappropriate fluid(s). If there is any ambiguity about damaging effects, err on the side of caution, for example, by avoiding washing the core.

### 2.2.8.4 Analysis of WRC Cores

The extent to which the WRC core is analyzed varies from operator to operator. The core analysis procedures for WRC cores differ significantly from those used for conventional cores. In conventional coring operations, the core is returned to a laboratory for analysis and, at some future time, the core analysis results are adjusted to downhole log depths. With WRC core, much of the analysis is performed in the field, and

in some cases, the core may never be archived. Typically, a wellsite geologist should describe the section with sufficient lithological detail to enable core-to-log adjustment and correlation. The geologist should note the hydrocarbon shows, porous intervals, and facies changes. Some operators use mobile laboratories through which they perform fairly sophisticated analyses of the WRC core, including core gamma scanning, ultraviolet photography, gas chromatography, and measurements of porosity, density, magnetic susceptibility, mineralogy, and acoustic properties.

### 2.2.9 Oriented Core Barrel

Orientation of the core barrel is accomplished using electronic, multi-shot instruments and specialized core scribing equipment. Alternatively, paleomagnetic rock signature can be used for core orientation purposes. Strict handling procedures must be followed to ensure that orientation data are positively depth correlated and matched to the proper piece of core material. This is particularly critical in fractured rock units where disposable inner barrels and liners are commonly used.

## 2.3 FIELD SAMPLING AND ANALYSIS

### 2.3.1 General

In general, sampling of recovered core material at the wellsite is not recommended. If it is necessary to sample immediately, precautions must be taken to minimize the exposure time of the core. Sampling should be quick, efficient, and performed in accordance with sound safety practices. Always obtain samples using the least damaging or contaminating method available. The entire core should be saved in all cases.

Specific reasons for wellsite sampling include, but are not limited to, a) chip sampling for lithologic description and/or mineralogical determination, b) measurement of basic rock properties, c) fluid compatibility-completion testing, d) wettability studies, e) observation of oil fluorescence/cut, f) anelastic strain recovery measurements, and g) methane desorption studies for the analysis of coal. All sections removed from the cored interval should be recorded on the field data sheet (see 2.3.3) and physically represented in continuous core sections using rigid spacers. The removed sample should be preserved, labeled, and packaged in a manner consistent with the test desired. Any additional pertinent data should accompany the samples to the laboratory or be available for wellsite analysis. Other special wellsite core analysis techniques are feasible if adequate mobile facilities are available to run tests under controlled conditions.

Hammering can damage the core and may preclude core analysis. If possible, chip samples should be taken at naturally occurring breaks in the core or with a precision trim saw. The sample size should be kept to the minimum necessary to perform the desired analysis. Place samples in individual

bags and preserve the fluid saturation with a suitable preservation technique (see 2.5).

If a detailed core examination is to be made at the wellsite, sampling and core handling should be done quickly, and only if the examination is critical to the success of the well objective.

### 2.3.2 Transportation and Logistics

The transport method should be expedient and provide protection against damage from environmental changes, mechanical vibration, and mishandling. Other important factors to consider when choosing the mode of transport include, a) distance and remoteness from the wellsite to the laboratory, b) onshore or offshore conditions and terrain, c) core material competence, d) weather conditions, e) type of preservation or packaging, and f) cost.

In all cases, precautions must be taken to securely stabilize the core material. In air transport, the storage cabin may not be pressurized, and this can be a factor in the core preservation. Do not stack core in such a manner as to damage the core material. Commercial carriers unaccustomed to transporting fragile materials should be used with caution. For safety reasons, cores packed in dry ice may have to be treated as a “chemical” for transportation purposes.

In all methods of transportation, a transmittal letter or contents documentation form with pertinent shipping information should accompany the shipment. A separate copy of this letter should be sent to the recipient via surface mail or fax. All applicable U. S. Department of Transportation regulations should be followed in the shipment of core materials. When standard core boxes are used they can be palletized, banded, and shipped as is. Cores, particularly those of unconsolidated materials, may be frozen or refrigerated at the wellsite for preservation and stabilization during transportation and storage. If freezing is used, the core must be entirely frozen before shipment to avoid mechanical damage. Frozen core is usually crated in insulated containers and packed with dry ice. Refrigerated core is usually shipped in self-contained refrigerator units. A temperature monitoring and recording device should accompany the core to ensure the desired conditions are maintained during transportation (see 2.5.2.2).

### 2.3.3 Data Sheet

A suitable data sheet should be provided for and completed by the wellsite engineer or geologist, to supply as complete a record as possible of the conditions of coring. This information will be valuable in qualifying the interpretation of the core analysis data. Further, this record may suggest either that certain additional tests be run to supplement the basic tests, or that other tests would not yield significant data. This will result in the most useful analysis for the least time and cost. Figures 2-2 and 2-3 are example forms, and the use of these or similar forms is recommended.

It is important to have as much pertinent data as possible accompany the core material. The following is a list of desirable information:

- a. Well identification, API well number, elevation, vendor names and contacts, as well as telephone/telefax numbers and addresses.
- b. Drilling fluid type, contents, and measured data.
- c. Core type and equipment used.
- d. The formation(s) cored, with the top and bottom driller's depth.
- e. Designation of critical coring information and any pertinent coring notes, i.e., total coring/trip time, difficulties, and recovery.
- f. Formation water salinity and production fluid data.
- g. Preservation guidelines. Exposure time.
- h. Analysis requested.
- i. Coring log and drilling records.
- j. A core description.
- k. Well logs and mud logs (if available).

## 2.4 ROCK TYPES AND SPECIAL CONSIDERATIONS IN HANDLING

### 2.4.1 General

The term “rock type” is used to describe the major distinguishing feature(s) of core material. This can refer to the degree of consolidation, presence of fractures or vugs, composition (shale), or physical properties (e.g., low permeability) of the rock. Geological descriptions of rock are more complex and classification schemes have been devised to categorize specific rock types with respect to texture, type of cementation, grain size, etc. Many special considerations must be taken into account when designing a wellsite core handling program. Paragraphs 2.4.2 through 2.4.13 include general guidelines for various rock types.

### 2.4.2 Consolidated Rock

Consolidated rocks are hardened as a result of cementation. They need no special treatment at the wellsite. Cementation in rocks is defined as the process of precipitation of cementing materials around the solid grain surfaces. Rocks can be described as consolidated, poorly consolidated (friable), or unconsolidated, depending on the degree of compaction and cementation. Common consolidated rocks include limestone, dolomite, sandstone, and chert.

### 2.4.3 Unconsolidated Rock

Unconsolidated rocks have little or no cement and are essentially compacted sediments. Poorly consolidated rocks have minor cement but not enough to make them hard. These rocks are best cored using an inner core barrel liner or a disposable inner barrel (see 2.2.4). Care must be taken to prevent

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Full document details: API RP 40-1998

General Information

Analysis Requested

Date

M

M

D

D

Y

Y

API #

File #

Requested By:

☐ Full Diameter or ☐ Plug : Size

Units

Method

Special Instructions

☐ Saturation

☐ Porosity

☐ Permeability

☐ Other

Objective of the tests as agreed by parties involved

Transportation and Inventory

Carrier

Date Shipped

Core Arrival Date

Core condition on arrival:

☐ Preserved

☐ Frozen

☐ Unpreserved

☐ Cleaned

☐ Other

Correlation Depths: Driller's

Log

TVD

Units

Allocation of the missing cored interval:

☐ Bottom

☐ Middle

☐ Top

Screening

☐ CT

☐ X-ray

☐ NMR

☐ Fluroscopy

☐ Other

Sample Handling

Core Gramma (yes/no, type)

Lab Preservation (prior to analyses)

Sampling Method

Sample Sleeve

☐ Yes

☐ No, Type

Nominal Sample Diameter/Length

Units

Plugging/Trimming Fluid

Treatment prior to testing (flushing, evaluation, resaluration, etc.)

Core Disposition (removed samples, storage location, preservation, etc.)

Lab Analyst

Other Service

☐ Slab

☐ Resination

☐ Photo:

☐ BW

☐ Color

☐ U.V.

☐ Other

Supplementary Tests

Methods and Conditions

Cleaning:

Methods

Conditions

☐ No Cleaning

☐ Dean-Stark

☐ Soxhlet

☐ CO2/Solvent

☐ Flow Through

☐ Others

Solvents

Temperature

Pressure

Time

Volume and Rate

Others

Drying:

Methods

Conditions

☐ Convection oven

☐ Vacuum oven

☐ Humidity oven

☐ Others

Temperature

Time

Relative Humidity %

Porosity:

Methods

Grain Volume

Bulk Volume

☐ Boyle's Law

☐ Saturation

☐ Summation-Of-Fluids

☐ BV-GV

☐ Other

☐ Boyle's Law

☐ Archimedes

☐ BV-GV

☐ Other

☐ Caliper

☐ Archimedes

☐ Mercury Displacement

☐ GV+PV

☐ Other

Conditions/Fluids

Confining Stress (Magnitude and Type)

Units

Gas

Liquid

Pressure

Permeability:

Methods

Conditions

☐ Steady State

☐ Unsteady State

☐ Probe

☐ Empirical

☐ Not Measured

☐ Others

Fluid Type

Confining Stress

Sleeve Durometer

Pore Pressure

Klinkenberg:

☐ Measured

☐ Empirical

☐ No Correction

Inertial Factor:

☐ Measured

☐ Empirical

☐ No Correction

Saturation:

Methods

Conditions

☐ Distillation Extraction (DS)

☐ High Temperature Retort

☐ Others

Temperature

Fluids

Water Density

Oil Density

Correction for Salt:

☐ Corrected for Water Volume

☐ Corrected for Oil Weight

☐ Not Corrected

Quality Assurance: (Page number in report where the information is provided)

Comments/Remarks:

Data Anomalies:

Figure 2-3—Basic Core Analysis Laboratory Data

the core from disintegrating. This includes making sure the core is brought to the surface, laid down smoothly, and preserved in such a way that it will survive transportation (see 2.5.2).

#### 2.4.4 Unconsolidated Rock—Light Oil and Gas

It is critical to preserve unconsolidated cores containing light oil in an efficient and expedient manner. Any unnecessary movement of the core should be avoided. The two methods commonly used to preserve this rock type involve environmental methods, such as freezing or chilling and mechanical stabilization with epoxy, foam resin, etc. Unconsolidated core containing light oil is susceptible to significant fluid loss during handling at the surface. As with most rock types, by the time the core has been brought to the surface, it has undergone mechanical stress relief due to the removal of overburden pressure and has had varying amounts of gas expansion when internal pore pressure is lost. The degree to which these effects will alter the core depends on depth, reservoir pressure, oil gravity, fluid properties, sediment type, and coring procedures. Care must be taken to ensure that pressure does not build-up within the core barrel during handling. The inner core barrel liner or disposable inner barrel can be predrilled with holes [ $\frac{1}{8}$  inch (3.18 millimeter) diameter] to avoid pressure buildup. Cored intervals should be limited in length to prevent possible rock damage under its own weight. As the core is raised through the upper 500 feet (152 meters) of the well, the core barrel should be retrieved at a slow rate to minimize chances of disaggregating the rock and causing damage to the core. If freezing is used to stabilize unconsolidated materials, the core should not be transported before it is fully frozen, as partial freezing can cause structural damage to the core (see 2.5.2.2).

Filling the annulus between the disposable inner barrel or liner and core with coring fluid is recommended for stabilization when epoxy or a permanent setting material is not used; however, this procedure can alter rock fluid saturation and wetting characteristics. When epoxy, resin, or foam injection are used, the drilling fluid must be fully displaced or drained from the annulus. The casting material must completely conform to and encase the core surface.

#### 2.4.5 Unconsolidated Rock—Heavy Oil

The greatest difficulty in handling unconsolidated rocks that contain viscous heavy oil is prevention or minimization of delayed core expansion. The expansion is the result of slow gas evolution from the heavy oil, with no possibility of short-term drainage because of the low mobility of gas. Swelling of the rock may easily continue until the gas phase becomes continuous, and this may require volumetric expansion in excess of 6 percent to 8 percent. In liners, unconsolidated heavy oil sandstones will expand radially to fill empty annular space. Once the swollen core is tight in the liner, further

gas evolution may cause a piston action, causing core to extrude from the ends of the liner sections leading to overrecoveries as high as 5 percent. It is tempting to simply cut off the extruded core and discard it, but this must be avoided. Extruded material is kept at the liner end from which it came, the plastic end caps may aid in keeping it slightly retained.

Improving core quality in unconsolidated heavy oil sandstones requires the following considerations:

- Provide mechanical restraint to expansion.
- Provide a means to allow gas drainage.
- Provide mechanical strength to the core.

Item a involves use of liners that have an internal diameter only slightly larger [ $\frac{1}{8}$  inch (3.18 millimeters)] than the core bit, to reduce radial expansion. During handling and preservation, flexing of liners, heating of core, and prolonged exposure of liner ends must be avoided. Axial restraint will help reduce the tendency to extrude the core. This restraint may be provided in a number of ways, including:

- Rigid liner caps rather than rubber end caps, with the end caps stapled to the liner at a number of points, and secured with screw clamps.
- Cutting liner segments to precise lengths and placing in a strong core box so that the ends of the box provide axial restraint. Alternatively, cores can be wedged into the core boxes with pieces of wood planks cut to lengths.
- Special handling techniques devised by various operators may also be used, including special storage cylinders or axial retention methods.

Gas evolves slowly from heavy oil, and will continue for months. It is recommended that pre-perforated liners be used in all areas to shorten the gas flow path and eliminate piston effects. The pre-drilled holes [ $\frac{1}{8}$  inch (3.18 millimeter) diameter] should be spaced no further apart than the radius of the liner. Post-drilling of liners is not recommended as an acceptable alternative because it prolongs core handling and may lead to damage. If required, liner and core segments may be placed in cylinders and repressured with an inert gas ( $N_2$ ) to slow or stop gas evolution, and to avoid oxidation.

Freezing of unconsolidated heavy-oil core may be necessary, although in general, freezing is not well understood. Freezing has the following effects: a) it reduces gas evolution speed and volume, b) it enhances oil viscosity that restricts expansion, and c) it freezes interstitial water that gives the core some mechanical strength to restrict expansion and fracturing. Because the pore water is usually saline, the temperature will have to be reduced below  $-40^\circ\text{F}$  ( $-40^\circ\text{C}$ ) to ensure full mechanical benefits (see 2.5.2.2).

Core handling during transportation and storage for unconsolidated materials containing heavy oil must maintain the mechanical restraint and low temperature. When preparing core sections for analysis, the temperature should be allowed to rise slowly, so that evolved gas can dissipate; mechanical

restraint should be fully maintained until the core is equilibrated, a process that may take weeks because of the high oil viscosity and low relative permeability.

#### 2.4.6 Vuggy Carbonates

Large vugs can weaken the core material and cause difficulties with recovery. In many cases, core recovery is reduced in friable vuggy intervals. Standard consolidated core preservation methods should be used on this rock type (see 2.5).

#### 2.4.7 Evaporites

Salt rocks are generally quite competent, and, except for their solubility, may be considered as consolidated rocks. Core containing salts in continuous sequences or as vug and fracture fillings should not be washed with fresh water under any circumstances. Because the physical properties of salt rocks can be altered by small changes in moisture content, cores containing salts must be immediately wiped to a surface dry state and preserved. Transportation and storage of cores containing salts must always be undertaken keeping the soluble nature of the material in mind. Cores of evaporite, anhydrite, gypsum, or calcite present no special core handling problems.

#### 2.4.8 Fractured Rock

Many reservoir rocks are naturally fractured. Disposable inner barrels or liners made of aluminum or fiberglass are recommended for coring fractured rock (see 1.6 and 2.2.4). An oriented core can be useful in determining fracture strike and in situ stress direction (see 1.6 and 2.2.4).

#### 2.4.9 Rocks Rich in Clay Minerals

Clay minerals may be present in small quantities in rocks, yet have a major impact on rock properties. Some of the major concerns in rocks containing clay minerals include:

- The presence of smectite (a swelling clay mineral), even in very small quantities (1 percent), is of importance in core handling because of swelling potential, high cation exchange capacity, and osmotic suction potential.
- Interstitial clay minerals can be physically mobilized by changes in fluid content, chemistry, or mechanical disturbance, leading to pore throat blocking or changes in surface wetness characteristics of pores or other physical changes.
- Clay minerals in contact with their natural pore fluids are in thermodynamic equilibrium, and exposure to other fluids will alter this leading to changes in clay mineral activity, exchangeable cations, and consequent changes in mechanical and flow behavior.
- Smectitic shales and sandstones may swell when confining stress is removed if free water is available, even if the free water has properties identical to the interstitial fluids.

Any excess fluid or mud cake should be immediately wiped from cores of smectitic materials and clay mineral rich materials, followed by immediate preservation (see 2.5.2).

#### 2.4.10 Shale

In addition to the recommendations for clay mineral containing rocks (see 2.4.9), there are special issues relating to handling highly fissile shale. These materials have fissility planes of low strength that may split spontaneously, even if core is handled with great care. Once a fissile shale core has split, it may be impossible to obtain specimens large enough for core analysis.

It is recommended that fissile shale cores be handled in the following manner:

- Avoid excessive handling or movement of the core.
- Remove any excess water.
- Preserve immediately to stop desiccation.
- Masking tape or fiberglass packaging tape may be wrapped around core segments perpendicular to the fissility planes to reduce further splitting. Alternatively, heat-shrinkable plastics can be used.

Shales have low permeability and slow internal transfer of moisture will inevitably take place between beds of different mineralogy and fabric during long-term storage. If the core is totally unconstrained, this may result in delayed splitting even without desiccation or handling. Fissile shales are exceptionally sensitive to temperature changes, and should be maintained at a constant temperature during transportation and storage. Freezing of shales must not be allowed, since this leads to massive microfissuring and internal moisture movement.

Oil shales with organic chemical volumes in excess of 20 percent are sensitive to temperature and oxidation, and must be preserved with particular speed if detailed analysis is required. The much stronger matrix-supported oil shales are typically more quartzose and with organic chemical volumes less than 20 percent and in general do not require special handling.

#### 2.4.11 Low Permeability Rock

Evaporation of fluids, a problem with all core materials, is a particular difficulty in low permeability and low porosity core where the percentage change in saturation may be much greater for the same volume of fluid evaporated. The time period before core is protected from evaporation is critical for these samples. The presence of clay minerals may make damage by evaporation irreversible in some samples (see 2.4.9).

#### 2.4.12 Coal

In situ gas content, gas sorption behavior, permeability, relative permeability, cleat and fracture analysis, core composition

tion, and mechanical behavior are the major interests in coal analysis for coalbed methane production. Gas desorption studies may be performed at the wellsite with desorption canisters. Procedures for handling of coal core should include instructions for these special studies. Wireline retrieved core barrels, core barrels with disposable inner barrels or liners, and pressure-retained core barrels have been used to cut coal cores.

Gas content and gas desorption rate are commonly measured from coal by canister desorption methods using conventional cores, mechanically-drilled sidewall cores, wireline-retrieved continuous cores, or drill cuttings. Coal segments are sealed in a canister and isothermally maintained while the volume of gas evolved from the sample is measured. Gas content measurement by canister desorption requires an estimate of gas volume lost while bringing the core to the surface and before sealing the samples in the canister. Gas content must be normalized to a mineral free matter basis. Since the gas evolved will not be 100 percent methane, the composition of the gas must be analyzed.

Pressure-retained core technology, that does not require an estimate of lost gas, offers a more accurate means to determine the total in situ gas content of a coalbed. The volume of gas evolved from the coal core in the pressure barrel is measured as a function of time, temperature, and pressure. If pressure-retained methods for coring coal are used, a special internal temperature sensor is incorporated, and no coring fluid flushing is carried out (see 2.2.5). In one procedure, the entire pressure-retained barrel is returned to bottomhole temperature and allowed to equilibrate for up to several days before the pressure is allowed to dissipate and the device is disassembled. During the temperature and pressure dissipation phase, changes should be gradual to minimize both the magnitude of the pressure gradient and the temperature gradient. The former may cause the coal to fracture internally, whereas rapid cooling may cause tensile cracks to open in the outer part of the coal core. These may affect both permeability and mechanical behavior. Alternatively, the pressure-retained coal core can be cut into one foot sections and placed in desorption canisters for measurement of the gas content and gas desorption rate.

Coal core must be handled with care at the wellsite because of its heterogeneous nature, and because the methane found in small pores within the core is under pressure. Careless treatment, liner flexing, or a sharp blow to the core barrel may cause the core to fragment, rendering the core of little use for core analysis. The internal gas pressure may aid this tendency to deteriorate, and time is required to permit gas dissipation. Coring fluids in contact with coal intended for fluid flow or mechanical tests should not contain materials capable of altering the coal structure.

Fresh coal oxidizes when exposed to air, potentially changing its surface properties and sorption characteristics. Exposure time to air must be minimized, and special handling may

include canisters to receive coal core segments, followed by flushing of the cylinders with inert gas or methane.

White or yellow pens or paint crayons should be used to mark the surface of the core lengths. As with any core, preservation of moisture and minimization of exposure time is advised. Freezing of coal core is not recommended, nor is it considered necessary.

#### 2.4.13 Diatomite

Diatomites are generally high-porosity, low-permeability rocks composed of opaline-quartz phases with varying amounts of detrital material. Diatomites are cored with disposable inner barrels or liners (see 2.2.4).

Diatomite can be preserved by environmental means, wrapping, etc. Freezing of diatomite is not recommended. Temperature should be controlled to maintain a constant temperature [35 to 40°F (1.67 to 4.44°C)] during wellsite and transportation operations.

### 2.5 PRESERVATION OF CORES FOR ANALYSIS

#### 2.5.1 General

The preservation of a core is an attempt to maintain it, prior to analysis, in the same condition as existed upon its removal from the core barrel. In the process of cutting a core, recovering it, and bringing it to the surface, the fluid content of the rock is altered by unavoidable changes in pressure, temperature, etc. Pressure-retained core methods attempt to minimize these effects (see 2.2.5). Careless or incorrect practices in handling and preservation cause further alteration of the core and its fluids, thereby making the core even less representative of the formation.

Preservation and packaging of cores may vary depending upon the test(s) required, the length of time before testing, and the potential of performing wellsite tests. If the core samples are to be used to determine fluid saturation or for special core analysis, it is necessary that they be preserved for transportation to the laboratory. Evaporation and migration of fluids as well as oxidation within the sample must be avoided to obtain reliable core analysis. An additional objective of the preservation program is to prevent breakage of the cores during shipment and storage. Consolidated core may be durable enough not to require special handling procedures. However, special care should be taken with unconsolidated or fractured rock, etc. (see 2.4).

The use of unprotected glass jars, easily deformable plastics (if not properly stabilized), paper cartons, non-rigid containers, and air-tight cans are not recommended for core preservation purposes.

#### 2.5.2 Methods of Preserving Cores

There is no one best preservation method. Experience can help determine the most satisfactory method for the rock type

in question. The choice of method will depend on the composition, degree of consolidation, and distinguishing features of the rock. Therefore, general use of one specific method of preservation will not apply to all rock types. The techniques required to preserve cores for testing may depend upon the length of time for transportation, storage, and the nature of the test to be performed. Some variation in the method of preservation may depend upon whether the cores will be analyzed locally or whether they must be prepared for long-distance shipping. Preferred methods to preserve cores for laboratory analysis include one or more of the following:

- a. Mechanical stabilization.
- b. Environmentally controlled preservation using chilling, regulated humidity, or freezing, if necessary (see 2.5.2.2).
- c. Heat-sealable plastic laminates.
- d. Plastic bags.
- e. Dips and coatings.
- f. Sealing in disposable inner barrels, liners, and tubes.
- g. Anaerobic jars.

### 2.5.2.1 Mechanical Stabilization

All rock types should be mechanically stabilized prior to shipment to the laboratory. This is particularly true for unconsolidated rock (see 2.4.4 and 2.4.5). Core that has been cut using plastic, fiberglass, or aluminum liners/disposable inner barrels can be cast using resin, wax, or foam to fill the annular space between the core and the sleeve. Resin has low viscosity and will fill fine fractures. However, it is only poured into the annulus and is not under enough pressure to displace pore fluids in the rock and therefore does not impregnate the core.

Mechanical stabilization for well consolidated cores may also be as simple as wrapping the core in bubble wrap or other suitable cushioning materials. All core material should be considered fragile and handled carefully (see 2.3.2). Care should be taken to avoid disturbing poorly consolidated or fractured core prior to mechanical stabilization.

### 2.5.2.2 Environmental Preservation

Controlling environmental conditions to which the core is subjected by chilling or maintaining a humid environment can help to preserve the core (refer to core preparation information in Section 3). Core chilling is used primarily to minimize fluid evaporation and provide mechanical stabilization. This technique is useful in preventing the core from drying; however, its effectiveness is subject to the coring fluid type and the reservoir rock and fluid properties. When chilling core, it is still necessary to mechanically stabilize the rock for transport to the laboratory (see 2.5.2.1).

Cores that are preserved by freezing should be frozen by application of dry ice, liquid nitrogen, or placement in an electrically-operated freezer unit. Freezing may result in the migration or diffusion of fluids within the core structure or

breakage of the core. Freezing can cause significant evaporative losses through sublimation. Unconsolidated cores that have been frozen can be packed with a  $\frac{1}{4}$  inch (6.35 mm) thick layer of frozen brine (surface ice cake) to reduce the sublimation process. This measure is critical if freezing is used for long-term core storage. Structural damage to the core may occur if it dehydrates while frozen.

The practice of freezing core is most common for unconsolidated rocks (see 2.4.4 and 2.4.5). The full effect of freezing on a core's petrophysical properties is unknown. The freezing of consolidated core with interstitial water is not well understood. Expansion of ice crystals may cause irreversible structural damage to core. Freezing may affect the properties of rock flushed with fresh water more than those flushed with saline drilling fluid filtrate. These effects will decrease with decreasing water saturation. If it is necessary to allow the core to warm to ambient temperature before testing, the condensation of moisture from the atmosphere onto the core surface must be prevented. Thawing of the core may cause some redistribution of the fluids within the core matrix.

The fluid saturation and reservoir (mineral) properties can also be preserved by controlling the relative humidity of the core environment with specially designed ovens. This technique has wide applicability and is most effective with rocks containing moisture sensitive clay minerals and/or chemically bound water contained in minerals (see 2.4.9).

### 2.5.2.3 Heat-Sealable Plastic Laminates

Several heat-sealable plastic laminates are available. Aluminum foil or mylar may be used to add rigidity to the laminate. The laminated core preservation package should act as an impermeable barrier to water vapor and gases, and be resistant to chemical alteration and degradation by fluids. Laminates are easy to use and the preservation process can be performed quickly. Care should be taken to prevent tears or punctures in the laminate. A clean, flat surface is required for smoothing the laminate prior to sealing. All core should be prewrapped and taped with durable plastic or other material to cover the core ends and sharp edges. The packaged core segment should be labeled with well and depth information.

The heat sealing process is critical to the success of using this preservation method. The heat sealer must be set to the proper temperature in accordance with manufacturer's specifications to obtain an effective seal. Any discontinuity in the seal will negate the barrier properties of the material. Some laminates are available in tubular form that requires the sealing of only two ends rather than four. The head space in the preservation package should be minimized; however, enough material should be used to prevent weakening if the package will be opened and resealed more than once. In some cases, it may be advisable to evacuate the gas space where the loss of light-end hydrocarbons is not an issue. An inert gas such as nitrogen can also be blanketed over the rock to minimize oxidation.

dation. When core material degasses, the laminate package will inflate; this will pose no problem if the package is sealed properly. If necessary, the evolved gas may be sampled directly with a standard gas syringe and the package resealed. The preservation package must be labeled and mechanically stabilized for shipping (see 2.5.2.1). At no time should the preservation package be subjected to extremes of temperature.

#### 2.5.2.4 Plastic Bags

Plastic bags are only recommended for short-term preservation. Core samples should have a minimum of air space between the core and bag wall. Any excess bag can be folded against the core wall and taped to assure a tight fit. As always, clear labeling and proper stabilization procedures should be followed.

#### 2.5.2.5 Dips and Coatings

Dips and coatings are used when cores are not to be tested within a few hours or days and when the material is to be transported over long distances. Dip coatings can also be used with plastic laminates to add mechanical integrity.

**CAUTION:** Cores should never be dipped directly into any molten wax or plastic material.

All core should be prewrapped with a heat-sealable laminate or plastic film and aluminum foil prior to dipping. All core segments should be labeled with well and depth information. The purpose of the plastic film wrap is to prevent contact of the core and pore fluids with the aluminum foil outerwrap. Such contact can cause oxidation of the foil and loss of its moisture and oxygen barrier properties. The following procedures should be used with the wrap and dip method:

- a. Prepare a heating vat for dip-coating several hours prior to preserving the core. Observe all safety precautions. Follow the dip manufacturer's recommendations for handling. Overheating the dip can cause the coating to be ineffective.
- b. Wrap the core tightly in plastic film that will conform to the surface of the rock, crimping the free ends together. Several layers of high quality plastic film are desirable to prevent puncturing.
- c. Wrap the core with several layers of aluminum foil, crimping the free ends together. Avoid puncturing the aluminum wrap.
- d. Tie a wire around the core to make a handle.
- e. Dip the foil-wrapped core sample in the molten coating material. A liberal amount of dip coating should encase the core; a  $\frac{1}{8}$ - to  $\frac{1}{4}$ -inch (3.18- to 6.35-millimeter) thick coating is recommended. This is accomplished through the use of multiple dips, allowing each dip coating to harden prior to the application of additional dip material. It is recommended that

the dip coating be hardened by suspending the core in air by means of the wire handle.

- f. The wire handle should be cut flush with the dip coating. Additional dip should be applied to the wire end to eliminate a pathway for evaporation or oxidation.

Coating material must have certain properties, as follows:

- a. It must be dimensionally stable over long periods of time.
- b. It must not react with oil or water and not contain acids, oils, solvents or any other liquid that may be exuded when set.
- c. Permeability to gases, oils, and water must be low when set.
- d. It should have a low melting point, preferably below 200°F (93.3°C) maximum and have a fairly low viscosity when melted. Higher melting points are acceptable if exposure time to the dip is minimized.
- e. When removed from heat and exposed to ambient conditions, it should be dry and set tack-free within 5 to 15 seconds.
- f. When set, it should be tough but pliable, slightly elastic but with good tensile strength, and not melt at temperatures below 180°F (82.2°C).

As with all core preservation methods currently used, the long term effectiveness of dips and coatings remains uncertain.

#### 2.5.2.6 Disposable Inner Barrels, Liners, and Rigid Tubes

A convenient means of core preservation is possible when disposable inner barrels or liners made of plastic, aluminum, or fiberglass are used (see 2.2.4). The core may be preserved as-is by sealing the ends of the cut inner barrel or liner. This is not recommended as a long term preservation method, but will allow the core to be processed quickly and without special equipment. Holes in the inner barrel should be sealed prior to shipping. The core can be rapidly shipped to the laboratory for sampling and testing, and, if required, additional preservation of the sealed containers is possible (see 2.5.2.2). When a conventional core barrel is used, steel, aluminum, or plastic tubes with suitable couplings, caps, or O-ring seals may be used to preserve the core. To be used effectively, the tube and end pieces must be nonreactive with the core and its fluids. Segments may be stabilized according to guidelines established in 2.5.2.1 to minimize damage in shipment.

#### 2.5.2.7 Anaerobic Jar

Immersion of the core in liquid within an anaerobic jar can be used to prevent oxidation, evaporation, and drying during the handling of core. The anaerobic vessel is an elongated jar with a sealable lid, into which a liquid can be introduced and any free oxygen removed. The immersion liquid must be compatible with the core and pore fluids, and be able to main-

tain the current wettability of the sample (see 2.6). Typically, the following fluids are used for immersion:

- a. Deoxygenated formation brine or synthetic formation brine with biocide.
- b. Crude oil.
- c. Depolarized refined mineral oil.

As always, follow all safety precautions when using anaerobic jars for preserving reservoir samples.

## 2.6 RECOMMENDATIONS FOR CORE HANDLING TO PRESERVE WETTABILITY

### 2.6.1 General

Wettability alteration can take place during coring, core treatment at the wellsite, or during the period of storage before measurements are made in the laboratory. Only core treatment at the wellsite is discussed here, although the measures recommended can only be successful in preserving wettability if adequate precautions are taken at each step of the core recovery and analysis process.

The validity of many laboratory core tests depends on maintenance or reestablishment of reservoir wetting conditions; however, there is rarely an initial reference point to define in situ wettability. The practices recommended here are intended to provide measures of wettability as early as possible after removal of core from the formation so that a reference point for wettability is established. Cores should not be exposed to air for any longer than is necessary.

Wettability tests should be made at the wellsite. A simple observation of imbibition of water and oil droplets placed on the core surface should be recorded routinely. In many cases, this will be the extent of wellsite wettability testing, but much more comprehensive tests can be initiated at the wellsite as well. Some special facilities would be required, including:

- a. The capability to cut core plugs from newly recovered whole core. Any delay in cutting core plugs allows capillarity and diffusion to distribute surface active drilling fluid constituents to the uninvaded portions of the core. Synthetic reservoir brine or refined laboratory oil should be used as the cutting fluid.
- b. Core holders and core flooding equipment to allow flushing of plugs are needed. It may be possible to avoid damage done by an unstable oil phase (one from which asphaltenes or paraffins are deposited because of changes in pressure and temperature) if the oil phase is quickly replaced by a stable, non-damaging oil.
- c. Imbibition test facilities are also needed since tests of imbibition rate and extent are the best indicators of wettability in porous media.

Requirements for maintaining wettability will vary from one reservoir to another and to some extent will have to be

experimentally determined. Suitable core preservation methods to control fluid loss are described in 2.5.2.

## 2.7 PRECAUTIONS

### 2.7.1 General

The fundamental objective of core analysis is to obtain data representative of in situ reservoir rock properties. Coring, handling, and preservation should be conducted in such a manner as to prevent both loss of the interstitial fluids and contamination with foreign fluids. The core should never be washed with water or oils prior to preservation. Suitable coring and handling procedures must be adopted to obtain laboratory data that are meaningful. Alteration of the rock can occur during coring, handling, preservation, sampling, and preparation prior to or during analysis. For a reliable determination of the fluid content of cores, a uniform procedure must be designed for handling and preservation. It should be emphasized that a properly designed program will benefit not only the near term user, but also future users of the core material. Some precautions in the handling and packaging of samples are listed:

- a. All cores should be preserved as soon as possible after removal from the core barrel. Even after preservation, the samples should not be exposed to extreme conditions. The long term effectiveness of core preservation materials currently in use is unknown. A tested and trusted material should be used if the core is to be stored for extended periods of time.
- b. Always minimize the gas head space in core preservation containers to prevent evaporation losses during core storage. This procedure will also minimize condensation losses on the inside surface of the container and help prevent breakage of the more loosely consolidated samples during shipment.
- c. To minimize fluid loss, do not contact the core with cloth, paper, or any other dry material with fine capillaries.
- d. Do not dip or coat the core directly with any fluid.
- e. Follow stringent handling instructions for the processing and preservation of unconsolidated core (see 2.2.4 and 2.5).
- f. Do not preserve an unconsolidated rock or other rock type in the same container as a rock of a vastly different lithology. This will minimize the potential of mechanical damage to weak samples.
- g. Should any core be exposed to harsh handling conditions or washing, this should be noted. All pertinent data must be supplied with the core (see Figures 2-2 and 2-3).
- h. Label each preservation container properly. In cases where confidentiality is an issue, this data should be coded with numbers and referenced to a master list.
- i. It is recommended to have a company representative familiar with wellsite handling and preservation present during the coring operation. If this is not possible, explicit written instructions should be given to the service company.

representative responsible for this activity. Upon arrival at the laboratory, cores should remain in a preserved state until ready for analysis.

j. ALL APPLICABLE SAFETY REGULATIONS MUST BE FOLLOWED WHEN HANDLING CORING EQUIPMENT AND CORE MATERIAL. The wellsite team should be protected, as necessary, against exposure to hazardous material using overalls, gloves, protective eyewear, etc. A hard hat, steel-toed shoes, and hearing protection are also recommended. Where toxic gases such as hydrogen sulfide are present, appropriate personal protective breathing apparatus must be available. Safety training is required for all wellsite workers prior to handling coring equipment, processing equipment, machinery, and core material.

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## **SECTION 3—CORE SCREENING AND CORE PREPARATION**



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# Recommended Practices for Core Analysis

## 3 Core Screening and Core Preparation

### 3.1 GENERAL

The recommendations included in this document may involve the use of hazardous materials, operations, and equipment. This document does not address all of the relevant safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices prior to use and to comply with all applicable regulatory requirements regarding use and disposal of materials and equipment.

### 3.2 CORE DESCRIPTION

#### 3.2.1 Principle

The purpose of core examination and description is the recognition of lithological, depositional, structural, and diagenetic features of whole or slabbed core. Qualitative and quantitative core descriptions provide the basis for routine core analysis sampling, facies analysis, and further reservoir studies such as reservoir quality and supplementary core analyses. A description provides a permanent, accessible record of the core.

#### 3.2.2 Apparatus and Supplies

The following equipment is recommended for use in standard descriptions of the core:

- a. Logging form for systematic data collection.
- b. Microscope or hand lens.
- c. Length measurement scale.
- d. Grain size scale.
- e. Appropriate chemicals such as:
  1. Water or brine to improve visibility of geological structures.
  2. Dilute HCl acid to identify carbonate minerals.
  3. Alizarin red to differentiate calcite and dolomite.
  4. Hydrocarbon solvents to facilitate the detection of oil fluorescence under ultraviolet light.
- f. Coring log, drilling report, mud logs, well site information on lost core.
- g. Core gamma log.
- h. Ultraviolet light.

#### 3.2.3 Precautions

The following precautions should be observed:

- a. If the samples being described have been preserved for special testing, exposure of the samples to air and chemicals

should be avoided until tests on the preserved core have been completed.

- b. Choose an appropriate logging format. The objective of a logging form should be to accurately represent the core. When describing core, it is important to collect and record data in a systematic manner.

#### 3.2.4 Procedures

The following procedures should be used:

- a. Lay out the core to be analyzed on a viewing table.
- b. Check the amount of core with the coring report and ensure that no core material has been lost during transportation. Note any damage or alteration to the core during well-site handling and transportation.
- c. Check the numbering and order of boxes or containers against cumulative depth.
- d. Check core continuity and orientation with respect to the top of the core. If the core has been marked in accordance with 2.2.3, the top of the core is up when the red scribe mark is on the right.
- e. Check the order of core segments in the boxes; look for matching “breaks” or scribe marks from one piece to the next and from one box to the next.
- f. Measure and mark footage on each box. Mark core to the nearest  $\frac{1}{2}$  inch (1 centimeter).
- g. If downhole gamma-ray logs are available, a comparison should be made with the core gamma-ray logs (see 3.3) to verify that the cored interval depths are consistent with well log depths.
- h. Assess the entire cored sequence before commencing. Seek out distinguishing features such as units, contacts, unique markers (e.g., bentonite, coal).
- i. Record major features such as the following using standardized nomenclature and abbreviations (see Section 8):
  1. Core lithology (shale, sandstone, limestone, etc.).
  2. Color.
  3. Bedding (thickness, bed contacts, erosional markers).
  4. Obvious sedimentary structures.
  5. Texture (grain size, angularity/roundness and sorting).
  6. Composition (grains, cement, fossils).
  7. Porosity types.
  8. Diagenetic and tectonic features.
  9. Note any oil stain and related fluorescence.
- j. Minimize centimeter-by-centimeter descriptions. Some fine scale features may be important and should be recorded.
- k. Record nonreservoir rocks, e.g., mudrocks, in addition to potential pay sequences. Subtle changes in lithology may assist correlation between core and well logs and definition of relevant zonation.

l. Record fracture information such as width, extent, density, fracture orientation if core is oriented, and presence of cementation or mud. Where possible, differentiate between natural and coring induced fractures.

### 3.3 CORE GAMMA LOGS AND CORE SPECTRAL GAMMA LOGS

#### 3.3.1 Principle

Naturally occurring gamma-ray emitters (radiogenic daughters of uranium and thorium along with potassium-40) give a measurable gamma-ray response that can be recorded with depth. If such a record measured at the surface is compared with the gamma-ray readings taken from a downhole gamma-ray log, the results can frequently be used to adjust the depth of the core to coincide with the open-hole logging depths and to identify zones where core has been lost.

#### 3.3.2 Apparatus

The recommended apparatus consists of a conveyor for moving core, lead shielding to reduce background gamma radiation, and suitable gamma-ray detectors. A typical detector system consists of a shielded scintillation crystal coupled with a photomultiplier. The scintillation crystal is normally sodium iodide doped with thallium [NaI(Tl)]. Other scintillation crystals include cesium iodide (CsI) and bismuth germanate (BiGeO).

Signals from the detectors are processed and the gamma-ray events are energy-sorted and counted. Standard gamma-ray units should provide total gamma counts in APIU units. With the spectral gamma units these counts are converted into potassium, uranium, and thorium concentrations, and standard gamma-ray log API units. Signals are displayed on a computer graphics screen or plotted in downhole log formats and scale for direct comparison with downhole logs.

#### 3.3.3 Procedures

The following procedures should be used:

- Set the recorder readout to correspond to the scale used with the downhole gamma-ray log.
- Log the core gamma-ray response from bottom to top. This conforms with the sequence used in downhole logs.
- Core gamma-ray logging should be carried out smoothly, without interruption, in the correct order and spacing with matching core breaks fitted together.
- Record a repeat section near the bottom of the core to establish the reproducibility of the measurement.

#### 3.3.4 Advantages

Core gamma-ray logging is widely available and is used in general practice to correlate core depth with log depth. The spectral gamma-ray apparatus will differentiate uranium,

thorium, and potassium concentrations and can be used to better identify and differentiate shale, particularly in sandstone cores with large amounts of potassium feldspar and mica.

#### 3.3.5 Limitations

This technique is unable to detect low gamma-ray activity and can suffer from significant background interference. Analysis of samples for spectral gamma-ray response requires a slower rate of logging than that used to determine total gamma-ray response.

#### 3.3.6 Calibration

The apparatus should be calibrated before evaluating any core material. Calibrations are sensitive to the size of core and the gamma-ray energy range. Calibration should be done by measuring the gamma-ray response to calibration tubes containing pure samples of the elements of interest. The total gamma-ray apparatus requires a calibration tube containing potassium (K-40), uranium (U-238), and thorium (T-232) of known activities. The calibration procedure for the spectral gamma unit requires the same elements but in individual tubes. A blank calibration tube should be measured to ensure a minimal amount of background gamma-rays are interfering with the apparatus. The speed of the conveyor should be slow enough, to provide an acceptable ratio of signal to background noise. A ratio of three times the square root of the count rate to background count rate greater than one is acceptable, i.e.:

$$\frac{3 + \sqrt{\text{count rate}}}{\text{background count rate}} > 1$$

#### 3.3.7 Accuracy

The precision of the measurement varies with the square root of the count rate.

### 3.4 CORE IMAGING

A recorded image of the core is essential. This record will provide information that can be used if viewing of the core is not possible. The record may include visual images of the surface features of the core using photographic techniques, visual representations of the internal structures of the core such as x-radiographs, computed x-ray tomographs, magnetic resonance images, or acoustic images. Any record should include information on core depth along with a scale or legend indicating intensity range of the recorded image.

In addition to photographic representations, modern imaging techniques provide quantifiable information for the core that can be used as the basis for routine core analysis sampling, facies analysis, reservoir quality studies, supplementary core analyses, and downhole log interpretations.

### 3.4.1 Photography

#### 3.4.1.1 Principle

Core is normally photographed under both natural (5,500 K) and ultraviolet light (254-365 nm) along with a standard color scale. The natural light photographs show lithology and sedimentary structures and allow specific features recorded in the core description to be examined. Ultraviolet light photography can highlight hydrocarbon-bearing zones by causing most oils to fluoresce in shades ranging from orange-brown for heavy oils to bright yellow for high gravity oils; condensates can appear as a very light white to blue-white color. Non-hydrocarbon bearing zones will appear as purple regions, although some minerals such as chalky-limestones also appear purple.

#### 3.4.1.2 Advantages

Core photography provides a visual record of the core that can be used to reconstruct damaged core pieces, minimize core handling, and identify the location of samples if photographed following sampling.

#### 3.4.1.3 Limitations

Photographic colors may not represent true colors of the core. Highlighting of features may require wetting the core surface for photography. A scale and color bar are required if adjustments are necessary.

### 3.4.2 X-Ray Techniques

#### 3.4.2.1 Principle

X-ray techniques can be used to noninvasively examine the internal character of a core. An x-ray beam is directed through the core and variations in attenuation of the incident x-ray beam are measured. In order of increasing definition, these techniques are: fluoroscopy, x-radiography, and computed tomography (CT scanning).

The utility of these methods relies on their sensitivity to density contrasts within the core. Consequently, non-porous, dense areas will be contrasted against porous, low-density areas. High definition of density variations within the core requires multi-directional measurements or spatial separation of the contrasted areas.

#### 3.4.2.2 Fluoroscopy

In this technique, the core is moved across an x-ray source. The beam, attenuated by the core, impinges on a fluorescent screen, is intensified, and is recorded by a video camera. The captured image can be viewed on a monitor, recorded on a video cassette, and converted to digital format for later processing and viewing. The output from this technique is a continuous image along the length of the core.

Because the core is moving, the resolution of the resulting image may be diminished. It does, however, enable identification of density variations, some geological structures, and areas of lost core within plastic or fiberglass sleeves. It is also useful in identifying fractured and badly broken zones.

#### 3.4.2.3 X-Radiography

A core sample is positioned between an x-ray source and an x-ray sensitive film. Attenuation of the x-ray beam by the core is captured on film. The developed film can be viewed on a light table, or used to make a black and white print.

It is possible to obtain multiple images of the same piece of core and display them side-by-side. The core should be first x-rayed to obtain an initial image and is then rotated 90 degrees in order to obtain a second image. This is useful in orienting sleeved core prior to slabbing because it can establish the bedding direction.

During x-radiography, the core sample is stationary and provides a higher resolution image than the fluoroscopy method. X-radiography enables detection and evaluation of internal geological structures such as bedding planes, fractures and nodules, lithological changes, and bulk density.

#### 3.4.2.4 Computed Tomography (CT)

In CT, the core is scanned by a highly collimated x-ray beam. Detectors on the opposite side of the core measure the intensity of the transmitted beam. The x-ray source and/or detectors rotate or translate around the sample. A series of x-ray attenuation measurements are made and numerically reconstructed to give the spatial distribution of x-ray attenuation coefficients within the sample.

The resolution of the image depends on the thickness of the x-ray beam, the number of detectors in the scanner, and the size of the pixel array used to reconstruct the image. X-ray beam thickness varies from about 2 millimeters to 10 millimeters. CT enables detection and evaluation of internal geological structures such as bedding planes, fractures and nodules, lithological changes, and bulk density. Combination of sequential x-y scans along the core axis can provide slab images or three-dimensional images of the core.

#### 3.4.2.5 Advantages

X-ray techniques provide quantified, objective representations of the core. These representations can provide similar advantages as described for core photographs in 3.4.1.2 without the need for exposing a surface of the core.

#### 3.4.2.6 Limitations

Resolution of the images is less than that provided by photographs. X-ray attenuation may vary with mineralogy, depending on the energy of the x-ray beam. Some applications are still in the development stage.

of the relationships between rocks and x-ray attenuation may extend these methods to other areas of core analysis.

### 3.4.3 Nuclear Magnetic Resonance (NMR)

#### 3.4.3.1 Principle

NMR imaging is used to provide a reconstructed image of fluids within a core sample. NMR measurements are based on the observation that when the proper radio frequency excitation energy is applied to an ensemble of nuclei, a portion of nuclei at a lower energy level can be promoted to a higher energy level. When the excitation is removed, the rate at which excited nuclei return to the lower level can be detected and measured. The excitation energy is supplied by an oscillating magnetic field in resonance with the nuclei. The nuclei response is measured through a tuned receiver coil. The location of the excited nuclei can be determined by the application of magnetic field gradients during the excitation and detection processes.

The primary nucleus used in core analysis applications is  $^1\text{H}$ . Other nuclei that can be imaged include, but are not limited to,  $^2\text{H}$ ,  $^{31}\text{P}$ ,  $^{23}\text{Na}$ ,  $^{13}\text{C}$ .

#### 3.4.3.2 Advantages

Magnetic resonance images are noninvasive and provide an image showing fluid locations within a sample. The advantages described in 3.4.2.5 apply provided the sample is contained within a suitable non-metallic holder.

#### 3.4.3.3 Limitations

This technique is not descriptive of the core but of the liquids within the core. The technique requires a high density of resonant nuclei for an adequate signal. Hence, low porosity cores will give weak signals. Paramagnetic or ferromagnetic minerals may inhibit or degrade the measured signal and can distort the image.

## 3.5 CORE SAMPLING AND CORE PREPARATION (BASIC CORE ANALYSIS)

### 3.5.1 Principle

The sampling procedure for basic core analysis is determined by the type of information required. Sampling will generally take into account one or more of the following:

- Lithological distribution.
- Porosity and permeability variations within the lithological units.
- Distribution of hydrocarbons.

#### 3.5.1.1 Plug Samples

Referred to as plugs, should be removed from sections of whole core oriented either vertically or horizontally with respect to the whole core axis or with respect to the normal of the bedding planes. These plugs will provide data on matrix properties. See 3.5.2.4 for procedures for removal of core plugs.

#### 3.5.1.2 Full Diameter Samples

Full diameter samples (sections of whole core), in addition to plug samples, should be taken in the following types of zones or where there are significant large scale heterogeneities that are different from the matrix properties. These can occur in, but are not limited to:

- Vuggy carbonates—Vugs can bias the measurement of porosity within a sample. Samples should be taken to obtain a representation of the relative proportion of vugs-to-rock in the reservoir.
- Fractured reservoirs—Fractured zones may be difficult to sample due to the fragile nature of the rock. However, natural fractures can have a significant positive impact on reservoir permeability and should be sampled where possible or appropriate.
- Conglomerates—Within a conglomerate, if the pebble size is large with respect to the sample size, sample size can greatly bias rock property measurements. To obtain a representative sample of a unit of conglomerate it is necessary that sample size be sufficient to include all pebble sizes.

## 3.5.2 Sample Cutting, Trimming, and Mounting

### 3.5.2.1 Principle

The core should be cut and trimmed to provide regularly shaped samples, most commonly right cylinders. Unconsolidated, disintegrating, and very friable samples may have to be mounted prior to testing. Regardless of the degree of lithification, sample handling should be kept to a minimum.

#### 3.5.2.2 Apparatus and Supplies

The following equipment and supplies are commonly used in core sample cutting and trimming operations:

- Large slab saw with a diamond blade.
- Trim saw with a diamond blade.
- Drill press with diamond-edged core drills, capable of drilling cylindrical samples.
- Dressing wheel or saw for squaring plug ends.
- Fluid pumps for delivering various coolants (brine, oil, air, water, liquid  $\text{N}_2$ ) to the cutting surfaces.
- Indelible marking medium such as India ink.
- Sleeves of lead, aluminum, or heat shrinkable plastic for mounting soft, unconsolidated, or very fragile samples.

The following information should be available prior to cutting, trimming, or mounting operations:

- a. The total number of samples required.
- b. Size and orientation needed.
- c. Exact depth locations for samples and how they are to be labeled.
- d. Fluids to use for cutting samples (cores containing clays or shale laminations sensitive to fresh water will deteriorate unless proper drilling fluids are used).
- e. Available core images.
- f. If required, materials for the preferred method of preservation for both plugs and core from which the plugs are cut.

### 3.5.2.3 Precautions

The following precautions should be enforced during sample cutting, trimming, and mounting operations:

- a. Saw and drill press operators should wear protective ear-plugs, goggles, gloves, and other necessary safety equipment.
- b. Lubricant/coolant flow should be sufficient to cool the drill bit or saw blade and remove the cuttings without eroding the sample.

### 3.5.2.4 Procedures

The following procedures for preparing various type core samples should be followed:

- a. Plug samples:
  1. Drill plugs at specified points using the appropriate size bit. Care should be taken to drill straight plugs. If too much pressure is applied during the drilling operation, the bit will flex causing the plug to deform.
  2. Trim plugs to the required length making sure that the ends are parallel. Keep and label trimmed ends.
  3. Label, preserve, and/or store samples, as required.
- b. Full diameter samples:
  1. Cut sections of the core selected for analysis slightly longer than required to allow for finish grinding operations.
  2. Remove barbs and smooth chipped edges by dressing the ends. Cylinder ends should be as close to parallel as possible.
  3. Clearly mark the samples and preserve or store as required.
- c. Unconsolidated samples—There are two distinct methods of preparing unconsolidated cores. The procedures depend on whether the core is stabilized by freezing, epoxy impregnation, or both or is unstabilized. Stabilized cores are generally drilled while unstabilized cores are plunge cut.

1. Stabilized cores—Frozen cores are obtained using the practices listed for plug samples, with appropriate modifications to avoid thawing of the core:

- (a) Pre-cool the core with dry ice and drill with liquid N<sub>2</sub> coolant.
- (b) Drill plugs at specified points using the appropriate size bit. Care should be taken to drill straight plugs. If too much pressure is applied during the drilling operation, the bit will flex causing the plug to deform. Ensure that there is adequate liquid nitrogen flow so that the sample is kept frozen and the cuttings are being removed.
- (c) Trim plugs to the required length using a liquid N<sub>2</sub> cooled saw blade, making sure that the ends are parallel. Keep and label trimmed ends.
- (d) Mount plugs in a suitable pre-weighed sleeve with pre-weighed and properly sized end screens.
- (e) Label, preserve, and/or store samples as required.

Epoxy-stabilized cores can be frozen and drilled using the procedures described in a-e above or by the procedures described for plug samples (see 3.5.2.4.a).

2. Unstabilized cores—Unfrozen cores can be cut using a plunge cut technique. The cutter should be slowly pushed in the core and removed. The cut plug should be gently removed from the cutter and inserted directly into a pre-weighed sleeve. The plug ends are then trimmed.

## 3.6 CORE CLEANING

### 3.6.1 Introduction

Prior to most laboratory measurements of porosity and permeability, the original fluids must be completely removed from the core sample. This is generally accomplished through flushing, flowing, or contacting with various solvents to extract hydrocarbons, water, and brine.

### 3.6.2 Apparatus and Supplies

Various techniques and apparatus for cleaning are described in the procedures below and in Section 4.

Some solvents used for hydrocarbon extraction purposes are listed in Table 3-1. Listed solvents are those most frequently used for extracting samples for routine analysis. Some are preferred for specific applications; e.g., chloroform has been found to be excellent for many North American crudes and toluene has been found useful for asphaltic crudes. Prior to cleaning samples with unknown oil properties, a sub-sample should be tested with various solvents for cleaning efficiency.

Since residual salt crystals affect the measured porosity and permeability, core samples containing a formation water with high salinity may require additional extraction to remove

salt. Salt can be removed with methyl alcohol or other solvents in which salt is soluble.

The various solvents used for extracting core samples can be reclaimed by well-known physical and chemical methods.

Such recovery techniques can make practical the use of an expensive solvent.

Table 3-1—Selected Solvents and Their Use

| Solvent                               | Boiling Point, °C | Solubility         |
|---------------------------------------|-------------------|--------------------|
| Acetone                               | 56.5              | oil, water, salt   |
| Chloroform/methanol azeotrope (65/35) | 53.5              | oil, water, salt   |
| Cyclohexane                           | 81.4              | oil                |
| Ethylene Chloride                     | 83.5              | oil, limited water |
| Hexane                                | 49.7–68.7         | oil                |
| Methanol                              | 64.7              | water, salt        |
| Methylene chloride                    | 40.1              | oil, limited water |
| Naphtha                               | 160.0             | oil                |
| Tetrachloroethylene                   | 121.0             | oil                |
| Tetrahydrofuran                       | 65.0              | oil, water, salt   |
| Toluene                               | 110.6             | oil                |
| Trichloroethylene                     | 87.0              | oil, limited water |
| Xylene                                | 138.0–144.4       | oil                |

### 3.6.3 Precautions

The following precautions should be enforced during core sample cleaning operations:

- When using solvents, it is the responsibility of the user to establish appropriate safety and health practices prior to use and to comply with all applicable regulatory requirements regarding use and disposal of materials.
- The solvent selected should not attack, alter, or destroy the structure of the sample.
- Chloroform may hydrolyze during extraction, forming hydrochloric acid as a product.
- Not all solvents are compatible with all extraction equipment configurations. Possible solvent/equipment reactions should be considered in selecting equipment and solvent for use in core cleaning operations.
- Closed-type electrical heaters should be used whenever flammable solvents are used. Safety precautions such as adequate ventilation of the laboratory and ready accessibility of fire extinguisher equipment and safety showers should be observed.
- Extraction should be conducted under ventilating hoods equipped with forced-draft ventilation.
- Temperature effects on the samples should be considered. See 3.7 for recommendations regarding drying of core samples.

### 3.6.4 Procedures

#### 3.6.4.1 Solvent Flushing by Direct Pressure

Extraction of hydrocarbons and salt from reservoir rocks can be achieved by injecting one or more solvents into the

core sample under pressure and at room temperature. The pressure used should be dependent on the sample permeability and may range from 10 to 1,000 psi. The core samples may be held in a rubber sleeve under overburden pressure or in a suitable core-holding device that will permit the flow of solvent through the matrix of the sample. The volume of solvent required to completely remove hydrocarbons in the core sample is dependent on the hydrocarbons present in the sample and the solvent used. The core is considered clean when the effluent is clean. In some instances, more than one solvent may be required to remove heavy, asphaltic-type crude oils.

#### 3.6.4.2 Flushing by Centrifuging

A centrifuge with a specially designed head is used to spray warm, clean solvent (from a still) against the core samples. The centrifugal force causes solvent to flow through samples displacing and extracting the oil (and water). The speed of rotation should be varied from a few hundred to several thousand revolutions per minute (rpm), depending on the permeability and degree of consolidation of the core. Most common solvents can be used. The apparatus and procedure are described in Conley and Burrows.<sup>1</sup>

#### 3.6.4.3 Gas-Driven Solvent Extraction (U.S. Patent 2,617,719)

In this procedure, a core is subjected to repeated cycles of internal-dissolved or solution-gas drive until the core is cleaned of hydrocarbons. The remaining solvent and water are removed by means of a drying oven.

<sup>1</sup>Conley, F. R., and Burrows, D. B., "A Centrifuge Core Cleaner," *Journal of Petroleum Technology*, VIII, 61, October 1956.



When a core from an oil-bearing formation is brought to the surface and depressurized, the gas dissolved in the oil comes out of solution and displaces some of the oil and water out of the core. This results in some gas-filled pore space at atmospheric pressure. The gas-filled space in the core can be almost completely filled with solvent by surrounding the core with a suitable solvent containing a dissolved gas and applying sufficient hydraulic pressure. Under this condition, the solvent mixes with oil in the core and subsequent depressurizing to atmospheric pressure removes some of the residual oil.

Carbon dioxide gas is excellent for this purpose because of low fire or explosion hazards and high solubility in most solvents. Some of the solvents that can be used are naphtha, toluene, or mixtures of solvents. With certain types of crude oil, cleaning time may be reduced if the core chamber is heated by a water bath, steam bath, or by electric heaters. One successful application of this method for routine cleaning of cores uses carbon dioxide and toluene at 200 psig, with a hydraulic pressure of 1,000 psig. Cycles of approximately 30 minutes are used. The apparatus and procedure are described by Stewart.<sup>2</sup>

#### 3.6.4.4 Distillation Extraction Method

A Soxhlet extractor and suitable solvent or solvents should be used to dissolve and extract oil and brine. Extraction can be arranged in a manifold so that the oil-and water-laden solvent siphons from each extractor into a common still from which fresh solvent is continuously distilled, condensed, and again distributed to all the extractors.

The cleanliness of the sample is best determined from the color of the solvent that siphons periodically from the extractor. Extraction should be continued until the extract remains clear. Non-luminescence of extract under fluorescent light is a good criterion for determining complete extraction of the oil for a given solvent. It should be noted that the complete extraction of certain oils from core samples may require more than one solvent, and the fact that one solvent is clear after contact with the sample does not necessarily mean that oil has been completely removed from the sample. Details of one apparatus and procedure may be found in 4.3.

#### 3.6.4.5 Liquefied Gas Extraction

Liquefied gas extraction uses a pressurized Soxhlet extractor and a condensed, low-boiling-point, polar solvent. The process is a distillation extraction procedure that uses pressurized solvent to clean the core. Solvent is regenerated through low temperature distillation. Because the extraction is conducted at or below room temperature, it can be performed on heat-sensitive core such as those containing gypsum.

<sup>2</sup>Stewart, Charles R., U. S. Patent Number 2,617,719, "Cleaning Porous Media," November 11, 1952.

### 3.6.5 Advantages

Cleaning a core removes original fluids from the core, preparing it for further tests that do not require those fluids.

### 3.6.6 Limitations

Individual test conditions may require a particular technique for optimal results. Some techniques may be more applicable to particular rock types or cleaning requirements.

## 3.7 DRYING

Conventional core samples can be dried by the methods listed in Table 3-2:

Table 3-2—Core Sample Drying Methods

| Rock Type                        | Method                                  | Temperature, °C |
|----------------------------------|-----------------------------------------|-----------------|
| Sandstone<br>(low clay content)  | Conventional oven                       | 116             |
|                                  | Vacuum oven                             | 90              |
| Sandstone<br>(high clay content) | Humidity oven,<br>40% relative humidity | 63              |
| Carbonate                        | Conventional oven                       | 116             |
|                                  | Vacuum oven                             | 90              |
| Gypsum-bearing                   | Humidity oven,<br>40% relative humidity | 60              |
|                                  | Conventional vacuum                     |                 |
| Shale or other high<br>clay rock | Humidity oven,<br>40% relative humidity | 60              |

Each core sample should be dried until the weight becomes constant. Drying times may vary substantially, but are generally in excess of four hours.

### 3.7.1 Precautions

Some precautions that should be observed in drying samples for routine core measurements are:

- Samples containing clays must not be dehydrated during preparation. Care must be exercised in drying these samples. In some cases, temperatures lower than those indicated in Table 3-2 should be used to prevent the dehydration of clays.
- Samples containing gypsum will require specific procedures during preparation. Extreme care should be exercised to avoid both loss of water and change of the crystalline structure.
- Samples must be protected from erosion by the drip of clean solvent when utilizing the distillation extraction technique.
- The extraction technique should not physically damage the core.
- The usual criterion for sample cleanliness is a clean extract. However, many solvents are not complete solvents for all types of oils and a clean extract may reflect oil solubility and not complete extraction.

