2.3 Methods of Logging

There are two general methods of sample description and logging, the interpretive system and the percentage system. The interpretive log is preferable but its accuracy depends in some measure on the quality of the samples, and the geologist's familiarity with the local stratigraphic section. Obvious caved material is to be disregarded, and only the lithology believed to be representative of the drilled section is logged. If several different rock types are present in the sample, all assumed to be derived from the drilled interval, they are logged as discrete beds, interbeds, intercalations, lenses, or nodules, rather than as percentages. The interpretation in this case is based on the geologist's knowledge of the section. On interpretive logs, lithologic contacts are drawn sharply, and the entire width of the log column is filled with appropriate symbols. One hazard in this form of logging is that of overlooking unexpected repetitions of lithologic types.

Experience and good training are essential for making a good interpretive log. Generally the person examining the samples is best qualified to recognize lithologic and formational contacts. Although formation contacts should be picked on the basis of sample evidence rather than on mechanical logs, the latter, as well as drilling time logs, can be useful in defining boundaries of specific lithologic units, and zones of porosity.

In percentage logging, the geologist, after eliminating the obvious foreign matter and unquestionable caved material, plots each rock type with a width of symbols proportional to its percentage in the sample. This system of logging may be used to advantage in areas where:

1) the details of the stratigraphy are unknown,
2) samples are of very poor quality,
3) no mechanical logs are available,
4) the sampled interval is very large compared to the thickness of the rock units,
5) the stratigraphic sequence is interrupted by structural complications, or
6) the person studying the samples is inexperienced or is not a professional geologist.

The principal disadvantages of this system are that lithologic breaks do not show up sharply on the log, and the intricate logging of each rock percentage often gives a confused and meaningless picture of the rock present.

A modification of interpretive logging which has been employed occasionally is a combination interpretive/percentage log. The objective in this case is to indicate on the log as a percentage of the whole sample only that portion of the sample which the logger interprets as being in place. The remainder of the lithic column is left blank. This type of logging has the advantage of other interpretive logs, except that the log which results from the examination of poor samples has few symbols plotted and is therefore more
difficult to interpret. It does afford a graphic record of the quality of the samples, but this fact can just as well appear in the column of written description.
3.0 SAMPLE DESCRIPTION

3.1 Sample Quality and Examination Techniques

The quality of a sample log is frequently a direct measure of the quality of the samples. Clean, good quality samples are exceptions rather than the rule. The geologist logging samples must learn to make his interpretations from samples of widely varying quality. Cavings and other contaminants must be recognized and disregarded. (See Section 7.0)

Many methods of examining samples are in use throughout the industry. Some geologists pour and examine one sample at a time; others lay out the samples in compartmented trays so that a sequence of from five to ten samples may be observed in a single tray.

The following procedure is recommended: the samples are laid out in a stack of five-cell trays with the depths marked on the trays. The cuttings should just cover the bottoms of the trays. It is sometimes desirable to separate the obvious cavings by either sieving or dry panning. Attention should generally be focused on the smaller cuttings with angular shape and fresh appearance.

A standard practice is to scan 100 or more feet of samples, observing the lithologic "breaks." The samples are then re-examined for more detailed study, dry for porosity estimates, wet for all other properties. Wetting the samples not only cleans off mud and other contamination, but also brings out rock characteristics that are not apparent in dry samples. The tray should be dipped in a basin of water, agitated gently to remove any fine contaminants, and then removed and drained for study, leaving the samples still covered by a film of water. After the cuttings have been logged, they are set aside to dry and are then returned to the sample bags.

The technique of scanning samples, or looking ahead, before logging them in detail has many advantages. In addition to helping the examiner pick tops and lithologic breaks it may also aid him in determining the extent of porous and hydrocarbon bearing intervals. However, the principle advantage of this technique is that it provides the geologist the opportunity to observe and interpret depositional sequences. When sample intervals are laid out in sequence subtle changes in texture, mineralogy, color and facies often become apparent even before microscopic examination. Thus the observer is alerted to look for these changes when making the detailed examination. This method of examining samples encourages geologists to observe and log lithologic rather than sample interval units. It eliminates the laborious and time consuming task of routinely describing each sample interval, it increases speed of logging and it invariably helps the geologist make a more meaningful log.

Textures in carbonate rocks can be clearly observed with the aid of special wetting agents such as mineral oil, glycerine, clove oil, etc. A further refinement of this technique is the use of transmitted light described below.

3.11 Use of Transmitted Light

Textural and structural details often become evident when light is transmitted through thin slivers of carbonate rock. This technique is particularly useful for the routine examination of drill cuttings.

Representative cuttings selected for their thin, platy shape are etched lightly in dilute HCl, placed in a clear pyrex spot plate, and then
completely covered with a wetting agent. Light is transmitted through the chips by the use of a substage mirror, or a small reflecting mirror placed directly on the stage and underneath the plate.

A mixture of water and glycerine is recommended as the wetting agent because (1) it evaporates slowly, and (2) chips may be washed clean with water after examination (a useful quality when working with small amounts of samples which must be refilled).

3.2 Abbreviations

Abbreviations should be used for all descriptions recorded on lithologic logs. Appendix II is a list of the terms most commonly used in sample examination, and their recommended abbreviations. Abbreviations for nouns are designated with capital initial letters; other terms are abbreviated entirely in small letters.

3.3 Order of Written Description

When written descriptions are required a standardized order of description (1) reduces the chance of not recording all important properties, (2) increases the uniformity of description among geologists, and (3) saves time in obtaining specific information from descriptions.

The following order is used:

1) Rock type - underlined and followed by classification
2) Color
3) Texture - including grain size, roundness, and sorting
4) Cement and/or matrix materials
5) Fossils and accessories
6) Sedimentary structures
7) Porosity and oil shows

Examples

Ls: ool. Grst., brn., med.-crs., arg., Brach.-Bry.,
glauc., gd. intpar. por., gd. Stn., gd. cut Fluor.

Sst: lithic, bu.-wh., f.-med., ang., spl. arg., mica.,

3.31 Rock Types

A proper recording of rock type consists of two fundamental parts: the basic rock name (underlined): e.g., dolomite, limestone, sandstone, and the proper compositional or textural classification term: e.g., lithic, oolitic grainstone, etc.

3.32 Color

Color of rocks may be a mass effect of the colors of the constituent grains, or result from the color of cement or matrix, or staining of these. Colors may occur in combinations and patterns, e.g., mottled, banded, spotted, variegated. It is recommended that colors be described on wet samples under
ten-power magnification. It is important to use the same source of light all of the time and to use constant magnification for all routine logging. General terms such as dark gray, medium brown, etc., generally suffice, however, if more concise designation is required the color symbol as determined from the GSA Rock-color Chart may be used.

Ferruginous, carbonaceous, siliceous, and calcareous materials are the most important staining or coloring agents. From limonite or hematite come yellow, red, or brown shades. Gray to black color can result from the presence of carbonaceous or phosphatic material, iron sulfide, or manganese. Glaucnite, ferrous iron, serpentine, chlorite, and epidote impart green coloring. Red or orange mottlings are derived from surface weathering or subsurface oxidation by the action of circulating waters.

The colors of cuttings may be altered, after the samples are caught, by oxidation caused by storage in a damp place, insufficient drying after washing, or by overheating. Bit or pipe fragments in samples can rust and stain the samples. Drilling mud additives may also cause staining.

3.33 Texture

Texture is a function of the size, shape, and arrangement of the component elements of a rock.

1) Grain or crystal sizes. Size grades and sorting of sediments are important attributes. They have a direct bearing on porosity and permeability and may be a reflection of the environment in which a sediment was deposited. Size classifications, based on a modified Wentworth scale, are shown in Appendix IV, Chart X. The microscopist should not try to record size grades without reference to some standard comparator of mounted sieved sand grains or photographs of these. A convenient comparator made of transparent film positive is included in an attached pocket in Appendix III, Section 12.4. This comparator is small and handy and can be placed on top of, or adjacent to, cuttings in a sample tray so that a direct visual comparison of grain sizes can be made. Lower fine is designated by underlining (f). Other comparators in Appendix III, Sections 12.5 and 12.51 are photomicrographs of thin sections from Beard and Weyl (1973) showing both grain size and sorting. Both simple and useful is a photographic grid of half-millimeter squares which may be fixed on the bottom of a sample examination tray.

2) Shape. Shape of grains has long been used to decipher the history of a deposit of which the grains are a part. Shape involves both sphericity and roundness.

Sphericity refers to a comparison of the surface area of a sphere of the same volume as the grain, with the surface area of the grain itself. For practical purposes, distinction is usually made in large particles on the basis of axial ratios and in grains by visual comparison with charts such as those in Appendix III, Section 12.6.

Roundness. Roundness, which refers to the sharpness of the edges and corners of a fragment, is an important characteristic that deserves careful attention in detailed logging. Five degrees of rounding may be distinguished as shown on charts in Appendix III, Section 12.6.
Angular - edges and corners sharp; little or no evidence of wear.

Subangular - faces untouched but edges and corners rounded.

Subrounded - edges and corners rounded to smooth curves; areas of original faces reduced.

Rounded - original faces almost completely destroyed, but some comparatively flat faces may be present; all original edges and corners smoothed off to rather broad curves.

Well rounded - no original faces, edges, or corners remain; entire surface consists of broad curves, flat areas are absent.

3) Sorting. Sorting is a measure of dispersion of the size frequency distribution of grains in a sediment or rock. It involves shape, roundness, specific gravity, and mineral composition as well as size. A classification given by Payne (1942) that can be applied to these factors is:

Good: 90% in 1 or 2 size classes

Fair: 90% in 3 or 4 size classes

Poor: 90% in 5 or more size classes

More nearly precise values may be determined by direct comparison with the sorting comparators shown in Appendix III, Sections 12.5 and 12.51.

3.34 Cement and Matrix

Cement is a chemical precipitate deposited around the grains and in the interstices of a sediment as aggregates of crystals or as growths on grains of the same composition. Matrix consists of small individual grains that fill interstices between the larger grains. Cement is deposited chemically and matrix mechanically.

The order of precipitation of cement depends on the type of solution, number of ions in solution and the general geochemical environment. Several different cements, or generations of cement, may occur in a given rock, separately or overgrown on or replacing one another. Chemical cement is uncommon in sandstone which has a clay matrix. The most common cementing materials are silica and calcite.

Silica cement is common in nearly all quartz sandstones. This cement generally occurs as secondary crystal overgrowths deposited in optical continuity with detrital quartz grains. Opal, chalcedony, and chert are other forms of siliceous cement. Dolomite and calcite are deposited as crystals in the interstices and as aggregates in the voids. Dolomite and calcite may be indigenous to the sandstone, the sands having been a mixture of quartz and dolomite or calcite grains, or the carbonate may have been precipitated as a coating around the sand grains before they were lithified. Calcite in the form of clear spar may be present as vug, or other void filling in carbonate rocks. Anhydrite and gypsum cements, are more commonly associated with dolo-
mite and silica than with calcite. Additional cementing materials, usually of minor importance, include pyrite, generally as small crystals, siderite, hematite, limonite, zeolites, and phosphatic material.

Silt acts as a matrix, hastening cementation by filling interstices, thus decreasing the size of interstitial spaces. Clay is a common matrix material, which may cause loss of porosity either by compaction, or by swelling when water is introduced into the formation. Argillaceous material can be evenly distributed in siliciclastic or carbonate rocks, or have laminated, lenticular detrital or nodular form.

Compaction and the presence of varying amounts of secondary quartz, secondary carbonate, and interstitial clay are the main factors affecting pore space in siliciclastic rocks. While there is a general reduction of porosity with depth due to secondary cementation and compaction, ranges of porosity vary considerably due primarily to extreme variations in amounts of secondary cement. For instance, coarse-grained sandstones have greater permeability than finer ones when the same amount of cementing material is available to both. However, the same thickness of cement will form around the grains regardless of their size, therefore the smaller interstices, which occur in finer grained sandstones, will be cemented earliest.

3.35 Fossils and Accessories

Microfossils and some small macrofossils, or even fragments of fossils, are used for correlation and may also be environment indicators. For aid in correlation, anyone making sample logs should familiarize himself with at least a few diagnostic fossils. The worldwide Cretaceous foraminiferal marker, Globotruncanice, for example, should be in everyone's geologic "vocabulary." Any geologist who examines samples should be able to distinguish such forms as foraminifera, ostracods, chara, bryozoa, corals, algae, crinoids, brachiopods, pelecypods, and gastropods so as to record their presence and relative abundance in the samples being examined. More detailed identification will probably have to be made with the aid of the literature, and/or the advice and assistance of a paleontologist. An excellent reference for the identification of the more common macrofossils is "Recognition of Invertebrate Fossil Fragments in Rocks and Thin Sections," by O. P. Majewske (1969). Fossils may aid the sample examiner in judging what part of the cuttings is in place and what part is caved. For example, in the Gulf Coast region, fresh, shiny foraminifera, especially with buff or white color, are usually confined to Tertiary beds; their occurrence in samples from any depth below the top of the Cretaceous is an indication of the presence of caved material. It would be helpful to each sample-logger to have available one or more slides or photographs illustrating the principal microfossils which might be expected to occur in each formation he will be logging.

Accessory constituents, although constituting only a minor percentage of the bulk of a rock, may be significant indicators of environment of deposition, as well as clues to correlation. The most common accessories are glauconite, pyrite, feldspar, mica, siderite, carbonized plant remains, heavy minerals, chert, and sand-sized rock fragments.
3.36 Sedimentary Structures

Most sedimentary structures are not discernible in cuttings. On the other hand, one or more of them can always be found in any core, and they should be reported in the description thereof. Structures involve the relationship of masses or aggregates of rock components. They are conditioned by time and space changes; e.g., stratification may result from discrete vertical (time) change in composition, as well as changes in grain sizes or of fabric. In time of origin, they are formed either contemporaneously with deposition (syngenetic), or after deposition and burial (epigenetic). Syngenetic structures are often very important indicators of the environments of deposition of sediments.

Symbols shown in Appendix IV, Charts XVI, XVII and XVIII should be used in logging sedimentary structures observed in outcrops, cores, and samples.

3.37 Porosity and Permeability

Among the most important observations made in the course of sample examination are those relating to porosity and permeability. These are discussed in Section 5.0.

A number of classifications considering various aspects of carbonate porosity and permeability have been developed, including those by P. W. Choquette and L. C. Pray (1970) and by G. E. Archie (1952). A detailed discussion of these classifications is given in Section 5.0 and in Appendix I, Section 10.7 and 10.8.

3.38 Hydrocarbon Shows

The recognition and evaluation of hydrocarbons present in well samples is another of the more important responsibilities of the geologist. He should be familiar with the various methods of testing for and detecting hydrocarbons, and should use them frequently in the course of routine sample examinations. Cuttings with good porosity should always be tested for hydrocarbons. See Section 6.0 for an extended discussion of hydrocarbon detection tests.

3.4 Methods of Recording Data

There are several methods of recording sample description and other data on the standard log form. The most commonly practiced of these is that of the geologist plotting the symbols and data on the standard log form as he examines the samples. This may tend to produce an untidy log. It is more desirable for the data to be written on a pad or rock description form or to be recorded on a dictaphone or tape recorder for later transcription. Although in most situations the plotting of data on logs is done by geologists, several companies employ log plotters, clerks, or draftsmen for this purpose. The use of nontechnical personnel for plotting logs has the distinct advantage of permitting the geologist to use his time in professional work. A well-trained log plotter can usually plot the lithologic descriptions of several geologists working full time on sample studies.

Condensed core descriptions should always be recorded and plotted
on the standard log form along with and at the same scale as the sample descriptions. The complete detailed core description can be recorded and plotted on an expanded scale of the standard log form, or on conventional core record sheets.

4.0 SOME CRITERIA AND PROCEDURES FOR ROCK AND MINERAL IDENTIFICATION

4.1 Testing Methods

4.11 Tests with Dilute HCl (10%) 

There are at least four types of observations to be made on the results of treatment with acid:

1) Degree of effervescence: limestone (calcite) reacts immediately and rapidly, dolomite slowly, unless in finely divided form (e.g., along a newly made scratch). While the effervescence test cannot yield the precision of chemical analysis or X-ray, it is generally adequate for routine examination. Unless the sample is clean, however, carbonate dust may give an immediate reaction that will stop quickly if the particle is dolomite. Impurities slow the reaction, but these can be detected in residues. Oil-stained limestones are often mistaken for dolomites because the oil coating the rock surface prevents acid from reacting immediately with CaCO₃, and a delayed reaction occurs. The shape, porosity, and permeability will affect the degree of reaction because the greater the exposed surface, the more quickly will the reaction be completed.

2) Nature of residue: carbonate rocks may contain significant percentages of chert, anhydrite, sand, silt, or argillaceous materials that are not readily detected in the untreated rock fragments. Not all argillaceous material is dark colored, and, unless an insoluble residue is obtained, light colored argillaceous material is generally missed. During the course of normal sample examination in carbonate sequences, determine the composition of the noncalcareous fraction by digesting one or more rock fragments in acid and estimate the percentage of insoluble residue. These residues may reveal the presence of significant accessory minerals that might otherwise be masked.

3) Oil reaction: if oil is present in a cutting, large bubbles will form on a fragment when it is immersed in dilute acid. See Section 6.13 under "Hydrocarbon Detection Methods" for more details of this method.

4) Etching: etching a carbonate rock surface with acid yields valuable information concerning the texture, grain size, distribution and nature of noncarbonate minerals, and other lithologic features of the rock.

Etching is accomplished by sawing or grinding a flat surface on a specimen, which is then submerged for a short time (10 to 30 seconds) in dilute acid with the flat surface parallel to the surface of the acid. After etching the surface is carefully washed by gentle immersion in water, care being taken not to disturb the insoluble material adhering to the surface of the specimen. Limestone specimens etched in HCl usually develop an "acid polish." Insoluble materials such as clay, silt, sand, chert, or anhydrite will stand out in
relief against the soluble matrix. Dolomite crystals usually stand out also, inasmuch as they are attacked by the acid more slowly than is calcite. The internal structures of fossils, oolites, and detrital fragments are commonly revealed on an etched surface. If the appearance of the etched surface is so diagnostic that a permanent record is desired, an acetate peel can be made (Appendix I, Section 10.6), or the surface can be photographed.

4.12 Hardness

Scratching the rock fragment surface is often an adequate way of distinguishing different lithic types. Silicates and silicified materials, for example, cannot be scratched, but instead will take a streak of metal from the point of a probe. Limestone and dolomite can be scratched readily, gypsum and anhydrite will be grooved, as will shale or bentonite. Weathered chert is often soft enough to be readily scratched, and its lack of reaction with acid will distinguish it from carbonates. Caution must be used with this test in determining whether the scratched material is actually the framework constituent or the cementing or matrix constituent. For example, silts will often scratch or groove, but examination under high magnification will usually show that the quartz grains have been pushed aside and are unscratched, and the groove was made in the softer matrix material.

4.13 Parting

Shaly parting, although not a test, is an important rock character. The sample logger should always distinguish between shale, which exhibits parting or fissility, and mudstone, which yields fragments which do not have parallel plane faces.

4.14 Slaking and Swelling

Marked slaking and swelling in water is characteristic of montmorillonites (a major constituent of bentonites) and distinguishes them from kaolins and illites.

4.2 Thin Sections (preparation techniques listed in Appendix I, Section 10.2)

Certain features of rocks may not be distinguishable even under the most favorable conditions without the aid of thin sections. Thin sections adequate for routine examination can be prepared without the use of the refined techniques necessary to produce slides suitable for petrographic study.

Some of the questions of interpretation which might be clarified by the use of thin sections include the following: mineral identification, grain-matrix relationships, grain-cement relationships, pore space relationships and distribution, grain sizes, source rock quality. Although wetting the surface of a carbonate rock with water, or mineral oil, permits "in depth" observation of the rock, some particles, or particle-matrix relationships still remain obscure until the rock is examined by transmitted light, plane and/or polarized. Once these features have been recognized in thin sections, they are frequently detectable in whole fragments, and only a few thin sections may be needed in the course of logging a particular interval. It is important to have polarizing equipment available for use in thin section examination - many features of
the rock texture, and some minerals, are most readily recognized by the use of polarized light.

4.3 Staining Technique for Carbonate Rocks

The distinction between calcite and dolomite is often quite important in studies of carbonate rocks. For many years several organic and inorganic stains have been used for this purpose, but with varying degrees of success. Friedman (1959) investigated a great variety of stains for use in identifying carbonate minerals. He developed a system of stains and flow charts for this purpose. These vary in ease of application, but most are not practical for routine sample examination. The reader is referred to Friedman's paper for an extensive discussion of carbonate mineral stains.

One stain that is applicable to routine sample examination and is both simple and rapid in Alizarin Red S. This stain can be used on any type of rock specimen, and it has proved especially useful in the examination of cuttings. The reactions to acid of chips of dolomitic limestone or calcareous dolomite are often misleading, and the rapid examination of etched chips does not always clearly show the calcite and dolomite relationships. Alizarin Red S shows clearly the mineral distribution. Calcite takes on a deep red color; other minerals are uncolored. See Appendix I, Section 10.3 for a discussion of the preparation and application of this stain.

4.4 Insoluble Residues

Carbonate rocks may contain significant percentages of chert, anhydrite sand, silt, or argillaceous materials that are not readily detected in the untreated rock fragments. The study of cherts and associated residues has been a common practice for many years in certain areas. For routine logging of micro-insoluble residues, symbols for accessory minerals, as shown in the standard lithologic legend, Appendix IV, Charts XIV and XV, should be used. A description of the methods for the preparation, examination, and description of the residue are provided in Appendix I, Section 10.4.

4.5 Versenate Analysis

Versenate analysis is a relatively fast and inexpensive method for determining quantitatively the calcite/dolomite ratios of given carbonate rocks. The method has shown merit in the mapping of intimately associated limestone and dolomite. It is based on the color reaction of a reagent on crushed and sieved carbonate samples. (Preparation and Technique in Appendix I, Section 10.5).

4.6 Heavy Mineral Studies

Heavy mineral studies are used today primarily when a geologist is seeking information concerning the source areas and distribution patterns of siliciclastic sediments. Their use as a correlation tool is limited. Excellent descriptions of techniques are available in the literature.

4.7 Tests for Specific Rocks and Minerals

Many of the more perplexing problems of rock and mineral identifi-
cation can be solved by the use of thin sections. However, certain simple and rapid tests are discussed as follows.

4.71 Clay

Shales and clays occur in a broad spectrum of colors, mineral composition, and textures. Generally, their identification is done with ease; however light colored clay is commonly mistaken for finely divided anhydrite. The two may be distinguished by a simple test.

Anhydrite will dissolve in hot dilute hydrochloric acid and, when cooled, will recrystallize out of solution as acicular needles. Clay remains insoluble in the hot dilute acid.

4.72 Chert

Recognition of the more common varieties of chert and siliceous carbonates generally is not a problem. Weathered chert, however, is often found to be soft enough to be readily scratched and mistaken for clay or carbonate. Lack of reaction with acid generally distinguishes this type of chert from carbonates. Clay and tripolitic chert may require petrographic techniques for differentiation. In thin sections under polarized light, chert commonly has a characteristic honey-brown color.

4.73 Evaporites

1) Anhydrite and gypsum are usually readily detected in cuttings. Anhydrite is more commonly associated with dolomites than with limestones, and is much more abundant in the subsurface than gypsum. At present, there appears to be little reason to distinguish anhydrite from gypsum in samples. Anhydrite is generally harder and has a pseudo-cubic cleavage; the cleavage flakes of gypsum have "swallow-tail" twins. Anhydrite can be readily recognized in thin sections by its pseudo-cubic cleavage, and, under polarized light, by its bright interference colors.

The dilute hydrochloric acid test referred to in Section 4.71 is a valid and simple test for anhydrite or gypsum in cuttings. Place the cutting(s) in a watch glass and cover with acid. Heat on a hot plate to 250°F ± (120°C ±) and wait for the sample to start dissolving. If anhydrite or gypsum is present, acicular gypsum crystals will form around the edge of the acid solution as it evaporates. If the sample contains much carbonate, a calcium chloride paste may form and obscure the acicular gypsum crystals. Dilute the residue with water, extract and discard the solution and repeat the test.

A simple method of distinguishing finely divided anhydrite from silt is a scratch test. This can be done by two methods:

a) Rub glass rod on residue in bottom of glass test plate and listen for gritty sound.

b) Place a drop of liquid containing the residue on a glass cover-slip, and cover with another slip. Rub them together between thumb and forefinger. Examine slips under microscope for scratch marks, or listen for gritty sound.
2) **Salts** are rarely found at the surface and generally do not occur in well samples. Unless salt-saturation or oil-base mud is used, salt fragments or crystals dissolve before reaching the surface. The best criteria for detecting a salt section are: (a) the occurrence of "salt hoppers" (molds of dissolved salt crystals in other rock fragments), (b) marked increase in salinity of the driling mud, (c) a sudden influx of abundant caved material in the samples, (d) a sharp increase in drilling penetration rate, and (e) mechanical log character, particularly the sonic, density, and caliper logs. Cores are the most direct method of determining whether salt is present, but they are not usually cut in salt sections.

Salts are commonly associated with cyclical carbonate sections and massive red bed sequences. In the former, they are usually thin bedded and often occur above anhydrite beds. Potassium-rich salts, the last phase of an evaporation cycle, are characterized by their high response on gamma ray log curves.

4.74 **Phosphate**

Place on the suspected mineral (either on the hand specimen or on an uncovered thin section) a small crystal of pure white ammonium molybdate. Allow one or two drops of dilute nitric acid to fall on the crystal. If the rock contains phosphate, the crystal rapidly takes on a bright yellow color.

4.75 **Siderite**

Siderite is usually readily distinguished by its characteristic brown color and slow rate of effervescence with dilute HCl. The mineral often occurs as buckshot-sized pellets. The presence of siderite or iron dolomite in the same rock with calcite may be difficult to recognize and the following stain procedure is recommended for use when such cases are suspected.

Polished face of chip is immersed for 5-10 minutes in a hot, concentrated solution of caustic potash to which a little hydrogen peroxide is added at intervals during treatment. The surface is finally washed and dried in the air. Siderite is stained brown while ferrous dolomite (ankerite) takes a weaker stain and ordinary dolomite remains colorless; calcite is roughened but is not destroyed and chamosite retains its green color unless carbonate of iron is present. This method is equally applicable to powders.

4.76 **Feldspar**

The presence, quantity and type of feldspar constituents can be important in the study of reservoir parameters in some sandstones, particularly the coarse arkosic sands or "granite washes." Staining techniques, operationally applicable to rather large etched core (or surface) sample surfaces, allows a better estimation of the amount and distribution of feldspar grains. One of these techniques is described in Appendix I, Section 10.3. The use of sections to make these estimates is expensive, and often difficult because of the small surfaces provided.

4.77 **Bituminous Rocks**

Dark shales and carbonates may contain organic matter in the form of kerogen or bitumen. Carbonates and shales in which the presence of bituminous matter is suspected should be examined by thin section and pyrolysis-fluorometer methods for possible source rock qualities. Dark, bituminous shales have a characteristic chocolate brown streak which is very distinctive.
5.0 POROSITY AND PERMEABILITY

5.1 Detection and Types

The detection and evaluation of porosity and the inferred presence or absence of permeability in the course of rock examination is one of the most important responsibilities of the geologist. Porosity is a measure of the volume of the void space in the rock; permeability is a measure of the capacity of a rock for transmitting a fluid. Permeability is dependent on the effective porosity and the mean size of the individual pores; it has a direct bearing on the amount of fluid recoverable, whereas porosity determines the amount that is present. Generally, the smaller the grain or crystal size, the lower the permeability.

The ability to estimate porosity accurately comes through practice and experience in examining samples. Although magnification of about 10× is frequently adequate to detect porosity, higher magnification is often necessary. Pores are easier to recognize in dry samples than in wet ones. Qualitative estimates of the pore size range and mean should be made for all porous intervals. Quantitative permeability measurements are not possible by microscopic examination, but qualitative indications often may be seen. The speed with which water is absorbed by a rock fragment is an indication of its relative permeability. Conversely, water will stand up in a bead on a completely impermeable fragment.

If porosity of any category is observed, it should be thoroughly described using the proper symbols to denote its relative quality. Additional comments about it should be made in the remarks column. Samples with porosity should always be checked for hydrocarbons regardless of whether or not staining is observed on the rock surface. High gravity oils may leave little or no visible staining on the rock. A chloroethylene or other nontoxic solvent cut should dissolve any trapped hydrocarbons from the inner pores that have not been previously dissipated.

In siliciclastic rocks three types of porosity are common: intergranular, moldic and fracture. Intergranular is by far the most common type and the most readily seen in cuttings. Normally it is difficult to detect moldic or fracture porosity in cuttings. Moldic porosity, the result of leaching of soluble grains is often difficult to differentiate from plucked grains. The presence of fragments of coarsely crystalline vein calcite in cuttings is often the only indication of the occurrence of fractures.

Porosity in carbonate rocks is generally classified in one of the following categories: interparticle, intercrystal, vuggy, moldic and fracture. These broad categories can be further subdivided into such specific types as inter-oolitic, leached fossil, pel-moldic, etc. These have genetic significance and should be described in detail on the log. (See Section 5.2 Choquette and Pray Carbonate Porosity Classification.) Interparticle porosity, the pore space between particles of the rock, and intercrystal, that between crystals, usually is not larger than the particles or crystals. Vuggy porosity, comprising pore space equal to or larger than the particles of the rock, commonly results from the leaching of particles, and may have the form of irregular shaped voids.
It is important to record the sizes of vugs, as well as their presence. Where vugs are as large as, or larger than, the cuttings, the only evidence of their presence may be the occurrence of crystals, either free, or cemented to a surface which is actually a portion of the wall of a vug. In this situation it may be impossible to differentiate vuggy from fracture porosity in carbonate rocks.

Two carbonate porosity classifications are listed below. One developed by Choquette and Pray emphasizes geologic or genetic interpretation. The other by Archie deals primarily with physical properties used for evaluating or exploiting the fluid contents of rock.

5.2 Choquette and Pray's Carbonate Porosity Classification

This is one of the best and most widely used carbonate porosity classifications and was published in the AAPG Bulletin in February 1970 (V. 54, No. 2, p. 207-250). The authors recognize that carbonates are generally complex in their geometry and genesis, and their classification is designed to aid in geologic description and interpretation of pore systems and their carbonate host rocks.

A discussion of the basic pore types used in the classification is given in Appendix I, Section 10.7. Although fifteen basic pore types are listed, Figure 10.71, it should be emphasized that differentiation of all these pore types from cuttings is impossible. Generally, both interparticle and intercrystal porosity are recognizable in cuttings. Often moldic porosity is identifiable, but the larger the pores the more difficult it becomes to distinguish among moldic, vuggy, intraparticle, fenestral and shelter porosity. In logging samples it is best to consider these voids as vuggy porosity if the pore space is larger than the size of the supporting particles or larger than the cuttings.

Logging symbols for the five predominant porosity types (intergranular, intercrystal, vuggy, moldic and fracture) are shown on Chart VIII, Appendix IV. It is recognized that in some instances more precise identification of pore type can be made. In these situations, if appropriate symbology is not provided in the legends, descriptive comments should be made in the remarks column of the log.

5.3 Archie's Classification of Porosity in Carbonate Rocks

This classification was published in the AAPG Bulletin in February 1952 (V. 36, No. 2, pp. 278-298). The scheme emphasizes the features of the pore structure in carbonate rocks that control fluid flow and fluid distribution without regard to the rocks genetic or diagenetic history. Carbonates are described according to matrix texture, including size and fit of individual grains, crystals or particles and size and amount of visible pores. The Archie classification shown in Figure 10.81 illustrates the appearance, grain size and non-visible, empirically determined laboratory measured porosity for the matrix of each of three rock textures. Visible pore sizes are also shown.

A comparison between lithic descriptions and an Archie classification description are shown below.
1) Genetic or descriptive classification
Sample 1 - limestone, oolitic grainstone, fine grained,
well sorted with interparticle porosity
Sample 2 - dolomite, finely crystalline, sucrosic, porous

2) Archie - III FB10
(a) III = sucrosic or granular texture
(b) F = fine grain size
(c) B = visible pores less than 0.125
(d) 10 = 10% porosity in B pores
(e) B size pores with 10% porosity + A size matrix pores
   with 7% = total φ 17%.

The Archie terminology defines both lithic rock types as having identical
potential as reservoir rocks although the stratigraphic implications as
to the origin of the rocks are entirely different.

Data emphasizing the petrophysical characteristics of carbonates
derived from Archie's classification can be included on sample logs in
conjunction with lithologic description. A more detailed discussion of
Archie's classification is included in Appendix I, Section 10.7.
6.0 HYDROCARBONS

Although petrophysical analyses may give a conclusive determination of the presence of commercial quantities of oil, it is the geologist's responsibility to report and log all shows, and to see that good shows are evaluated. Positive indications of hydrocarbons in cuttings can be a decisive factor in the petrophysicist's evaluation of a well.

Unfortunately, no specific criteria can be established as positive indications of whether or not a show represents a potentially productive interval. The color and intensity of stain, fluorescence, cut, cut fluorescence and residual cut fluorescence will vary with the specific chemical, physical, and biologic properties of each hydrocarbon accumulation. The aging of the shows (highly volatile fractions dissipate quickly), and flushing by drilling fluids or in the course of sample washing, also tend to mask or eliminate evidence of hydrocarbons. The presence or absence of obvious shows cannot always be taken as conclusive. In many cases, the only suggestion of the presence of hydrocarbon may be a positive cut fluorescence. In other cases, only one or two of the other tests may be positive. Hence, when the presence of hydrocarbons is suspected, it is very important that all aspects be considered: the porosity and thickness of the interval, the petrophysical evaluation, and the quality of the hydrocarbon tests. Listed below are some of the most common methods of testing for hydrocarbons in samples and cores that should be used by the geologist during routine sample examination.

6.1 Routine Hydrocarbon Detection Methods

6.11 Odor

Odor may range from heavy, characteristic of low gravity oil, to light and penetrating, as for condensate. Some dry gases have no odor. Strength of odor depends on several factors, including size of sample. Describe as oil odor or condensate odor. Depending on strength of odor detected, report as good, fair, or faint, in remarks column. Faint odors may be detected more easily on a freshly broken surface or after confining the sample in a bottle for 15-20 minutes.

6.12 Staining and Bleeding

The amount by which cuttings and cores will be flushed on their way to the surface is largely a function of their permeability. In very permeable rocks only very small amounts of oil are retained in the cuttings. Often bleeding oil and gas may be observed in cores, and sometimes in drill cuttings, from relatively tight formations.

The amount of oil staining on ditch cuttings and cores is primarily a function of the distribution of the porosity and the oil distribution within the pores. The color of the stain is related to oil gravity; heavy oil stains tend to be a dark brown, while light oil stains tend to be colorless.

The color of the stain or bleeding oil should be reported. Ferruginous or other mineral stain may be recognized by lack of odor, fluorescence, or cut.
6.13 Reaction in Acid of Oil-Bearing Rock Fragments

Dilute HCl may be used to detect oil shows in cuttings, even in samples that have been stored for many years. This is effected by immersing a small fragment of the rock to be tested (approximately 1/2 to 2 mm diameter) in dilute HCl. If oil is present in the rock, surface tension will cause large bubbles to form, either from air in the pore spaces or from CO$_2$ generated by the reaction of the acid with carbonate cement or matrix. In the case of calcareous rock, the reaction forms lasting iridescent bubbles large enough to raise the rock fragment off the bottom of the container in which the acid is held, and sometimes even large enough to carry the fragment to the surface of the acid before the bubbles break and the fragment sinks, only to be buoyed up again by new bubbles. The resulting bobbing effect is quite diagnostic. The bubbles which form on the surface of a cutting fragment of similar size which contains no oil do not become large enough to float the fragment before they break away, and the fragment, therefore, remains on the bottom. In the case of oil-bearing noncalcareous sandstone, large lasting bubbles form on the surface but may not float the fragment. The large bubbles result from the surface tension caused by the oil in the sample, which tends to form a tougher and more elastic bubble wall.

It should be pointed out that this test is very sensitive to the slightest amount of hydrocarbons, even such as found in carbonaceous shale; therefore, it is well to discount the importance of a positive test unless the bobbing effect is clearly evident or lasting iridescent bubbles are observed. The test is very useful, however, as a simple and rapid preliminary check for the presence of hydrocarbons. A positive oil-acid reaction alerts the observer to intervals worthy of more exhaustive testing.

6.14 Fluorescence

Examination of mud, drill cuttings and cores for hydrocarbon fluorescence under ultraviolet light often indicates oil in small amounts, or oil of light color which might not be detected by other means. All samples should be so examined. Color of fluorescence of crudes ranges from brown through green, gold, blue, yellow, to white; in most instances, the heavier oils have darker fluorescence. Distribution may be even, spotted, or mottled, as for stain. The intensity range is bright, dull, pale, and faint. Pinpoint fluorescence is associated with individual sand grains and may indicate condensate or gas. Mineral fluorescence, especially from shell fragments, may be mistaken for oil fluorescence, and is distinguished by adding a few drops of a solvent. Hydrocarbon fluorescence will appear to flow and diffuse in the solvent as the oil dissolves, whereas mineral fluorescence will remain undisturbed.

6.15 Reagent Cut Tests

Oil-stained samples which are old may not fluoresce; thus failure to fluoresce should not be taken as decisive evidence of lack of hydrocarbons. All samples suspected of containing hydrocarbons should be treated with a reagent. The most common reagents used by the geologist are chloroethylene, petroleum ether, and acetone. These reagents are available at most drug stores and give satisfactory results. The use of ether gives a more delicate test for soluble hydrocarbons than chloroethylene or acetone, however, the ether being used
should be tested constantly, for the least presence of any hydrocarbon product will contaminate the solvent and render it useless. Chloroethene is recommended for general use although it too may become contaminated after a long period of time. Acetone is a good solvent for heavy hydrocarbons but is not recommended for routine oil detection. (CAUTION: Carbon tetrachloride is a cumulative poison and should not be used for any type of hydrocarbon detection.)

To test cuttings or cores, a few chips of sample should be placed in a clean white porcelain evaporating dish or spot plate and covered with the reagent. The sample should be thoroughly dried at low temperature before applying the reagents, thus obstructing decisive results. The hydrocarbon extracted by the reagent is called a "cut." It is observed under normal light and should be described on the basis of the shade of the coloration, which will range from dark brown to no visible tint. A faint "residual cut" is sometimes discernible only as an amber-colored ring left on the dish after complete evaporation of the reagent. A very faint cut will leave a very faint ring, and a negative cut will leave no visible color. The shade of the cut depends upon the gravity of the crude, the lightest crudes giving the palest cuts, therefore, the relative darkness should not be taken as an indication of the amount of hydrocarbon present. A complete range of cut colors varies from colorless, pale straw, straw, dark straw, light amber, amber, very dark brown to dark brown opaque. A color photograph of these cuts is in "Show Descriptions from Core, Sidewall and Ditch Samples" by R. E. Wyman and J. R. Castano.

The most reliable test for hydrocarbons is the "cut fluorescence" or "wet cut" test. In this test the effect of the reagent on the sample is observed under ultraviolet light, along with a sample of the pure solvent as control. The sample should be thoroughly dried before applying the reagent. If hydrocarbons are present, fluorescent "streamers" will be emitted from the sample and the test is evaluated by the intensity and color of these streamers. Some shows will not give a noticeable streaming effect but will leave a fluorescent ring or residue in the dish after the reagent has evaporated. This is termed a "residual cut."

It is recommended that the "cut fluorescence" test be made on all intervals in which there is even the slightest suspicion of the presence of hydrocarbons. Samples that may not give a positive cut or will not fluoresce may give a positive "cut fluorescence." This is commonly true of the high gravity hydrocarbons which may give a bright yellow "cut fluorescence." Distillates show little or no fluorescence or cut but commonly give positive "cut fluorescence," although numerous extractions may be required before it is apparent.

Generally low gravity oils will not fluoresce but will cut a very dark brown and their "cut fluorescence" may range from milky white to dark orange. An alternate method involves picking out a number of fragments and dropping them into a clear one- or two-ounce bottle. Petroleum ether, chloroethene, or acetone is poured in until the bottle is about half full. It is then stoppered and shaken. Any oil present in the sample is thus extracted and will color the solvent. When the color of the cut is very light, it may be necessary to hold the bottle against a white background to detect it. If there is only a slight cut, it may come to rest as a colored cap or meniscus on the top surface of the solvent. CAUTION: Proper ventilation is important