1.0 INTRODUCTION

Accurate sample description is basic geologic work - the foundation upon which the entire structure of subsurface investigation rests. This manual has been compiled to furnish convenient reference data on standard stratigraphic procedures. Techniques of examining, describing, and logging well cuttings, cores, and outcrop samples are set forth.

Although the primary responsibility of the sample logger was once that of providing correlation points for structural mapping, it has become increasingly important for him to provide stratigraphic data. The source, transporting medium, environment of deposition, and post-depositional history of the sediments all can be determined by sample examination. Two elements are involved: logging to represent what is present in the samples, and interpretation of the geologic history from the material which is logged.

A description may become so detailed and voluminous as to obscure important characteristics; the stratigrapher must learn to be selective and report only significant details. Sample studies should be made carefully and attentively. The accuracy of a study is dependent upon the quality of the samples and the skill of the observer. Thorough and careful initial examination and description of samples will save time and avert the necessity for re-examination.

2.0 LOG FORMS, SYMBOLS AND LEGENDS

2.1 Log Forms

2.11 Standard

The lithologic log form, shown in Appendix IV, has been adopted as the standard for the logging system and legends presented in this manual. The standard log form is obtainable from Kraftbilt Company, Tulsa, Oklahoma, and is made in two styles. The conventional strip log is 3-1/2" wide and 44" long. A variant of this log is the modular well log made in 8" sections with a vinyl hinge. Sections may be joined together by removing the wax shield from the adhesive hinge, then placed in position and glued to each other. Headings are a separate module. The advantage of the modular log is convenience. Logs can be folded and placed in files with other well data, and they can be easily carried in a brief case.

This log form has a vertical scale of 1" = 100'. For more detail, the scale can be expanded. Convenient variations in scale are 1" = 50', and 1" = 20', corresponding with standard mechanical log scales with which the lithologic logs can be compared directly. Expanded scales are especially desirable for logging cored intervals for which the detailed descriptions and symbols usually take more space than is provided by the 1" = 100' scale. Special logs can be filed separately or can be attached as a flap to the standard well log. When they are filed separately, a notation should be made on the standard well log indicating their existence.

2.12 Special Types

Special quantitative methods and techniques of rock analysis, such as versenate analyses, the preparation of insoluble residues, examination of heavy mineral suites, detailed petrographic examinations, and granulometry data, require special log forms. Because of the wide variation in sample intervals, constituents plotted, and log scales, no standard forms are recommended.

2.2 Symbols and Legends

Symbols allow a maximum amount of information to be entered in a minimum amount of space. They eliminate the necessity for lengthy written description, and facilitate comparison of logs. Written comment cannot be dispensed with completely but should be employed only for clarity, emphasis, or fuller recording of lithologic characteristics that are not provided for by the use of symbols alone. Every geologist, whether he prepares lithologic logs regularly or only consults them occasionally, should understand these symbols.

The colored symbols to be used in all sample logging are shown in Appendix IV. Black and white symbols for representing lithologic and other information, as reproduced in Appendix IV, are to be used exclusively for plotting stratigraphic columnar sections and cross sections.

The standard log form provides a column for the recording of engineering data, and Chart VII, Appendix IV shows symbols for some of the more common data that should be plotted on logs. The symbols shown are far from complete; if needed symbols are not given, the geologist can create symbols to fill his needs. Any new symbols, however, should be noted under "Remarks" at the heading of the log.

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 <u>obvious</u> 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 subtile 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 refiled).

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., sli. arg., mica., fx.-bd., fr. intgran. por., gd. Stn., gd. cut Fluor.

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. Glauconite, 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 dolomite 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, Globotruncana, 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 $CaCO_3$, 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, is 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 identification 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 $250^{\circ}F \pm$ ($120^{\circ}C \pm$) 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 drilling 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^x 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 chlorothene 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 FB_{10}

   (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 chlorothene, 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 chlorothene 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. Chlorothene 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, place a few chips in a white porcelain evaporating dish or spot plate and cover with reagent. The sample should be dried thoroughly at low temperature, otherwise water within the sample may prevent penetration by 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 discernable 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 positive "cut fluorescence." This is commonly true of the high gravity hydrocarbons which 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, chlorothene, 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 when using petroleum ether as it may have a toxic effect in a confined space. In addition, petroleum ether and acetone are very inflammable and must be kept away from open flames.

6.16 Wettability

Failure of samples to wet, or their tendency to float on water when immersed, is often an indication of the presence of oil. Under the microscope, a light-colored stain which cannot be definitely identified as an oil stain may be tested by letting one or two drops of water fall on the surface of the stained rock fragment. In the presence of oil, the water will not soak into the cutting or flow off its surface, but will stand on it or roll off it as spherical beads. Dry spots may appear on the sample when the water is poured off. This, however, is not useful in powdered (air drilled) samples which, because of particle size and surface tension effects, will not wet.

6.2 Other Hydrocarbon Detection Methods

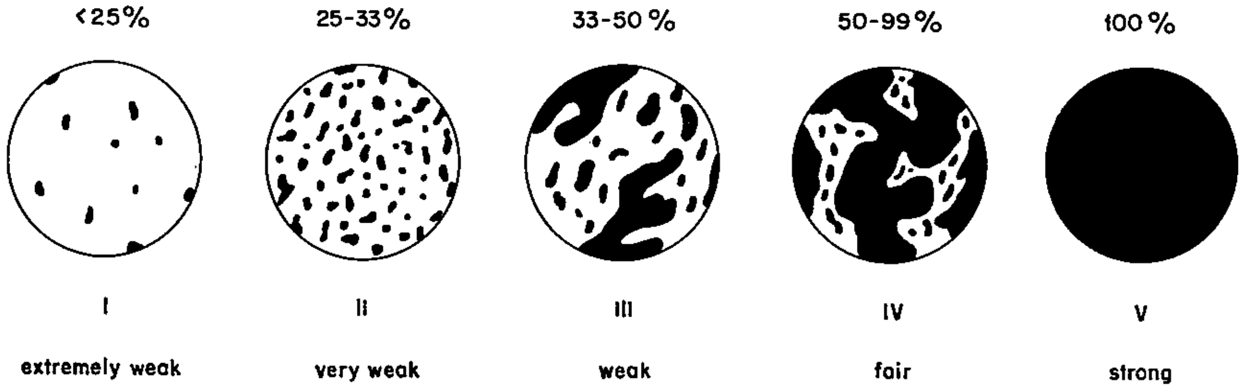
6.21 Acetone-Water Test

If the presence of oil or condensate is suspected, and provided no carbonaceous or lignitic matter is present in the rock sample, the acetone-water test may be tried. The rock is powdered and placed in a test tube and acetone is added. After shaking it vigorously it is filtered into another test tube and an excess of water is added. When hydrocarbons are present, they form a milky white dispersion, inasmuch as they are insoluble in water, whereas acetone and water are completely miscible.

6.22 Hot-Water Test

Place 500 cc of fresh, unwashed cuttings in a tin or beaker which has a capacity of 1,000 cc. Pour in hot water with a temperature of at least 170°F (77°C) until it covers the sample to a depth of 1 cm. Observe the oil film thus formed under ultraviolet light and record the amount of oil released using the scale illustrated.

DETERMINATION OF OIL SHOWS BY THE HOT WATER METHOD



6.23 Iridescence

Iridencence may be associated with oil of any color or gravity, but it is more likely to be observable and significant for the lighter, more nearly colorless, oils where oil staining may be absent. Iridescence may be observed in the wet sample tray. Iridescence without oil coloration or staining may indicate the presence of light oil or condensate.

6.24 Pyrolysis Test

When well samples of kerogen-rich rock are pyrolyzed in a thick walled test tube placed over a propane torch, oily material may be generated and condensed as a brown residue around the walls of the tube. This simple technique may be used to identify source rocks capable of generating liquid oil. However, the pyrolysis technique cannot distinguish between oil source rocks and those sediments rich in humic matter (carbonaceous shales and coals) which are considered to be dominately sources for gas. This test is also not responsive to post mature source rocks. The artificial test-tube generating process is believed to be similar to that associated with natural time-temperature dependent processes accompanying rock burial in depositional basins.

Hydrocarbons in organic rich sediments may be determined semi-quantitatively with a Turner fluorometer. One hundred milligrams of rock is pyrolyzed as above and the resulting condensation is diluted with 3 milliliters of chlorothene. The fluorescence of the solution thus produced is recorded in fluorometer units. For a more comprehensive discussion of pyrolysis and pyrolysis techniques refer to R. L. Heacock and A. Hood (1970).

6.3 Solid Hydrocarbons and Dead Oil

There has been much confusion, inconsistency and misunderstanding about the usage and meanings of these two terms. They are not synonymous.

Solid hydrocarbon refers to hydrocarbons that are in a solid state at surface conditions, usually brittle, and often shiny and glossy in appearance. There are a wide variety of substances called solid hydrocarbons with variable chemical and physical properties. The most significant of these variations is that of maturity. Some solid hydrocarbons, like gilsonite, are immature or barely mature oils, while others like anthraxolite represent the carbonaceous residue left after hydrocarbons have been overheated and thermally cracked. Anthraxolite is considered a thermally dead oil. Gilsonite, on the other hand, is certainly not a dead oil. It is a substance from which high-quality gasoline, industrial fuel oils and an endless list of other products are produced.

The term "dead oil" has been used indiscriminately in the industry to describe oils that are either (1) solid, (2) nonproducible or (3) immobile. All of these definitions are deceptive and misleading. Some solid hydrocarbons are not dead oil. Many so called "non-producible oils" are now productive because of improved recovery technology, and there are numerous examples of "immobile oil" at surface conditions that are fluid and mobile at depth. Other factors that have been used to distinguish them are extremely variable and have lacked general agreement by industry. For example, whether or not positive indications of fluorescence, residual cut, and/or cut fluorescence are considered requirements, or whether the physical state of the oil is solid or tarry.

In view of the above it is recommended that usage of the term "dead oil" be applied only to thermally dead solid hydrocarbons that will not fluoresce, or give a cut or cut fluorescence. Whenever the term is used, qualifying data should be listed.

6.4 Generalizations

No "rules of thumb" can be used to relate the evidences of the presence of hydrocarbons to potential production. However, there are some generalizations that are worth noting.

1) Lack of visible stain is not conclusive proof of the absence of hydrocarbons. (Gas, distillates and high gravity oils ordinarily will have no visible stain).

2) Lack of fluorescence is not conclusive proof of the absence of hydrocarbons.

3) Bona fide hydrocarbon shows will usually give a positive cut fluorescence (wet cut). High gravity hydrocarbons will often give a positive cut fluorescence and/or a residual cut, but will give negative results with all other hydrocarbon detection methods. (Minerals which fluoresce will not yield a cut).

4) The oil acid reaction test will give positive results when oil is present, but it is very sensitive and may give positive results in the presence of insignificant amounts of hydrocarbons.

7.0 PROBLEMS IN INTERPRETING DRILL CUTTINGS

7.1 Contamination from Previously Penetrated Beds

7.11 Cavings

Cavings may often be recognized as material identical to what has already been seen from much higher in the hole. This spalling of previously penetrated rocks into the ascending mud stream is particularly pronounced after trips of the drill stem for bit changes, drill stem tests, coring operations or other rig activities. It is suppressed by good mud control, but most samples will contain caved material. Soft shales, thinly bedded brittle shales, and bentonites cave readily and may be found in samples representing depths hundreds of feet below the normal stratigraphic position of those rocks.

Owing to differences in the hardness of rocks, the type and condition of the bit, and the practice of the driller, one cannot set any hard and fast rule for the size of true cuttings. Caved fragments tend to be larger than fragments of rock from the bottom, and they are typically rounded by abrasion. Flaky shape, freshness of appearance, sharp edges and signs of grinding by the bit may be used as criteria for the recognition of fresh cuttings. Casing points should be carefully noted inasmuch as they indicate to the geologist examining the samples what parts of the hole were open at various stages of the boring and thus were a potential source of cavings. Casing does not entirely eliminate uphole cavings. Some caved material is commonly cemented around the bottom of the casing and is likely to show up again in the mud stream while drilling deeper.

7.12 Recirculation

Recirculation chiefly refers to sand grains and microfossils from previously drilled rocks which re-enter the hole with the mud stream and contaminate the rising sample.

7.2 Other Contaminants

7.21 Lost Circulation Material

A large variety of substance may be introduced into the hole to combat lost circulation difficulties. These include such obviously foreign materials as feathers, leather, burlap sacking, or cotton seed hulls, as well as cellophane (which might be mistaken for selenite or muscovite), perlite, and coarse mica flakes which might be erroneously interpreted as formation cuttings. Most of these extraneous materials will float to the top of the sample tray when it is immersed in water, and so can be separated and discarded at once. Others may need more careful observation. Generally, the sudden appearance of a flood of fresh-looking material, which occupies the greater part of a sample, is enough to put the sample-logger on his guard. As a check, he can consult the well record for lost circulation troubles, and the kinds of materials introduced into the hole.

7.22 Cement

Cement fragments in cuttings are easily mistaken for sandy, silty, or chalky carbonate. However, most cements are of an unusual texture or color, frequently have a glazed surface, tend to turn yellow or brown when immersed in dilute HCl, and are usually full of fine black specks. The latter are sometimes magnetic, in which case the fragments of cement can be removed from the cuttings with the aid of a small magnet. If the identification of cement is questionable, the well record should be examined to determine where casing was set or cement poured.

7.23 Drilling Mud

In examining unwashed or poorly washed cuttings, it is often important to be able to recognize the drilling muds which were used. An inexperienced sample-examiner may confuse drilling mud with soft clay, bentonite, or sometimes gypsum or a carbonate. Thorough washing and rinsing in a pan of water will generally remove most mud contamination. If necessary, lithic fragments can be broken open to see if the interior (fresh) differs from the surface (coated).

Oil-base and oil-emulsion muds coat the cuttings with oil, and care must be taken to distinguish such occurrences from formation oil. They are generally recognized because they coat all cuttings regardless of lithology, rather than being confined to one rock type. Such contamination can sometimes be removed by washing the samples with a detergent or with dilute HCl. Lignosulfate muds may present problems in samples used in palynological studies.

7.24 Oil Contamination, Pipe Dope, etc.

Foreign substances, such as pipe dope, grease, etc., from the rig operations sometimes enter the mud stream. Oil may be used to free stuck drill pipe and, in some cases, a tank truck formerly used to haul fuel oil is used to haul water for rig use. In all these cases, the borehole can become contaminated with oil which can coat the drill cuttings. When foreign oil contamination is suspected, cuttings should be broken and their fresh surface examined. Naturally-occurring oil will tend to stain the chips throughout; contamination will remain on or near the surface of the chip.

7.25 Pipe Scale and Bit Shavings

Scale shavings of metal may also contaminate the samples, but they can be readily removed with a small magnet. They are usually rusty and rarely present a logging problem.

7.26 Miscellaneous Contaminants

Other lithic materials which may be present in cutting samples and obscure their real nature, or might be logged as being in place, include rock fragments used as aggregate in casing shoes.

7.3 Miscellaneous Interpretation Problems

7.31 Rock Dust

If samples are not washed sufficiently, a fine dust composed of powdered rock or dried drilling mud may cover the chips with a tightly adhering coat. In such cases, care should be taken that a fresh surface of the rock is described. Wetting the samples will tend to remove this coating, but if the chips are saturated with oil, the powder may still adhere to the surface even after immersion in water, unless a wetting agent or ordinary household detergent is used. These comments are particularly applicable to limestone and dolomite where the powdered rock film tends to be in the form of crystals which may mask the true texture of the rock. In this case, the best procedure is to break a few chips and obtain fresh surfaces for description.

7.32 Powdering (bit spin and percussion chalkification)

Powdering is the pulverization of the cuttings by regrinding (failure of the mud to remove cuttings from the bit), or by crushing between the drill pipe and the wall of the borehole. It can result in the disappearance of cuttings from some intervals, and the erroneous logging of chalky limestone where none exists.

7.33 Fusing

Shales drilled by a diamond bit may be burned and fused, resulting in the formation of dark gray or black hard fragments that resemble igneous rock.

7.34 Air-Gas Drilling Samples

Cuttings from wells drilled with air or gas instead of mud are usually made up of small chips and powder, which makes sample examination difficult. Often a simple screening of the cuttings to eliminate the powder will facilitate the sample study. When the cuttings are entirely of powder, little can be done beyond describing basic rock types and colors. When the cuttings are carbonates, the basic rock type will be difficult to determine because dolomite powder effervesces as readily as limestone powder.

Where well-indurated shale sections are air drilled, the samples can be cleaned conveniently by washing them with care on a 60-100 mesh screen. This cleaning procedure should be required, where feasible, as the dust coating on particles will mask the true color, texture and even the basic lithology of the drilled section. When "mist" drilling is done, particles can become plastered with fine mud which is removable only by a washing process; simple screening does not suffice.

7.35 Sample Lag Correction Error

Lag time is the time required for cuttings to travel from the bottom of the hole to the place at which they are collected. If new hole is drilled during this time interval, the depth assigned to the samples will be greater than the depth from which the cuttings originated.

Despite the many methods available for determination of lag time and for the correct labelling of depths shown on the sample sacks, the actual job is often done incorrectly, or not at all, by the person catching the samples, who is usually a roughneck at the well site. Subsequent sample studies are thus affected by significant discrepancies between indicated sample depth and true sample depth. As a result of these discrepancies (1) lithologies are plotted at incorrect depths, (2) interpolation of true depths becomes time consuming and requires unnecessary log manipulation, and (3) uncertainties as to the character of the formation penetrated may be introduced.

If erroneous lag correction is suspected or known, the geologist examining the samples should endeavor to plot the lithologic information obtained from the sample study at true depth. This can best be done with the aid of a penetration rate (drilling time) log or mechanical log. If the discrepancy from true sample depth is not determinable, or is questionable, the samples must be plotted as labelled, with an appropriate note in the remarks column. Lag correction is best controlled at the well site.

7.36 Spread

Spread is the separation of large from small cuttings by relative slippage (also called elutriation or differential settling) in the mud stream, so that the cuttings of a rock drilling up into fine chips may overtake the cuttings of a rock drilling up into coarse chips during their journey up the borehole. This results in the wrong sequence of rock types or very mixed samples being recovered.

7.37 "Boiler-housing" or "Dog-housing" of Samples

Unfortunately, because of inclement weather, lack of interest or supervision, breakdowns, or fast drilling, the sample catcher (generally an assigned roughneck) will occasionally sack up a number of samples only once during his tour. However, he then labels the samples as if they were properly caught at specific intervals. This collection procedure is known as "boiler-housing" or "dog-housing." Any geologist can readily see the errors inherent in this practice.

8.0 GEOLOGICAL NOTES

8.1 Unconformities

Notation on a sample log of any data which suggest the presence of an unconformity is important, even though the evidence is inconclusive. Supporting evidence may be found in nearby wells. In cuttings, the following criteria may indicate the presence of an unconformity:

1) Concentrations of minerals - e.g., phosphate, pyrite, glauconite, or manganese nodules.

2) Abrupt changes in mineral assemblages, fauna, lithologic character, or cementing material.

3) Iron oxide stains or manganese coatings.

4) Corrosion surfaces, as developed on conglomerates (e.g., blackened limestone pebbles).

5) Desert varnish, as polished surfaces on pebbles.

6) Basal conglomerate - generally more heterogeneous and weathered than other conglomerates.

7) Bone and tooth conglomerate - accumulated as a "lag zone" overlying an unconformity.

8) Siliceous shells with beekite rings - small, bluish gray to white doughnut-like rings occurring on siliceous shells below some unconformities.

9) Weathered chert - a definite indication of an unconformity, providing the chert is residual and not reworked.

10) Asphaltic residues can be present at unconformities at which oil seeped out to the surface. In the case of cherts, the oil or asphaltic residue may be in the residual chert and not in the overlying reworked material.

11) Porous zones in limestone, caused by solution by ground water, may be evidence of unconformities, but porous zones can develop for considerable distances below the surface. The porosity may not be in contact with the unconformity, but the erosional interval is the cause of it. Limestones that underlie unconformities should be more deeply leached than similar limestones which do not underlie unconformities. Other porous zones may occur at unconformities in various types of lithology because of the occurrence there of coarser material and the effects of weathering. An unconformity so established may be traced from well to well by recognition of the porous zones.

12) Caliche, and vadose pisolites, may form in carbonate rocks exposed to surface weathering.

The presence of two or more associated criteria greatly increases the chances that an unconformity is present.

8.2 Environments

Environments of deposition may be interpreted from (1) geometry and distribution of depositional units, (2) sedimentary structures and lithologic associations, (3) fossil assemblages. Information from drill cuttings, excepting fossil assemblages, is often insufficient to allow interpretation of environments. When a number of control wells are available in a region and sedimentary units can be traced, it is often possible to interpret at least generalized environments on geometry and distribution of units, lithologic associations, and in some cases, electric log shapes. Sedimentary structures and fossils observed in slabbed cores are the principal physical basis for identifying specific sedimentary environments, and determining sediment genesis.

Environments are classified with respect to sea level: continental, coastal, marine; and on the basis of physiography: shelf, slope, basin. Clastic sediments are controlled by the source of transported materials and the currents which disperse them; therefore, it is necessary to distinguish between coastal and continental environments in order to differentiate sand bodies which were formed by different processes and so have very different shapes and characters. The physiographic distinction between shelf and basin is important to the understanding of sandstones which may have been deposited in submarine fans and canyons. Carbonate sediments are generally best understood in terms of physiography. Tabular units may be expected to be present on the shelf, and lenticular units, such as mounds or reefs, form at the loci of major changes in slope; e.g., the shelf margin. The constituents of carbonate sediments are usually generated locally and not derived from external sources as are those of siliciclastics, so they may be found to change character abruptly in response to inherited or constructed topographic features anywhere in shallow marine environments. The distinction between continental, coastal, and marine is of lesser importance; most genetic units in carbonates are marine, although the landward limits of carbonate deposits may be within the coastal realm. Carbonates formed under subaerial conditions in a continental environment may not be volumetrically important but they demand particular attention as indicators of periods of exposure and thus of the intensive diagenesis which may occur under such conditions.

Description and logging of drill cuttings and cores is an essential step in providing data which will contribute to the interpretation of the environment of deposition and genesis of a sedimentary unit. To make this possible, adequate symbols must be employed.

8.21 Environment Classification and Color Legend

A generalized classification of depositional environments of both siliciclastic and carbonate sedimentation, and an environmental color legend to be used for designating interpreted environments on the standard lithologic log, is shown in Appendix IV, Section 13.4. Major depositional units can be logged by superimposing the appropriate letter designations over the color unit, as indicated on the chart.

Environmental interpretation from cuttings is extremely difficult and more often than not is impossible. However, in certain exploration areas even gross designations of basin, shelf or continental is useful information. More specific environmental interpretations can be very helpful in establishing local facies variations and sedimentologic sequences and should be recorded on the sample log along with qualifying data.

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10.0 APPENDIX I

EQUIPMENT, SPECIAL TECHNIQUES AND PROCEDURES

10.1 Equipment and Supplies for Routine Sample Examination

The following is an alphabetical listing of the principal items needed for sample examination in a well-equipped office. This list is not intended to include all items needed for specialized stratigraphic studies, nor equipment needed for a sedimentation or core laboratory.

Acid, hydrochloric; 10% or 15% solution

Alizarin Red S dye

Beakers (50 ml)

Bottles, dropper or wash. Use for acid, chlorothene, mineral oil, or glycerine

Brush (paint brush) for cleaning sample examination tray

Carborundum stone (paper or powder) or silicon carbide grit

Cement: Lakeside 70 plastic cement, or Canada balsam

Comparators for size, sorting, roundness, sphericity and percentage (may all be photographs)

Chlorothene

Dictaphone or tape recorder

Fluoroscope or ultraviolet light

Glycerine

Hot plate (electric)

India ink (black, red, green)

Lamp for microscope, with frosted and blue filters

Log forms (standard)

Logs (drilling time and mechanical) for wells under study

Magnet (pocket size)

Manual (standard sample logging manual)

Mineral oil (Nujol)

Microscope, binocular, with polarizing attachment desirable

Pan (wash pan), glass or plastic, for wetting samples

Pen (Rapidograph 00) for logging

Pencils (Eagle Verithin) in all standard colors

Plate (preferable glass)

Probes (dental probes work well)

Ruler or triangle

Scoop for picking up samples

Shield, log pattern

Sieves (ASTM No. 5 and No. 60 or No. 100)

Slides (glass, 1" x 3" or 1" x 2")

Spot plates (glass and porcelain)

Streak plate

Towels, paper or cloth

Tissue, for cleaning lens

Trays -- sample trays (metal and/or plastic)

Tweezers or forceps

Watch glasses

Water (distilled)

Wetting agent (or household detergent) for wetting powdered or contaminated samples

10.11 Comments on Some Essential Equipment and Supplies

Binocular microscope. The lens magnification should range from approximately 9 to 50 diameters. Magnification should be great enough to reveal the essential structure and texture of the sample. It should be low enough to reduce eyestrain and to provide a sufficiently wide field of view for estimating percentages of rock constituents. A magnification of approximately 9 to 12 diameters is best for routine sample examination, and 27 to 50 diameters for more detailed study. To reduce eyestrain, microscopes should be kept clean, properly focused, and in good condition. Lenses should be cleaned with lens paper; facial tissue, or a very soft, clean cloth may be used if lens paper is not available. A polarizing attachment for thin section study is a desirable accessory. Microscopes should be kept lightly lubricated.

Light. Natural or artificial light may be used; however, samples are usually examined under artificial light produced by one of several types of lamps. A Bausch & Lomb, Zeiss, or American Optical illuminator is recommended, but any lamp with a blue bulb or blue filter plate may be used. A lamp that produces a "rainbow" of colors should not be used as it will tend to mask or distort the true colors of the sample and will cause eyestrain. Not only should sufficient light be applied to the sample itself, but the work area around a microscope should be well illuminated to prevent excessive eyestrain. A gooseneck desk lamp with a blue bulb produces an excellent light, if a conventional microscope lamp is not available.

Sample trays and dishes. Several types of trays and dishes may be used for examining the sample under the microscope. A small flat tray made from wood, tin or other durable material may be used. Compartmented trays with partitions dividing the trays into five compartments are particularly useful. They are available commercially and are usually made of black plastic varying in size from 8-1/4 inches by 4 inches to 8-3/8 inches by 2-7/8 inches. Samples are poured into the trays for the examiner and the footage depth of sample is recorded on the side, or an elevated partition of each tray. This method enables the examiner to have cuttings from a complete well poured into trays for study; in addition, it facilitates the picking of sample breaks, inasmuch as gradations and variations in lithology are often readily visible and may be recognized before the samples are subjected to detailed examination under the microscope.

Fluoroscope (ultraviolet light). Geologists should have access to an ultraviolet light box at all times while examining samples, both at the well and in the office. All porous intervals should be thoroughly checked for hydrocarbons with this device. (See Section 6.0 on Hydrocarbon Detection Methods.)

Acid and solvents. Acid is used at all times in the running of samples; a dilute hydrochloric acid of 60 percent water and 40 percent acid (USP 37% HCl) is recommended.

Various chemical solvents can be used for testing for hydrocarbon shows. It is recommneded that chlorothene be used for this purpose because of its nontoxic qualities. Ether can be used also but is less desirable.

Pencils. Eagle "Chemi-Sealed" Verithin pencils are used to color stratigraphic logs. Color pencil numbers are listed in the lithologic legends of Appendix IV for each of the rock types and symbols represented by color. These colors do not smudge easily and make excellent photo-reproduction. Other types of colored pencils are available and can be used, but refrain from using brands that smudge and smear.

Ink. It is recommended that India ink (or an equivalent permanent ink) be used for recording all information on the lithologic log. Black ink should be used for all notations with the following exceptions:

1) Use red India ink for information or symbols pertaining to hydrocarbon shows and engineering data.

2) Use green India ink for all paleontologic data.

3) Use red pencil for tops.

Rapidograph pens #00 or crow quill pens should be used in recording all data on the logs.

These materials are recommended because they enable the logger to make neat precise logs which will not smear with use. Ball point pens, on the other hand, make heavy inscriptions that smear, smudge, and become illegible in a short time. Sample logs represent valuable and expensive pieces of geologic information. The effort required to make them neat and accurate is worthwhile.

10.2 Thin Sections from Drill Cuttings

10.21 Operational Method

Preparing thin sections of cuttings on an operational level is a relatively simple process. They may be prepared in the following manner:

Equipment

Hot plate

Glass slides

Lakeside #70 thermoplastic cement (broken to approx. 1/8" pieces)

Glass grinding plate, 1/4" x 10" x 10", carborundum stone or #300 or #400 grit (fine) silicon carbide paper

Carborundum loose grain abrasive (#240, #400, #600 grit)

Tweezers

Water pan

Procedure.

1) Melt cement on glass slide on hot plate and drop into it one or more selected cuttings.

2) Remove slide from hot plate and allow cement to harden by cooling.

3) Wet grinding surface and hone a flat surface on the chips. Keep grinding surface thoroughly wet by either dipping slide in water pan or sprinkling additional water on surface. Either glass plate and loose abrasive method, or wet stone or paper may be used.

4) Dry slide and place on hot plate.

5) Using tweezers or probe, turn over the honed surface of chip when cement melts.

6) Remove from hot plate and press the chip (honed surface down) against slide as cement hardens.

7) Hone the chip down to desired thinness on glass plate, wet stone or paper (as in Step 3).

NOTE OF CAUTION: Take care in Step 7 not to grind away the mounted chip entirely. It is not necessary to achieve any critical thinness. All that is necessary is to make the rock reasonably transparent. Therefore, check frequently by examining under the microscope. With a new stone, and especially with silicon carbide paper, the small chips will grind down quickly.

This process is simple in practice, and reasonable proficiency can be achieved with very few attempts. Using a carborundum stone, the whole procedure takes less than ten minutes; when using silicon carbide paper, even less time is required. Better quality sections result from using a glass plate with abrasives. Covering the finished section is unnecessary; simply wet the surface while examining.

10.22 Multiple Sample Thin Sections

The technique described above is adequate for making thin sections of well cuttings when time of preparation is a factor. Such sections can be made and examined minutes after the sample has been acquired.

Preparation of a large number of much better quality thin sections is possible by use of the following method. This method requires laboratory equipment as well as several days curing time for the resins and cements used in the process. Fifteen separate samples are cast in a single block of plastic; thus a 150 foot section of 10 foot interval samples can be examined on one 2 by 3 inch slide.

Dry drill cuttings are placed into each of 15 cavities of a polyethylene mold (Figure 10.23). An orientation mark in one cavity is molded into the casting so that the latter can be oriented after removal from the mold. This mark appears in the finished thin section. Figure 10.24.

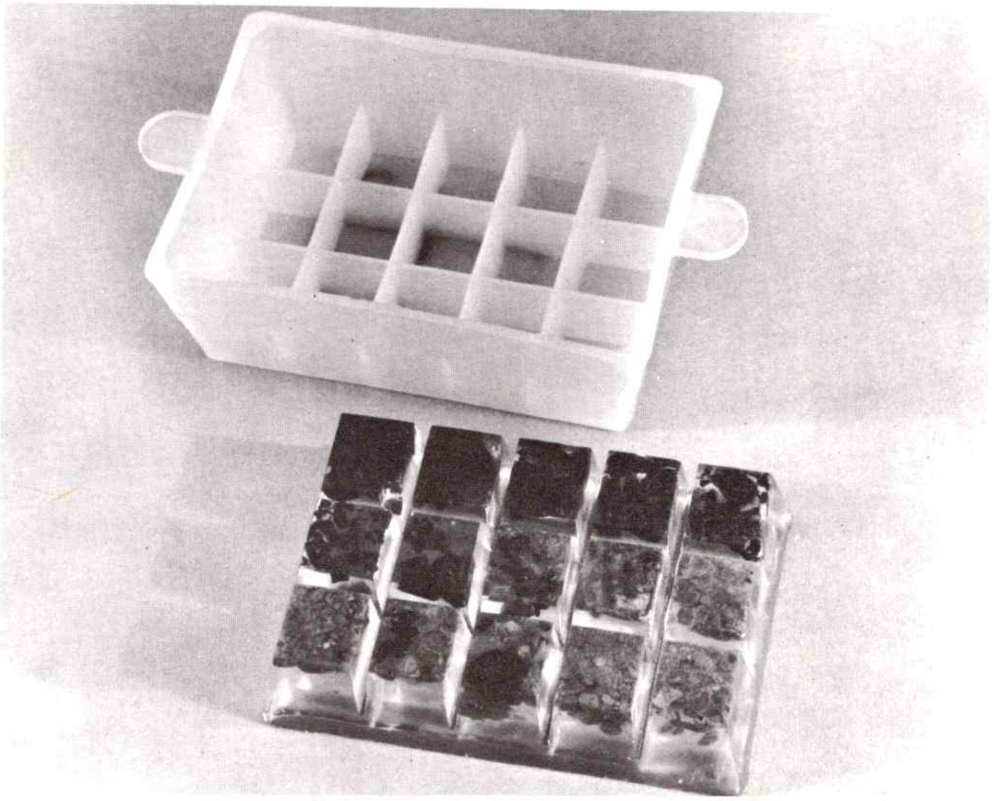
The mold is filled with polyester resin with the proper amount of hardener added. Several brands of clear casting resins are available at hobby shops. The measuring and mixing of resin and hardener should strictly adhere to the manufacturer's directions. Too much hardener will result in overheating of the casting and may melt the mold. Too little hardener will result in a soft casting which cannot be sawed or ground properly.

The cuttings should be stirred to remove air bubbles from the resin and to ensure thorough wetting of each chip. The resin will harden into a solid casting in several hours. The casting is then ground flat on a diamond or cast iron lap, the final finish being applied with 700 to 1000 mesh grit.

Water on the casting from the grinding operation is dried at room temperature. Heat will cause warping. Depending on the kinds of cuttings, several hours to overnight drying is required.

The dry casting is mounted on a flat 2 × 3 inch microslide with epoxy resin at room temperature. One resin system found to be a good adhesive and having a cured index of refraction of about 1.54 consists of 3 parts Epon 815 (Shell Chemical Co.) and 1 part Genamid 2000 (Henkel Corp.). The resin is applied to the ground surface of the casting and a 2 × 3 inch microslide lowered onto it. Gentle pressure is used to force air bubbles out from under the glass and the block is placed glass down on a level surface. The resin will harden in about 24 hours after which conventional thin sectioning techniques can be used to prepare the slides (Figure 10.24).

10.23 POLYETHYLENE MOLD AND CASTING



10.24 TYPICAL THIN SECTION OF ONE CAVITY OF CASTING

10.3 Staining Techniques

10.31 For Carbonate Rocks

Preparation of Alizarin Red S staining solution. The staining solution is prepared by dissolving 1 gram of Alizarin Red S in 998 ml distilled water and 2 ml concentrated hydrochloric acid.

Procedure.

1) Immerse the chips to be stained momentarily in acid, then briefly rinse in distilled water. (Dipping the chips, held in tweezers, in a spot plate depression filled with acid then one filled with distilled water is an effective way.)

2) Apply a drop or two of Alizarin Red S to the chip on a spot plate or impervious surface (or place the chip in the stain) for 45 seconds.

3) Remove chip and wash off excess staining solution with distilled water. Let stand until dry.

4) Examine chip under microscope. Calcite will stain red, dolomite and other minerals will not be stained.

NOTE: Stain will come off if mineral oil (Nujol), clove oil, or glycerine is applied to samples. It may be removed from samples or thin sections by scrubbing with warm water and a mild soap.

The concentration of HCl in the staining solution is extremely critical. Variations of a few tenths of a percent will give different contrasts between stained and unstained areas. It is recommended that each time a new solution is mixed, it has exactly the same HCl concentration as the solution being replaced. 0.2% HCl gives a good contrast between stained and unstained areas.

Preparation of samples for staining.

1) Samples must be clean and dry before stain is applied.

2) Stain boundaries are intensified by polishing the sample with 1000 grit and on a felt lap with stannic oxide.

3) Samples containing a high density of pores less than 1/2 mm in diameter do not stain well because the solution soaks in, coating the walls of the pore with stain, and pore differentiation is difficult. This type of rock is best stained if impregnated with plastic first. In this case the matrix is stained and the pore space is void of stain.

4) If the sample does not take a good stain with the first application, repeat the procedure for sample preparation.

10.32 For Feldspar
Hydrofluoric Acid, Sodium Cobaltinitrate and Rhodizonate Solution Technique

NOTE: Staining feldspars involves etching with Hydrofluoric acid (52%) vapor. HF acid fumes are extremely dangerous. Always work under a hood and wear rubber gloves and safety glasses.

Procedure.

1) Polish slab with 400 grit.

2) Etch polished slab surface in closed vessel of HF vapor for 5 minutes at room temperature.

3) Rinse specimen very briefly in water.

4) Quickly dip specimen twice in and out of 5% barium chloride solution.

5) Rinse specimen in water.

6) Place specimen etched surface down for one minute in saturated sodium cobaltinitrate solution. This solution is prepared by adding powdered sodium cobaltinitrate to distilled water in excess of that needed to reach saturation (40 gm/100 ml at 20-25°C).

7) Remove excess cobaltinitrate in tap water. Potassium Feldspar is stained yellow.

8) Rinse slab in distilled water and cover etched surface with rhodizonate reagent. Prepare reagent by dissolving 0.02 g of rhodizonic acid potassium salt in 30 ml of distilled water. The reagent is unstable.

9) Rinse in tap water to remove excess stain. Plagoclase Feldspar is stained red.

10.4 Detailed Insoluble Residue Studies

The procedure used in making detailed insoluble-residue analysis is described below.

Preparation of samples. Material used in the study of detailed insoluble residues may be obtained from well cuttings, cores, or outcrop samples. When cores or outcrop samples are used, a small chip should be taken at approximately one-foot intervals. It is usually desirable to group these fragments into five- or ten-foot intervals. The fragments should then be crushed and a cut made of the crushed material in order to obtain a more nearly representative sample. However, since well cuttings are generally the only source of material available, it is from them that most residues are prepared.

In the preparation of insoluble residues, a measured sample (approximately 10 grams by weight) is placed in a 200 ml beaker to which dilute (12 to 15 percent) HCl is added. The first application of acid should be done slowly, to prevent foaming and overflow caused by rapid effervescence. A few minutes after the initial application, additional acid may be added. After several hours of digestion, the samples should be washed once or twice to remove spent acid, then a second application of acid should be made. If the sample has only a small percentage of carbonate, a single application of acid will suffice for total digestion. Evidence of incomplete digestion will be the presence in the samples of dolomite fragments with rough surfaces, dolomite rhombs, or rounded limestone fragments. Finally, the sample should be washed to remove all traces of acid and prevent scum and caking of the residues.

Examination and description. The percentage of insoluble material remaining after acidization is determined by visual measurement and plotted on an insoluble-residue strip log. A typical plotted log is illustrated in Figure 2 of Ireland (1977).

Residues are examined under a binocular microscope at magnifications ranging from 9X to 50X. The observed material can be classed in one or more of the following groups: (1) cherts, (2) clastics, including argillaceous material, shale, silt, and sand, and (3) miscellaneous or accessories, which include minerals and siliceous fossils or, more frequently, fossomolds. The terminology used in describing these residues is based on morphology rather than genesis, as described by Ireland (1977).

Cherts are generally the most important constituent and are distinguished by their texture, color, and diaphaneity. The various textural types, which are frequently gradational from one to another are plotted in different colors. The cavities, oolites, and other structures of the cherts also serve to characterize them as being derived from a particular zone or formation. The clastic material, minerals, and fossils found in residues vary in quantity and importance, but are generally subsidiary to the chert.

The extensive use of insoluble residues involves expensive and time-consuming operations. Frequently it is more practical for the microscopist to prepare on-the-spot residues during routine study of well cuttings. However, caution should be observed, for seldom is a single constituent diagnostic of a particular zone or formation. Instead, an association of types of residues, or the relative abundance of a particular type and its position in the section are more significant criteria.

The symbols used in the logging of insoluble residues on the standard lithologic log are shown on Charts XII and XIII.

10.5 Versenate Analysis

A method for calcite/dolomite determinations. The versenate analysis is a relatively fast and inexpensive operational method to determine the exact calcite/dolomite ratio of a carbonate rock. The method is a color-reaction experiment which employs the use of a reagent and a crushed and sieved sample. 40 to 90 samples may be processed in one day.

Pure dolomite samples are readily identifiable with 15% dilute HCl acid, but the quantitative interpretation of mixtures of calcite and dolomite in well cuttings based on their reaction with acid is subjective and therefore variable between individuals. The versenate method has shown merit when limestone-dolomite stratigraphic traps are under investigation.

Due to variations in the chemicals employed in the reagent solution, it is necessary to test known calcite/dolomite mixtures and plot a reaction time vs calcite/dolomite ratio curve, since the pH of the buffer solution affects the reaction time.

<u>Preparation of the reagent</u>. A single reagent solution is prepared by mixing the proper volumes of three solutions: a solution of sodium ethylenediaminetetraacetate, a buffer solution, and an indicator solution. To prepare the ethylenediaminetetraacetic acid solution, dissolve 4.0 g of disodium dihydrogen ethylenediaminetetraacetate dihydrate, $Na_2 H_2 Y. 2H_2O$, in 750 ml of distilled water. To prepare the buffer solution, mix 6.75 g of ammonium chloride and 57.0 ml of concentrated ammonium hydroxide and dilute to 100 ml with distilled water. The pH of this solution is just over 10. To prepare the indicator solution, dissolve 1.0 g of eriochromeschwartz T (F241) in 100 ml of methyl alcohol. To prepare the final reagent solution, mix 50 ml of the sodium ethylenediaminetetraacetate solution, diluted with 50 ml of distilled H_2O, 12.5 ml of the buffer solution and 0.25 ml of the indicator solution. To prepare the Aerosol solution, a commercial agent, dissolve 0.1 g of Aerosol in 100 ml of water.

<u>Testing procedure</u>.

1) Crush the sample and collect the portion that passes through a 150 mesh sieve.
2) Place approximately 0.02 gm of the sample in a 10 ml beaker and wet the sample with one drop of Aerosol solution.
3) Place the beaker under a mixer with a glass stirring rod and start the mixing motor.
4) Add 3 ml of the reagent solution to the beaker and start a stopwatch when the solution comes in contact with the sample.
5) When the solution turns from blue to pink (approximate color of an Eagle Verithin #742-1/2 pencil), stop the watch and record the time on the Versene Analysis data sheet in the Reaction Time column.
6) The calcite/dolomite ratio is obtained from the accompanying chart. Silica and argillaceous impurities of less than 30% have no effect on the reaction time, but the presence of +15% anhydrite decreases the reaction in both limestone and dolomite.

10.51 % CALCITE/DOLOMITE VS. REACTION TIME CHART

CALC/DOLO RATIO	TIME (sec)	CALC/DOLO RATIO	TIME (sec)	CALC/DOLO RATIO	TIME (sec)
100/0	29	57/43	54	32/68	104-106
99/1	30	56/44	55	31/69	107-110
95/5	31	55/45	56-57	30/70	111-114
90/10	32	54/46	58	29/71	115-119
89/11	33	53/47	59	28/72	120-124
87/13	34	52/48	60-61	27/73	125-131
84/16	35	51/49	62	26/74	132-137
80/20	36	50/50	63	25/75	138-146
79/21	37	49/51	64	24/76	147-156
77/23	38	48/52	65-66	23/77	157-168
76/24	39	47/53	67-68	22/78	169-182
75/25	40	46/54	69-70	21/79	183-198
72/28	41	45/55	71-72	20/80	199-218
70/30	42	44/56	73-74	19/81	219-237
69/31	43	43/57	75-76	18/82	238-258
68/32	44	42/58	77-78	17/83	259-285
67/33	45	41/59	79-80	16/84	286-318
66/34	46	40/60	81-82	15/85	319-355
64/36	47	39/61	83-85	14/86	356-402
63/37	48	38/62	86-88	13/87	403-462
62/38	49	37/63	89-90	12/88	463-537
61/39	50	36/64	91-92	11/89	538-630
60/40	51	35/65	93-96	10/90	631-703
59/41	52	34/66	97-99		
58/42	53	33/67	100-103		

10.6 Acetate Peels

An acetate peel replica of the surface of most types of rock is quickly and easily made. It reproduces the microscopic detail of the rock structure and may serve in place of a thin section. It has the advantage over the latter of being non-destructive. Thus, when only small samples of the rock are available, notably in the case of sidewall cores, a peel can be prepared to preserve the details of grain size and structure before the core is destroyed in the course of paleontologic or petrophysical examination.

The first requirement for a successful peel is the preparation of a flat, polished rock surface. Initial grinding is done on a glass plate, using water-wet coarse (#220) silicon carbide grit. Final polish should be given with fine wet power (#800) silicon carbide.

In the case of siliciclastic rocks, no further preparation is necessary, save for carefully washing away the grit, and allowing the rock surface to dry.

Carbonate rocks must be lightly etched before a peel is made. A weak solution of hydrochloric, acetic, or formic acid (5%) is suitable for this purpose, the latter two being preferable. The rock surface is wet with water, and any excess shaken off. The surface is then flooded with acid, and held horizontal while effervescence occurs. Depending on the composition of the rock, 5 to 15 seconds are usually a sufficient time to produce suitable relief on the rock surface. Over-etching is more apt to occur than under-etching. After etching, the rock must be gently rinsed in water and left to dry for a short time.

To make a peel, the polished or etched surface is held in a horizontal position and wetted with acetone. A piece of drafting acetate of suitable thinness (.003 or .005 inch) is rolled onto it from one edge, care being taken to insure that there is no lateral movement as contact with the rock is made. When the peel has dried completely (which may be several hours, depending on the porosity of the rock) it can be removed from the rock.

When it is desired to make a peel of a coarse sandstone, or a very porous one, the surface of the rock is smoothed as described above, and wet with acetone, then a thin coat of cellulose-acetone solution is painted on it. This is left to dry overnight, and another coat applied the next day, if necessary. The resulting peel can be removed from the surface of the rock after it has dried for several hours.

The cellulose-acetate solution is prepared by mixing cellulose acetate powder and acetone in the proportion of 20 gms acetate to 130 cc acetone. This provides a stable stock solution. When peels are to be made, some of the stock solution is diluted to twice its volume with tetrachlorethane. The solution so constituted will only keep for about two weeks.

Finished peels can be mounted by placing them between two glass slides and sealing the edges with tape, or they may be stored in envelopes.

NOTE: Whenever a peel is pulled from a carbonate rock, it should be immersed in HCl before being studied or mounted, to dissolve any small particles which may have been plucked from the rock.

10.7 Choquette and Pray's Classification of Porosity in Sedimentary Carbonates

A principal element of this classification is the characterization of a given pore or pore system as one or more of several basic porosity types. Each type is simply a physically or genetically distinctive kind of pore or pore system that can be defined by such attributes as pore size, pore shape, genesis and position or association relative to either particular constituents or overall fabric.

The authors recognize 15 basic types of porosity which are shown in the summary chart of Fig. 10.71. Other pore types can be recognized, but these 15, in combination with the other elements of the classification, permit detailed geologic characterization of almost all porosity in sedimentary carbonates. Recognition of these basic types appears to be the most practical way to cope with the extreme physical and genetic diversity of pore systems in carbonates and still use current terms.

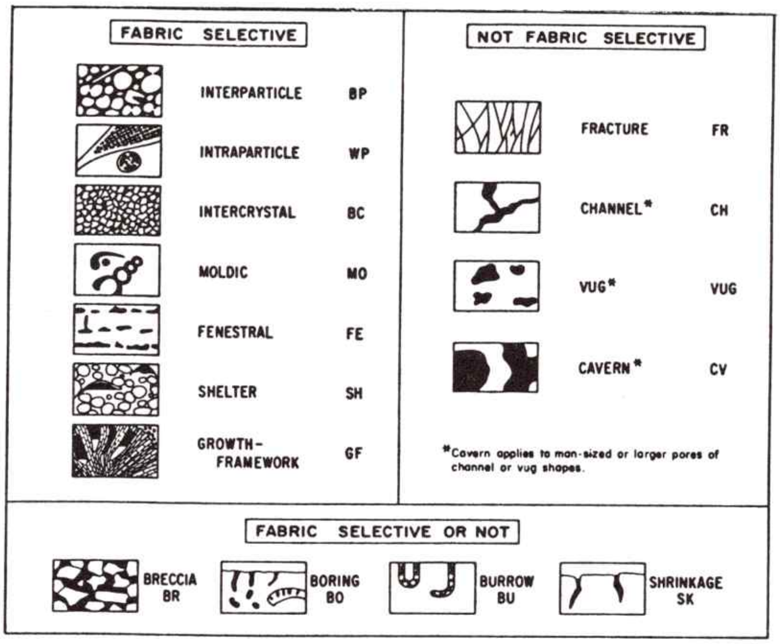
The basic types vary considerably in volumetric abundance and commonness of occurrence. Seven of them are extremely common and volumetrically important, probably forming the bulk of pore space in most sedimentary carbonates. These types are interparticle, intraparticle, intercrystal, moldic, fenestral, fracture, and vug porosity. The rest appear to be less abundant, although some are common (e.g., shelter porosity), and their separate designation and recognition can be useful for porosity characterization and facies interpretation.

The attributes that characterize the 15 basic porosity types, such as size, shape, genesis, or position with respect to fabric elements of the rock, merit further attention to clarify the nature of these types. The single element in determining three porosity types - interparticle, intraparticle, and intercrystal - is the position of the pore with respect to the fabric elements; pore size, shape, and origin are involved either secondarily or not at all. One basic type, cavern porosity, is determined solely on the basis of size. Others such as moldic, boring, and shrinkage are determined solely on the basis of origin. Still others such as vug, channel, and various minor types are identified on the basis of several attributes.

The basic porosity types can be characterized usefully on the basis of fabric selectivity (see Fig. 10.71) a property which stresses relations between pore space and other constituents. The two fabric-selectivity criteria of pore position and pore-boundary configuration help both in identifying basic porosity types and in interpreting their times of origin. Interparticle, intercrystal, moldic, and fenestral pores have both their positions and their boundaries determined by the fabric elements, hence are fabric selective. Most intraparticle porosity also is fabric selective and is so classed in Fig. 10.71. Some nonselective intraparticle porosity may be present, however, such as a vug within a clast. by definition, vugs and channels are not fabric selective. Fracture porosity is generally insensitive to the smaller scale features of the rock, and hence is considered not fabric selective.

Other factors dealt with in this classification are interpretation of the genesis of these pore types, the processes involved, the time of formation and the directions of porosity modification. For a more comprehensive discussion of porosity classification and nomenclature refer to Choquette and Pray's (1970) paper from which this writeup has been excerpted and modified.

10.71 Classification Of Carbonate Porosity Types



*Cavern applies to man-sized or larger pores of channel or vug shapes.

(Choquette & Pray 1970)

10.81 Modified Archie Classification For Porosity In Carbonate Rocks

Class	Crystal or Grain Size (Microns)	Usual Appearance (Luster)	Approximate Matrix Porosity % Not Visible (12X-18X)	Visible Porosity (% of Cutting Surface) Size of Pore-mm.			Approximate Total Porosity Percent	
				0.02	0.125-2.0	>2.0		
			A	B	C	D	A+B	A+C
I Compact Crystalline	1000 C 500 M 250 F 125 VF 62 XF 20 SL 4 Li	Resinous	2	e.g.10	e.g.15	†	12	17
		to						
		Vitreous +	5	e.g.10	e.g.15		15	20
III Sucrosic Granular	1000 C 500 M 250 F 125 VF 62 XF 20	Coarsely Sucrosic Granular	5	e.g.10	e.g.15		15	20
		to						
		Extremely Fine	7	e.g.10	e.g.15		17	22
II Chalky	20 SL 4 Li	Chalky +	15	e.g.10	e.g.15		25	30

+Where cuttings are between vitreous and chalky in appearance, designate as I/II or II/I.

†Where pores are greater than about 2.0 mm. and therefore occur at edge of cuttings (e.g., sub-cavernous pores), amount of such porosity is indicated by % of cuttings in an interval showing evidence of large pores.

Symbols:

III F-B_{10} = Finely sucrosic (therefore, matrix porosity about 7%), visible porosity about 10%, total porosity about 17%.

(II/I) VF-A = Chalky to vitreous, very fine texture (therefore, matrix porosity about 8%), no visible porosity, total porosity about 8%.

*Modified after Archie (1952) by changing to Wentworth size scale, lowering upper limit of Class II to 20 microns, and changing matrix porosity of Class III from 10% to 7% based on new empirical data.

10.8 Archie's Classification of Porosity in Carbonate Rocks

The Archie classification consists of two parts: one refers to the texture of the matrix, including grain size; and the other to the character plus frequency of the visible pore structure. As the classification provides a means of estimating the gross petrophysical relationships of a carbonate rock, its inclusion as a part of the description on all lithologic logs is recommended. (See Fig. 10.81)

The classification of the matrix gives lithological information on the minute pore structure (not visible under 10X magnification) between the crystals, or carbonate grains. Below is a tabulation of the three matrix classifications.

Class (Texture of Matrix)	Appearance of Hand Sample	Appearance Under 10X Microscope
I Compact, Crystalline	Crystalline, hard, dense, sharp edges and smooth faces on breaking. Resinous.	Matrix made up of crystals tightly interlocking, allowing no visible pore space between the crystals, often producing "feather edge" appearance on breaking.
II Chalky, Earthy	Dull, earthy or chalky appearing, hard to soft. Crystalline appearance absent because the small crystals or carbonate particles are less tightly interlocked, thus reflecting light in different directions.	Crystals, less effectively interlocking than above, joining at different angles. Extremely fine texture may still appear "chalky" under this power, but others may start appearing crystalline. Grain size for this type is less than 0.02 mm.
III Sucrosic or Granular	Sandy or sugary appearing.	Crystals less effectively interlocked, fracture generally along individual crystal faces giving a rough or sandy appearance. Generally more space between crystals. Oolitic, pisolitic and other granular textures also fall in this class.

When examining carbonate rocks it is common to find rock types that are gradational between the three Archie types. For example, Archie Type I is often found in association with Type III. Rocks in this category can be denoted as I/III with the dominant type given as the numerator. This indicates a rock gradational between Types I and III, and/or a close association of the two types, but closer to or dominated by Type I.

The crystals or grains composing the matrix are further described within the classification according to size; e.g. C, M, F, VF, etc.

The character of the visible pore size is classified according to size as listed below.

Class A: No visible porosity, at X10 magnification, or where pore size is less than about 0.02 mm diameter.

Class B: Visible porosity, greater than 0.02 but less than 0.125 mm. Cannot be seen without magnification.

Class C: Visible porosity greater than 0.125 mm, but less than size of cuttings (2 mm). Can be seen by naked eye.

Class D: Visible porosity as evidenced by secondary crystal growth on faces of cuttings or "weathered-appearing" faces showing evidence of fracturing or solution channels; where pore size is greater than the size of the cuttings.

In conjunction with qualifying the pore sizes, their frequency or amount is best denoted by affixing to the pore size classification a figure denoting the percent of surface area of the cutting or core taken up by any specific pore size.

Description of cuttings. Often more than one Archie matrix type of carbonate is present in a sample of cuttings being examined. In such cases it is necessary to estimate and report the percentage of the total sample represented by each matrix type. In addition, not all the cuttings of a specific rock type will be porous, so that a second percentage estimate indicating the amount of any rock type that is porous is required. These percentage estimates are required in order to estimate the average porosity over the sample interval. Once the various parameters of each type of carbonate present in a sample have been determined, the data are presented as follows:

Depth	Description
8410 - 20	50/70 Dol. III C B_6 C_3 50/- Ls. I F A

The numerator of the percentage unit indicates the percentage of that matrix type of the total sample, while the denominator shows the percentage of that rock type which is porous.

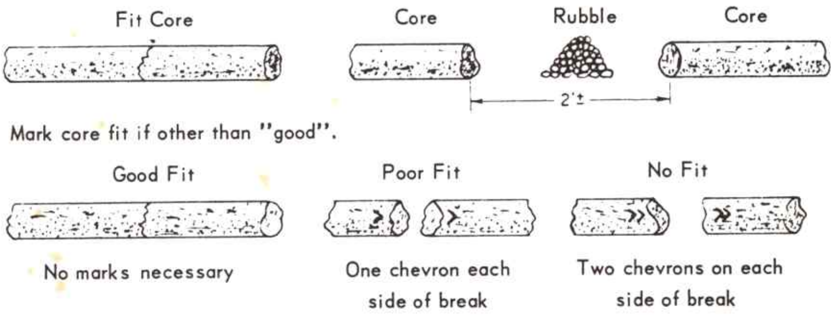
10.9 Core Handling Procedures

The primary purpose of coring is to obtain rock samples of sufficient size for making reservoir analysis tests to determine porosity, permeability and residual oil and water saturations. Cores provide the most reliable and beneficial source of all subsurface stratigraphic information. They are used to establish the physical character of formation boundaries, furnish paleontologic data for age and facies correlation, determine the structural attitude of strata, and provide sedimentologic and petrologic data from which depositional and diagenetic environment analysis can be made. It is essential that cores be properly marked, boxed, labeled and stored. The procedure listed on the following page is recommended.

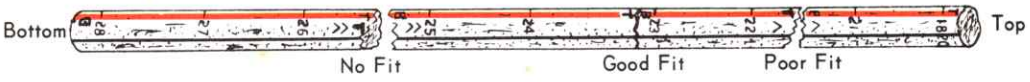
However, before boxing the core should be carefully sampled and described. There should be particular emphasis on hydrocarbon evaluation and description (see Section 6 on hydrocarbon detection methods). Beware of Contamination....It is common to find grease and/or pipe dope on cores, the result of excess "doping" used by service crews in making up core barrels and collars.

Cores should always be examined for sedimentary structures and should be described and logged using symbols shown in Appendix IV: Charts XVI, XVII, and XVIII.

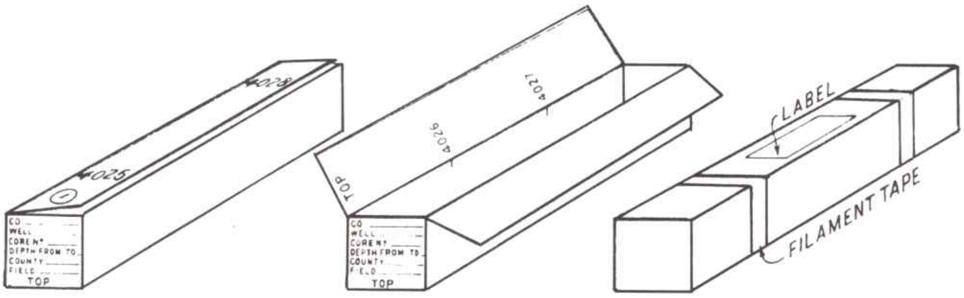
1. Prepare adequate number of boxes. Have rags.
2. Set up joints of drill pipe, etc., as required to lay out core.
3. Supervise core lay-out to insure correct orientation and order.
4. Wipe core clean, with clean dry rags. Do Not Wash.
5. Fit core. Space rubble between ends of core. Put rubble in sample sack and record depths.



6. Strap core. The unrecovered interval is understood to be at the bottom unless known otherwise.
7. Scribe core with reference lines and depths, using felt marker pens and straight edge. Black line always to the right; red line always to the left (this orients core for top and bottom). Marking the top of the core with a T and the bottom with a B is also helpful.



8. Describe core and shows.
9. Box core and mark boxes.



11.0 STANDARD ABBREVIATIONS FOR LITHOLOGIC DESCRIPTIONS

Note: Abbreviations for nouns always begin with a capital letter.

WORD	ABBREVIATION
about	abt
above	ab
absent	abs
abundant	abd
acicular	acic
agglomerate	Aglm
aggregate	Agg
algae, algal	Alg, alg
allochem	Allo
altered	alt
alternating	altg
ammonite	Amm
amorphous	amor
amount	Amt
and	&
angular	ang
anhedral	ahd
anhydrite (-ic)	Anhy, anhy
anthracite	Anthr
aphanitic	aph
appears	ap
approximate	apprx
aragonite	Arag
arenaceous	aren
argillaceous	arg
arkose (-ic)	Ark, ark
as above	a.a.
asphalt (ic)	Asph, asph
assemblage	Assem
associated	assoc
at	@
authigenic	authg
average	Av, av
band (-ed)	Bnd, bnd
basalt (-ic)	Bas, bas
basement	Bm
become (-ing)	bcm
bed (-ed)	Bd, bd
bedding	Bdg
bentonite (-ic)	Bent, bent
bitumen (-inous)	Bit, bit
bioclastic	biocl
bioherm (-al)	Bioh, bioh
biomicrite	Biomi
biosparite	Biosp
biostrom (-al)	Biost, biost
biotite	Biot
birdseye	Bdeye
black (-ish)	blk, blksh
blade (-ed)	Bld, bld
blocky	blky
blue (-ish)	bl, blsh
bored (-ing)	Bor, bor
bottom	Btm
botryoid (-al)	Bot, bot
boulder	Bld
boundstone	Bdst
brachiopod	Brach
brackish	brak
branching	brhg
break	Brk, brk
breccia (-ted)	Brec, brec
bright	brt
brittle	brit
brown	brn
bryozoa	Bry
bubble	Bubl
buff	bu
burrow (-ed)	Bur, bur
calcarenite	Clcar
calcilutite	Clclt
calcirudite	Clcrd
calcisiltite	Clslt
calcisphere	Clcsp
calcite (-ic)	Calc, calctc
calcareous	calc
caliche	cche
carbonaceous	carb
carbonized	cb
cavern (-ous)	Cav, cav
caving	Cvg
cement (-ed, -ing)	Cmt, cmt
cephalopod	Ceph
chalcedony (-ic)	Chal, chal
chalk (-y)	Chk, chky
charophyte	Char
chert (-y)	Cht, cht
chitin (-ous)	Chit, chit
chlorite (-ic)	Chlor, chlor
chocolate	choc
circulate (-ion)	circ, Circ
clastic	clas

WORD	ABBREVIATION
clay (-ey)	Cl, cl
claystone	Clst
clean	cln
clear	clr
cleavage	Clvg
cluster	Clus
coal	C
coarse	crs
coated (-ing)	cotd,cotg,Cotg
coated grains	cotd gn
cobble	Cbl
color (-ed)	Col, col
common	com
compact	cpct
compare	cf
concentric	cncn
conchoidal	conch
concretion (-ary)	Conc, conc
conglomerate (-ic)	Cgl, cgl
conodont	Cono
considerable	cons
consolidated	consol
conspicuous	conspic
contact	Ctc
contamination (-ed)	Contam, contam
content	Cont
contorted	cntrt
coquina (-oid)	Coq, coqid
coral, coralline	Cor, corln
core	c, ¢
covered	cov
cream	crm
crenulated	cren
crinkled	crnk
crinoid (-al)	Crin, crinal
cross	x
cross-bedded	x-bd
cross-laminated	x-lam
cross-stratified	x-strat
crumpled	crpld
crystocrystalline	crpxln
crystal (-line)	Xl, xln
cube, cubic	Cub, cub
cuttings	Ctgs
dark (-er)	dk, dkr
dead	dd
debris	Deb
decrease (-ing)	Decr, decr
dense	dns
depauperate	depau
description	Descr
detrital	detr
devitrified	devit
diabase	Db
diagenesis (-etic)	Diagn, diagn
diameter	Dia
disseminated	dissem
distillate	Dist
ditto	" or do
dolomite (-ic)	Dol, dol
dominant (-ly)	dom
drilling	drlg
drill stem test	DST
drusy	dru
earthy	ea
east	E
echinoid	Ech
elevation	Elev
elongate	elong
embedded	embd
equant	eqnt
equivalent	Equiv
euhedral	euhd
euxinic	eux
evaporite (-itic)	Evap, evap
excellent	ex
exposed	exp
extraclast (-ic)	Exclas, exclas
extremely	extr
extrusive rock, extrusive	Exv, exv
facet (-ed)	Fac, fac
faint	fnt
fair	fr
fault (-ed)	Flt, flt
fauna	Fau
feet	Ft
feldspar (-athic)	Fspr, fspr
fenestra (-al)	Fen, fen
ferruginous	ferr
fibrous	fibr
fine (-ly)	f, fnly
fissile	fis
flaggy	flg
flake, flaky	Flk, flk
flat	fl
floating	fltg
flora	Flo
fluorescence (-ent)	Fluor, fluor
foliated	fol
foot	Ft
foraminifer,foraminiferal	Foram, foram

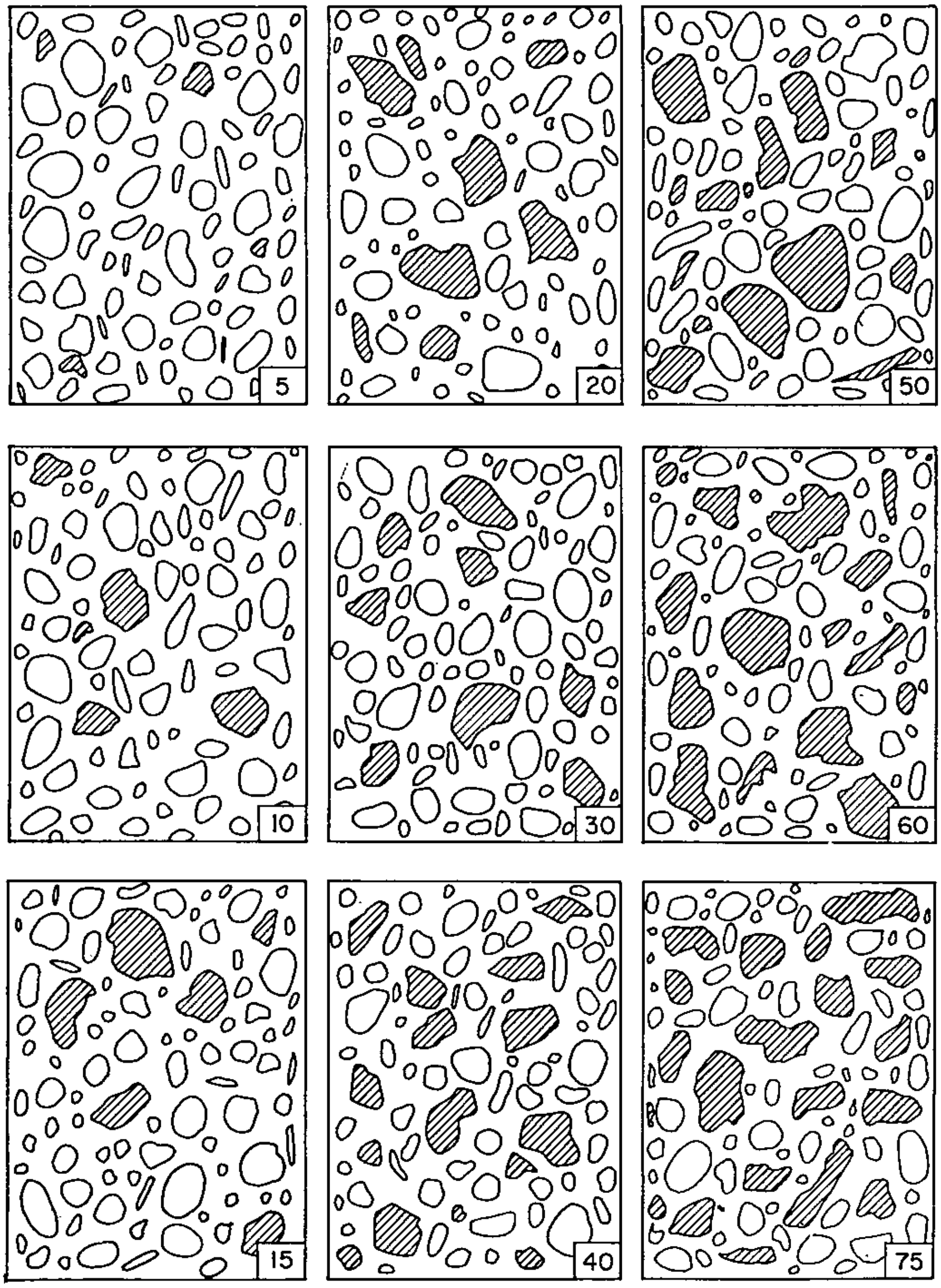
WORD	ABBREVIATION	WORD	ABBREVIATION
formation	Fm	igneous rock (igneous)	Ig, ig
fossil (-iferous)	Foss, foss	impression	Imp
fracture (-d)	Frac, frac	inch	In
fragment (-al)	Frag, frag	inclusion (-ded)	Incl, incl
frequent	freq	increasing	incr
fresh	frs	indistinct	indst
friable	fri	indurated	ind
fringe (-ing)	Frg, frg	*Inoceramus*	*Inoc*
frosted	fros	in part	I.P.
frosted quartz grains	F.Q.G.	insoluble	insl
fucoid (-al)	Fuc, fuc	interbedded	intbd
fusulinid	Fus	intercalated	intercal
		intercrystalline	intxln
gabbro	Gab	intergranular	intgran
gastropod	Gast	intergrown	intgn
gas	G	interlaminated	intrlam
generally	gen	interparticle	intpar
geopetal	gept	intersticies (-itial)	Intst, intst
gilsonite	Gil	interval	Intvl
glass (-y)	Glas, glas	intraclast (-ic)	Intclas, intclas
glauconite (-itic)	Glauc, glauc	intraparticle	intrapar
Globigerina (-inal)	*Glob*, glob	intrusive rock, intrusive	Intr, intr
gloss (-y)	Glos, glos	invertebrate	Invtb
gneiss (-ic)	Gns, gns	iridescent	irid
good	gd	ironstone	Fe-st
grading	grad	irregular (-ly)	irr
grain (-s, -ed)	Gr, gr	isopachous	iso
grainstone	Grst		
granite	Grt	jasper	Jasp
granite wash	G.W.	joint (-ed, -ing)	Jt, jt
granule (-ar)	Gran, gran		
grapestone	grapst	kaolin (-itic)	Kao, kao
graptolite	Grap		
gravel	Grv		
gray, grey (-ish)	gry, grysh	lacustrine	lac
graywacke	Gwke	lamina (-tions, -ated)	Lam, lam
greasy	gsy	large	lge
green (-ish)	gn, gnsh	laterite (-itic)	Lat, lat
grit (-ty)	Gt, gt	lavender	lav
gypsum (-iferous)	Gyp, gyp	layer	Lyr
		leached	lchd
hackly	hkl	lens, lenticular	Len, lent
halite (-iferous)	Hal, hal	light	lt
hard	hd	lignite (-itic)	Lig, lig
heavy	hvy	limestone	Ls
hematite (-ic)	Hem, hem	limonite (itic)	Lim, lim
Heterostegina	*Het*	limy	lmy
heterogeneous	hetr	lithic	lit
high (-ly)	hi	lithographic	lithgr
homogeneous	hom	lithology (-ic)	Lith, lith
horizontal	hor	little	Ltl
hydrocarbon	Hydc	littoral	litt

WORD	ABBREVIATION	WORD	ABBREVIATION
local	loc	novaculite	Novac
long	lg	no visible porosity	n.v.p.
loose	lse	numerous	num
lower	l		
lustre	Lstr	occasional	occ
lutite	Lut	ochre	och
		oil	O
macrofossil	Macrofos	oil source rock	OSR
magnetite, magnetic	Mag, mag	olive	olv
manganese, manganiferous	Mn, mn	ooid (-al)	Oo, oo
marble	Mbl	oolicast (-ic)	Ooc, ooc
marl (-y)	Mrl, mrl	oolite (-itic)	Ool, ool
marlstone	Mrlst	oomold (-ic)	Oomol, oomol
marine	marn	oncolite (-oidal)	Onc, onc
maroon	mar	opaque	op
massive	mass	orange (-ish)	or, orsh
material	Mat	*Orbitolina*	*Orbit*
matrix	Mtrx	organic	org
maximum	max	orthoclase	Orth
medium	m or med.	orthoquartzite	O-Qtz
member	Mbr	ostracod	Ostr
meniscus	men	overgrowth	ovgth
metamorphic rock,	Meta	oxidized	ox
metamorphic (-osed)	meta, metaph	oyster	Oyst
mica (-ceous)	Mic, mic		
micrite (-ic)	Micr, micr	packstone	Pkst
microcrystalline	microxln	paper (-y)	Pap, pap
microfossil (-iferous)	Microfos, microfos	part (-ly)	Pt, pt
micrograined	micgr	particle	Par, par
micro-oolite	Microol	parting	Ptg
micropore (-osity)	Micropor, micropor	parts per million	PPM
microspar	Microspr	patch (-y)	Pch, pch
microstylolite	Microstyl	pebble (-ly)	Pbl, pbl
middle	Mid	pelecypod	Pelec
miliolid	Milid	pellet (-al)	Pel, pel
milky	mky	pelletoid (-al)	Peld, peld
mineral (-ized)	Min, min	permeability (-able)	Perm, k, perm
minor	mnr	pendular (-ous)	Pend, pend
moderate	mod	petroleum, petroliferous	Pet, pet
mold (-ic)	Mol, mol	phlogopite	Phlog
mollusc	Moll	phosphate (-atic)	Phos, phos
mosaic	mos	phyllite, phyllitic	Phyl, phyl
mottled	mott	phreatic	phr
mud (-dy)	md, mdy	pink	pk
mudstone	Mdst	pinkish	pkish
muscovite	Musc	pin-point (porosity)	p.p.
		pisoid (-al)	Piso, piso
nacreous	nac	pisolite, pisolitic	Pisol, pisol
nodules (-ar)	Nod, nod	pitted	pit
north	N	plagioclase	Plag
no sample	n.s.	plant	Plt
no show	n/s	plastic	plas

WORD	ABBREVIATION
platy	plty
polish, polished	Pol, pol
pollen	Poln
polygonal	poly
porcelaneous	porcel
porosity, porous	Por, ϕ, por
possible (-ly)	poss
predominant (-ly)	pred
preserved	pres
primary	prim
probable (-ly)	prob
production	Prod
prominent	prom
pseudo-	ps
pseudo oolite (-ic)	Psool, psool
pumice-stone	Pst
purple	purp
pyrite (-itized, -itic)	Pyr, pyr
pyrobitumen	Pybit
pyroclastic	pyrcl
quartz (-ose)	Qtz, qtz
quartzite (-ic)	Qtzt, qtzt
radial (-ating)	Rad, rad
radiaxial	Radax
range	rng
rare	r
recemented	recem
recovery (-ered)	Rec, rec
recrystallized	rexlzd
red (-ish)	rd, rdsh
reef (-oid)	Rf, rf
remains	Rem
replaced (-ment)	rep, Repl
residue (-ual)	Res, res
resinous	rsns
rhomb (-ic)	Rhb, rhb
ripple	Rpl
rock	Rk
round (-ed)	rnd, rndd
rounded, frosted, pitted	r.f.p.
rubble (-bly)	Rbl, rbl
rudist	Rud
saccharoidal	sacc
salt (-y)	Sa, sa
salt and pepper	s & p
salt water	S.W.
same as above	a.a.
sample	Spl
sand (-y)	Sd, sdy
sandstone	Sst
saturation (-ated)	Sat, sat
scarce	scs
scattered	scat
schist (-ose)	Sch, sch
scolecodont	Scol
secondary	sec
sediment (-ary)	Sed, sed
selenite	Sel
shale (-ly)	Sh, sh
shell	Shl
shelter porosity	Shlt por
show	Shw
siderite (-itic)	Sid, sid
sidewall core	S.W.C.
silica (-iceous)	Sil, sil
silky	slky
silt (-y)	Slt, slty
siltstone	Sltst
similar	sim
skeletal	skel
slabby	slb
slate (-y)	Sl, sl
slickenside (-d)	Slick, slick
slight (-ly)	sli, slily
small	sml
smooth	sm
soft	sft
solution, soluble	Sol, sol
somewhat	smwt
sorted (-ing)	srt, srtg
south	S
spar (-ry)	Spr, spr
sparse (-ly)	sps, spsly
speck (-led)	Spk, spkld
sphalerite	Sphal
spherule (-itic)	Spher, spher
spicule (-ar)	Spic, spic
splintery	Splin
sponge	Spg
spore	Spo
spotted (-y)	sptd, spty
stain (-ed, -ing)	Stn, stn
stalactitic	stal
strata (-ified)	Strat, strat
streak (-ed)	Strk, strk
striae (-ted)	Stri, stri
stringer	strgr
stromatolite (-itic)	Stromlt, stromlt
stromatoporoid	Strom
structure	Str

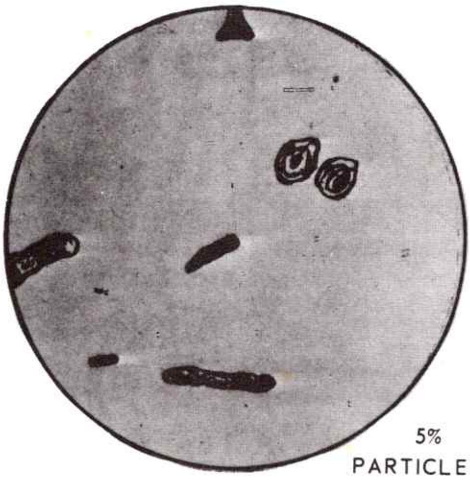
WORD	ABBREVIATION
stylolite (-itic)	Styl, styl
subangular	sbang
sublithic	sblit
subrounded	sbrndd
sucrosic	suc
sulphur, sulphurous	Su, su
superficial oolite (-ic)	Spfool, spfool
surface	Surf
syntaxial	syn
tabular (-ate)	tab
tan	tn
terriginous	ter
texture (-d)	Tex, tex
thick	thk
thin	thn
thin-bedded	t.b.
thin section	T.S.
throughout	thru
tight	ti
top	Tp
tough	tgh
trace	Tr
translucent	trnsl
transparent	trnsp
trilobite	Tril
tripoli (-itic)	Trip, trip
tube (-ular)	Tub, tub
tuff (-aceous)	Tf, tf
type (-ical)	Typ, typ
unconformity	Unconf
unconsolidated	uncons
underclay	Uc
underlying	undly
uniform	uni
upper	u
vadose	Vad, vad
variation (able)	Var, var
variegated	vgt
varicolored	varic
varved	vrvd
vein (-ing, -ed)	Vn, vn
veinlet	Vnlet
vermillon	verm
vertebrate	vrtb
vertical	vert
very	v
very poor sample	V.P.S.
vesicular	ves
violet	vi
visible	vis
vitreous (-ified)	vit
volatile	volat
volcanic rock, volcanic	Volc, volc
vug (-gy)	Vug, vug
wackestone	Wkst
washed residue	W.R.
water	Wtr
wavy	wvy
waxy	wxy
weak	wk
weathered	wthd
well	Wl, wl
west	W
white	wh
with	w/
without	w/o
wood	Wd
yellow (ish)	yel, yelsh
zircon	Zr
zone	Zn

12.1 CHART FOR ESTIMATING PERCENTAGE OF A GIVEN ROCK TYPE IN A TRAY OF CUTTINGS

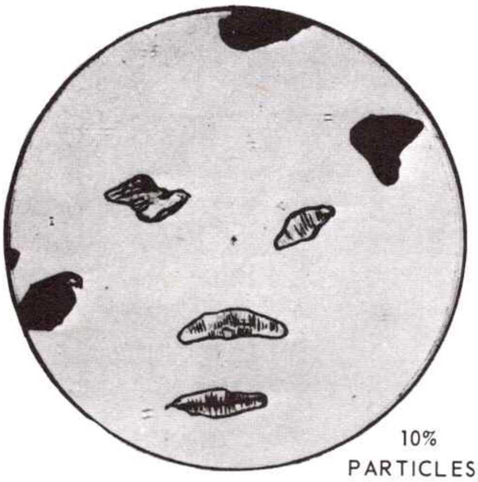


12.2 CHART FOR ESTIMATING PARTICLE PERCENTAGES

I



5%
PARTICLES



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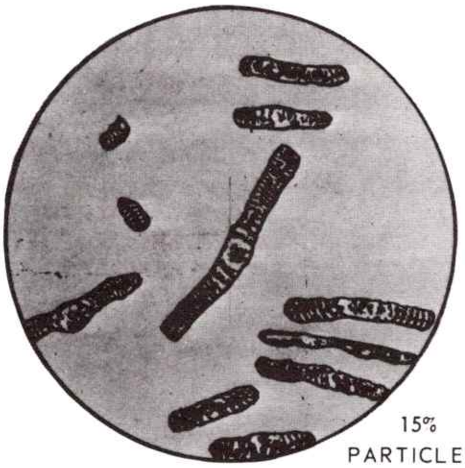
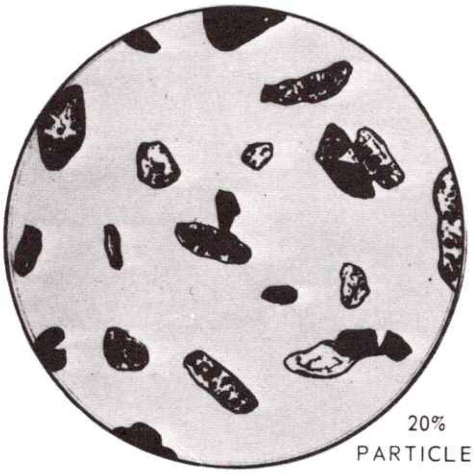
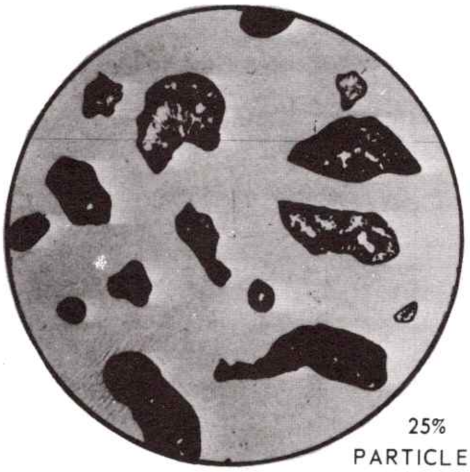
PARTICLES



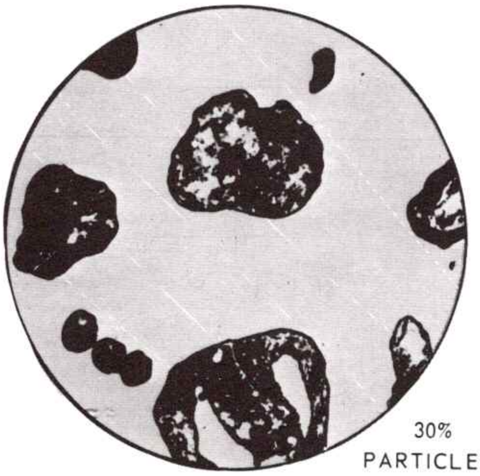
15%
PARTICLES



20%
PARTICLES



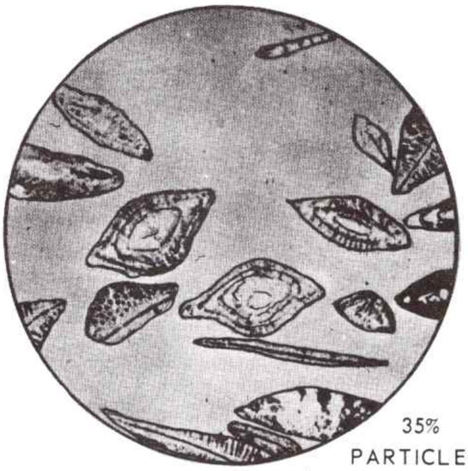
25%
PARTICLES



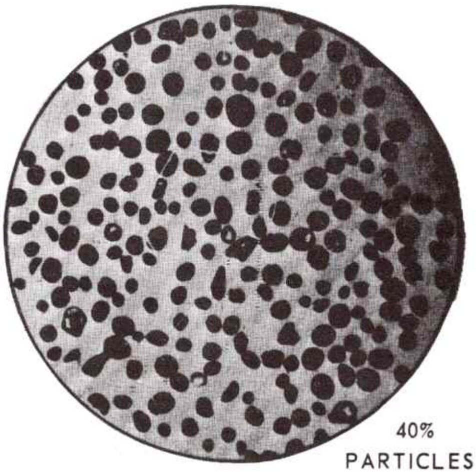
30%
PARTICLES

12.21 CHART FOR ESTIMATING PARTICLE PERCENTAGES

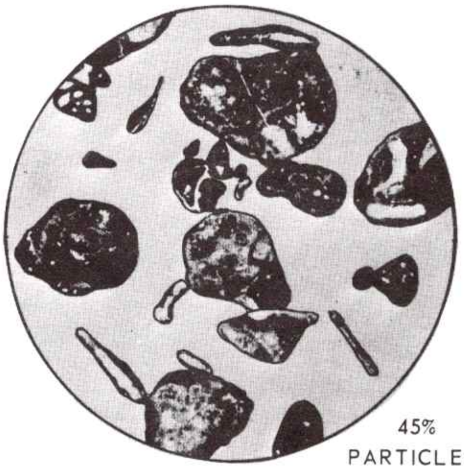
II



35%
PARTICLES



40%
PARTICLES



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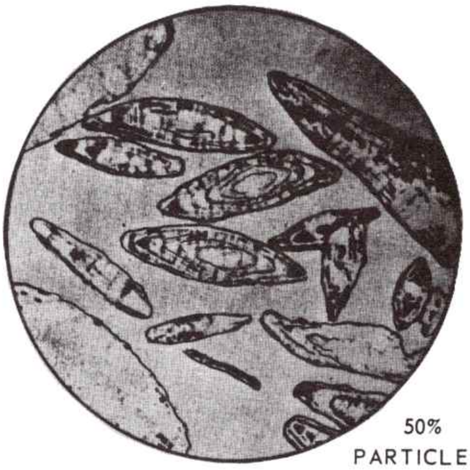

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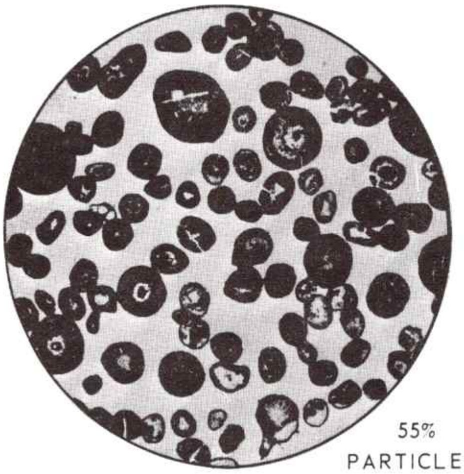
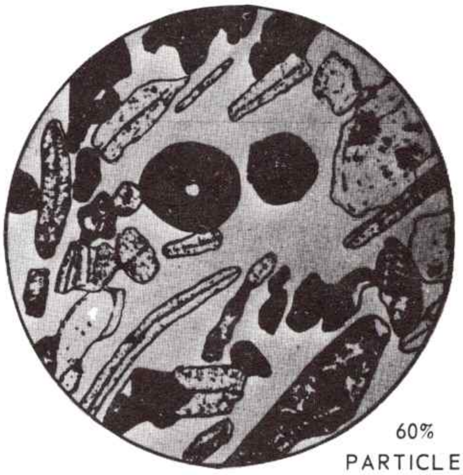
PARTICLES



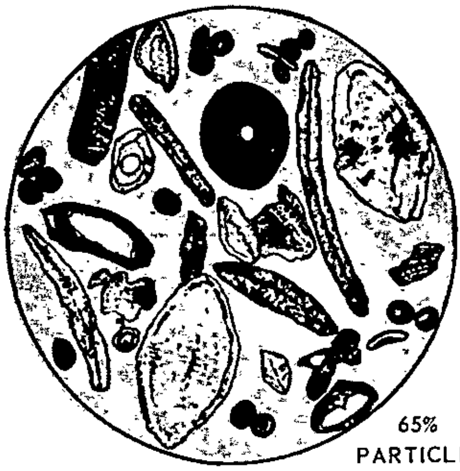
55%
PARTICLES



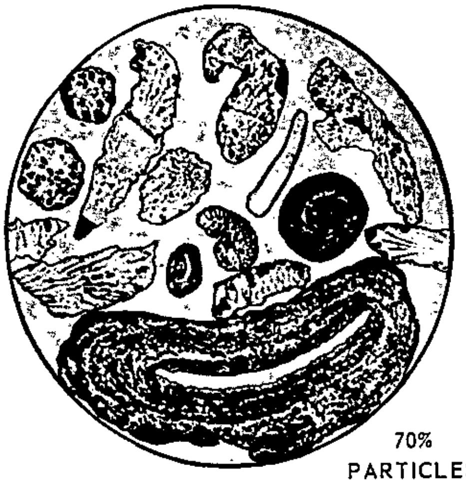
60%
PARTICLES

12.22 CHART FOR ESTIMATING PARTICLE PERCENTAGES

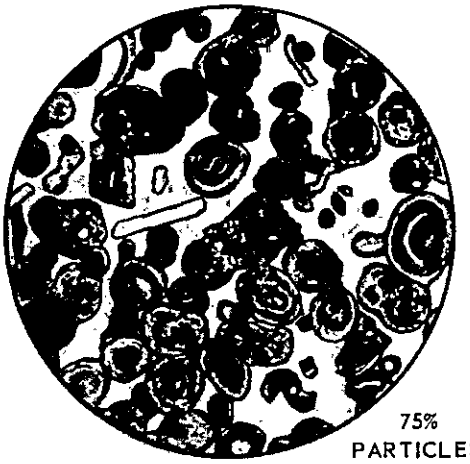
III



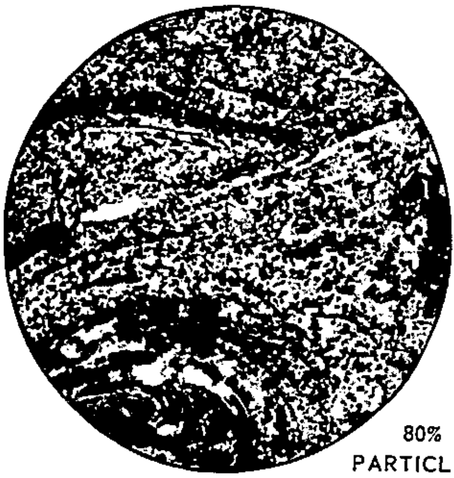
65%
PARTICLES



70%
PARTICLES

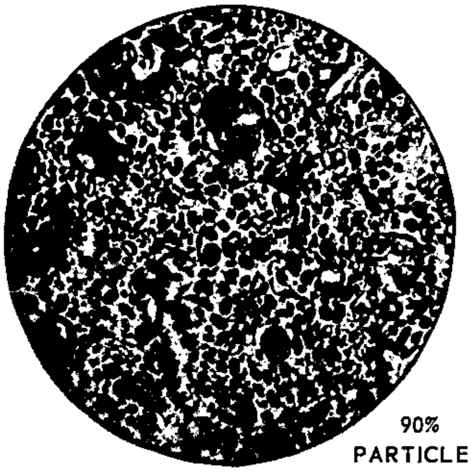


75%
PARTICLES



80%
PARTICLES

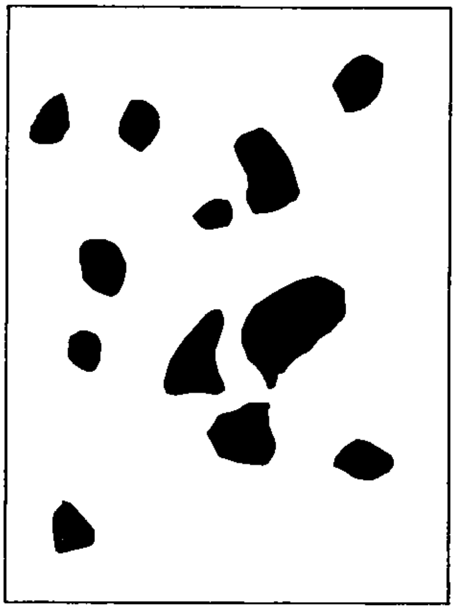
(46% FOSSILS, 34% WHITE QUARTZ GRAINS)



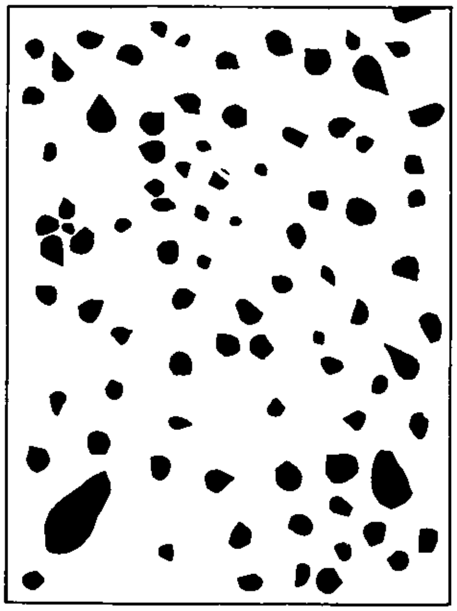
90%
PARTICLES

12.3 CHART FOR ESTIMATING PARTICLE PERCENTAGES

Chart I



11%

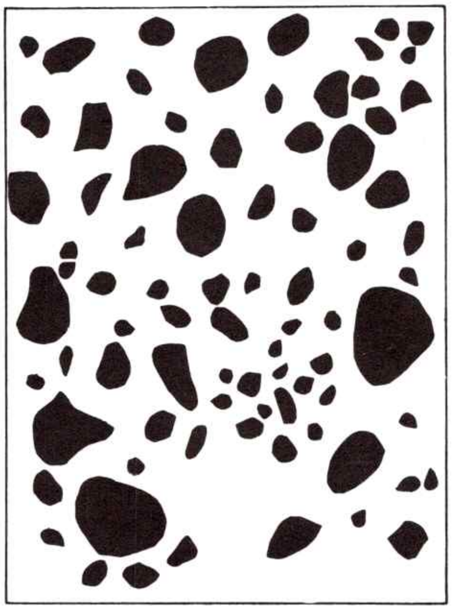


13%

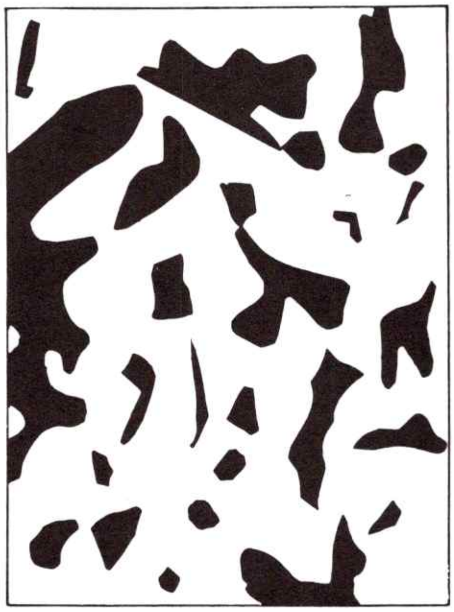
18%

12.31 CHART FOR ESTIMATING PARTICLE PERCENTAGES

Chart II



26 %



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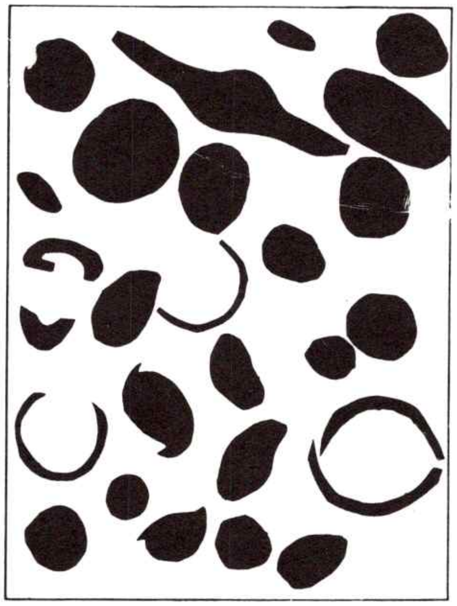
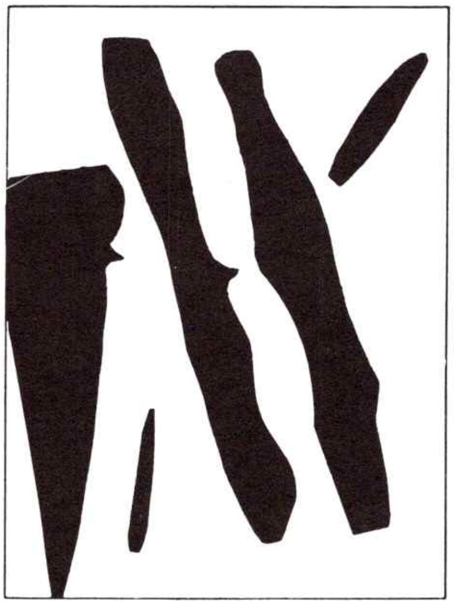


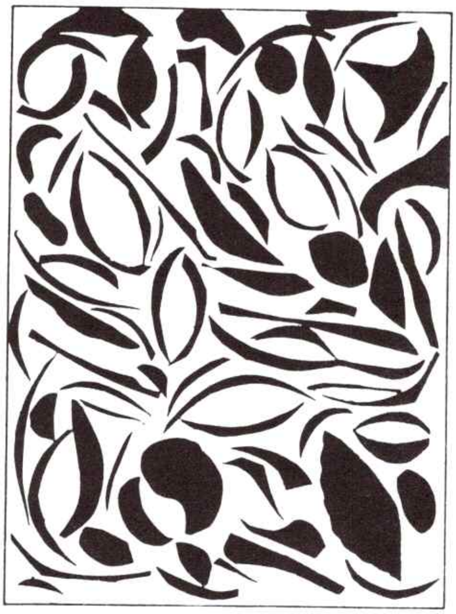
34 %



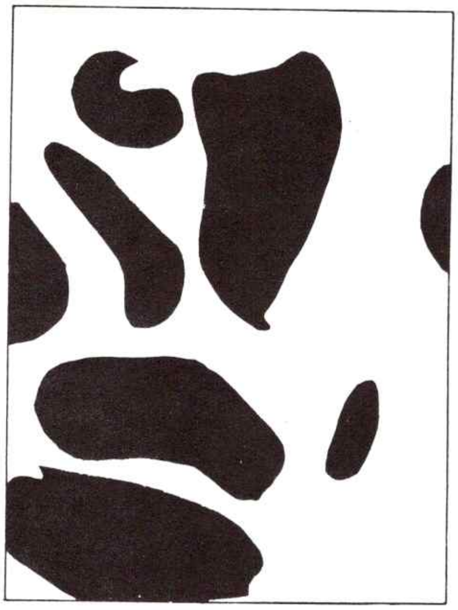
36 %

12.32 CHART FOR ESTIMATING PARTICLE PERCENTAGES

Chart III



40 %



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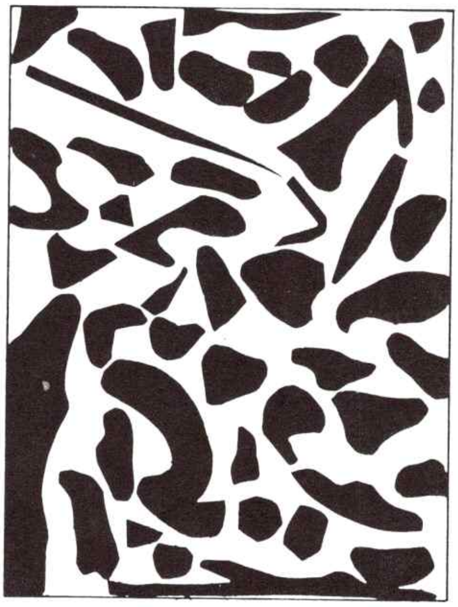
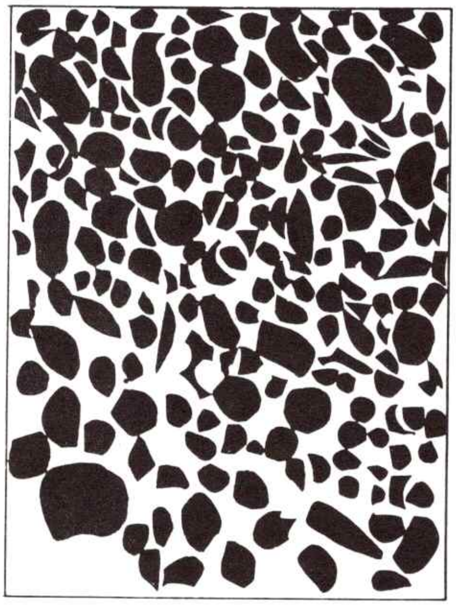


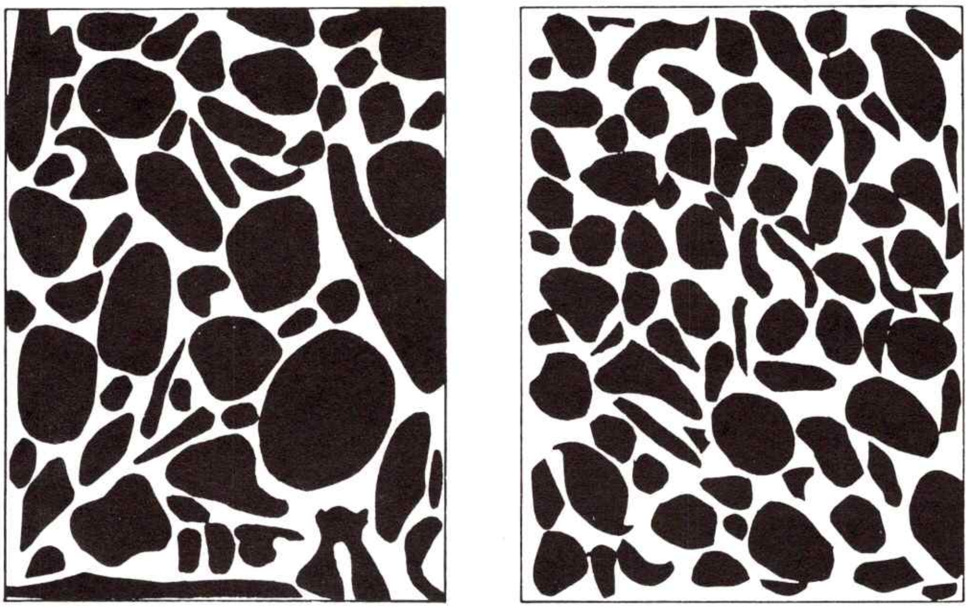
50 %



56 %

12.33 CHART FOR ESTIMATING PARTICLE PERCENTAGES

Chart IV



60 %

69 %

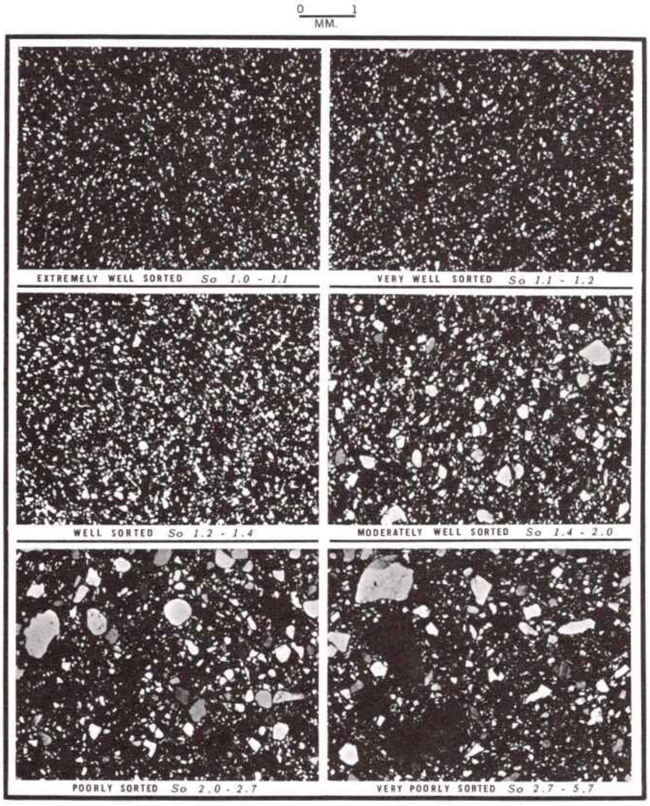
12.4 Grain Size Comparator

The film-strip comparator for grain size, referred to in the text as belonging under section 12.4, is attached to this binder in a special envelope and may be located elsewhere at receipt.

12.5 GRAIN SIZE AND SORTING COMPARATORS (Photomicrographs of Thin Sections)

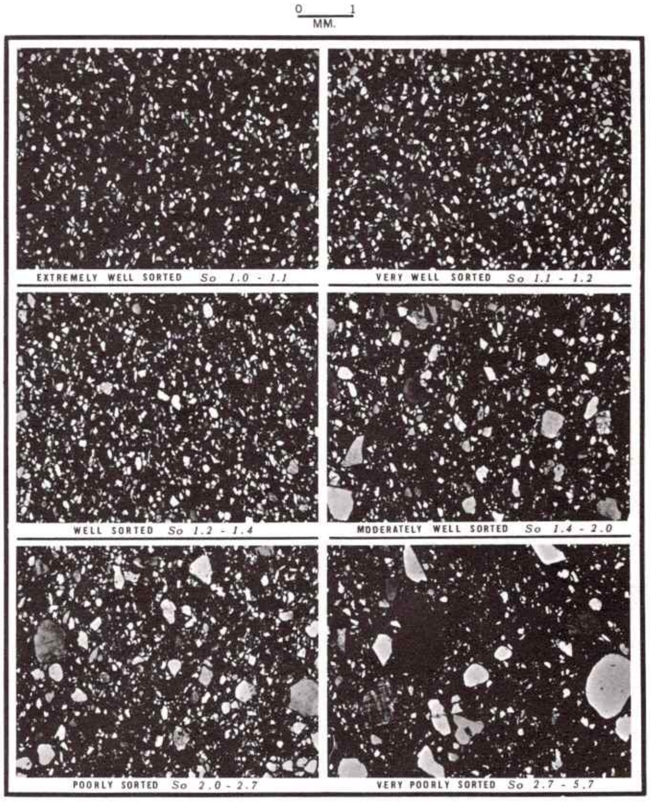
LOWER VERY FINE GRAIN SIZE

MEDIAN DIAMETER 0.074 mm. (•)



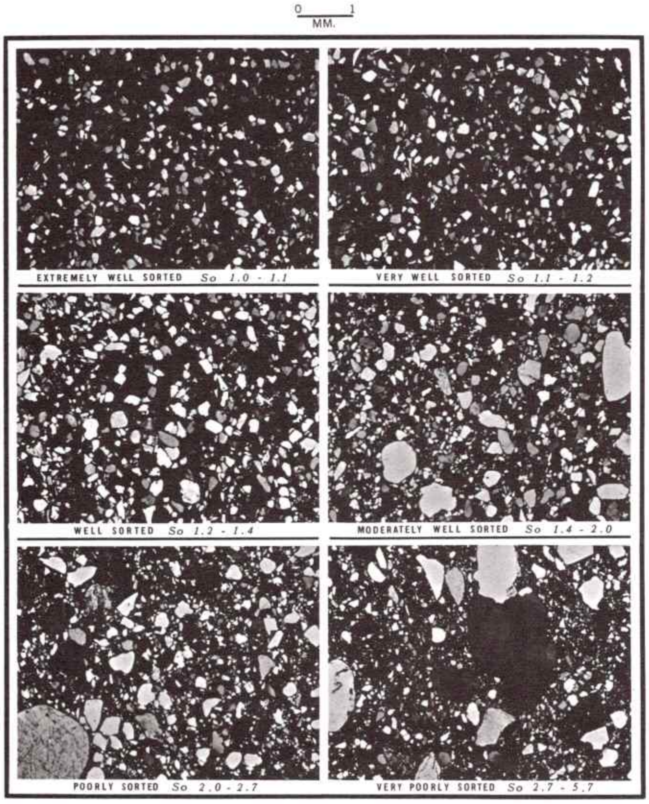
UPPER VERY FINE GRAIN SIZE

MEDIAN DIAMETER 0 105 mm. (•)



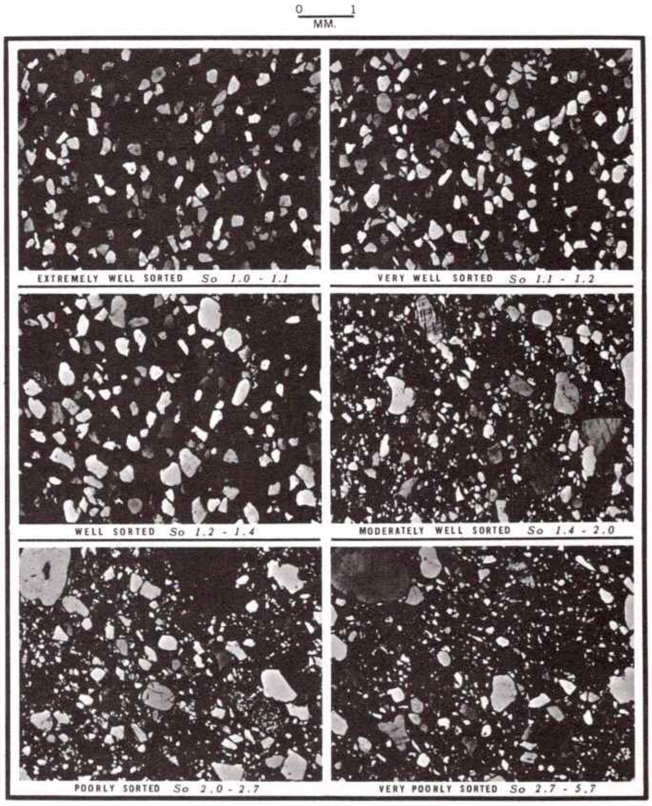
LOWER FINE GRAIN SIZE

MEDIAN DIAMETER 0.149 mm. (●)



UPPER FINE GRAIN SIZE

MEDIAN DIAMETER 0.210 mm. (●)



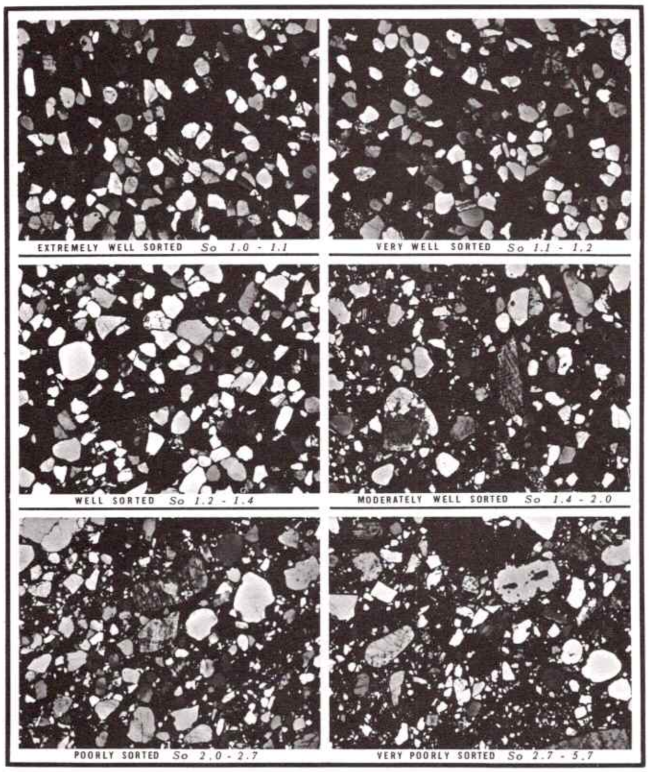
(from Beard and Weyl)

12.51 GRAIN SIZE AND SORTING COMPARATORS (Photomicrographs of Thin Sections)

LOWER MEDIUM GRAIN SIZE

MEDIAN DIAMETER 0. 297 mm. (●)

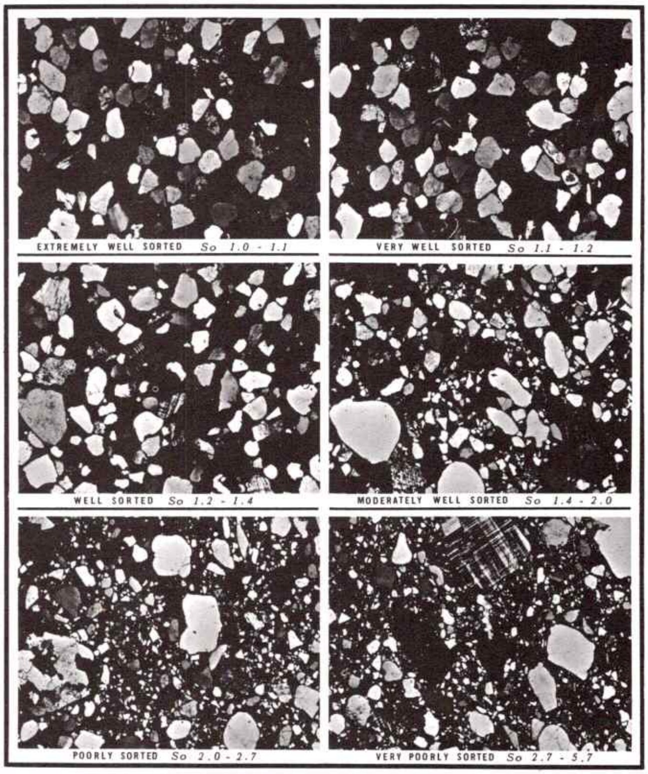
0 1 MM.



UPPER MEDIUM GRAIN SIZE

MEDIAN DIAMETER 0.420 mm. (●)

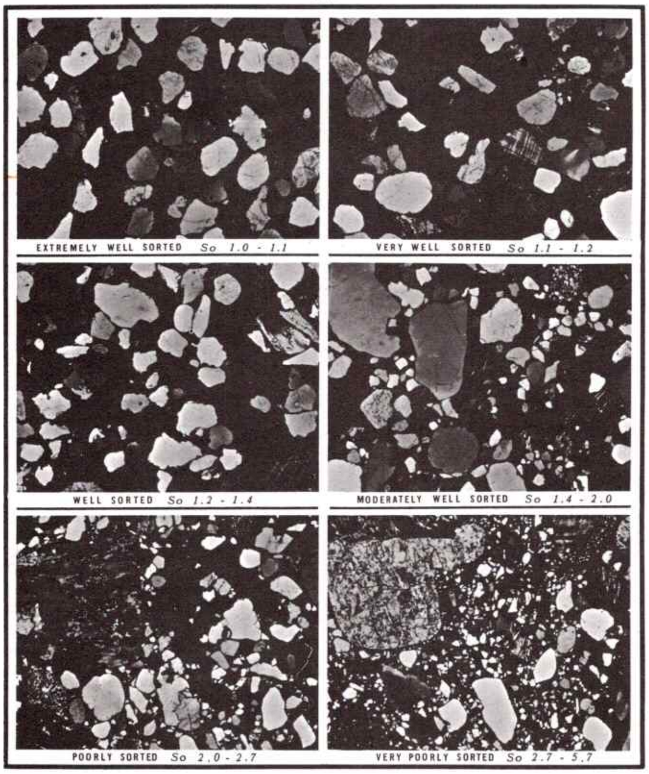
0 1 MM.



LOWER COARSE GRAIN SIZE

MEDIAN DIAMETER 0.590 mm. (●)

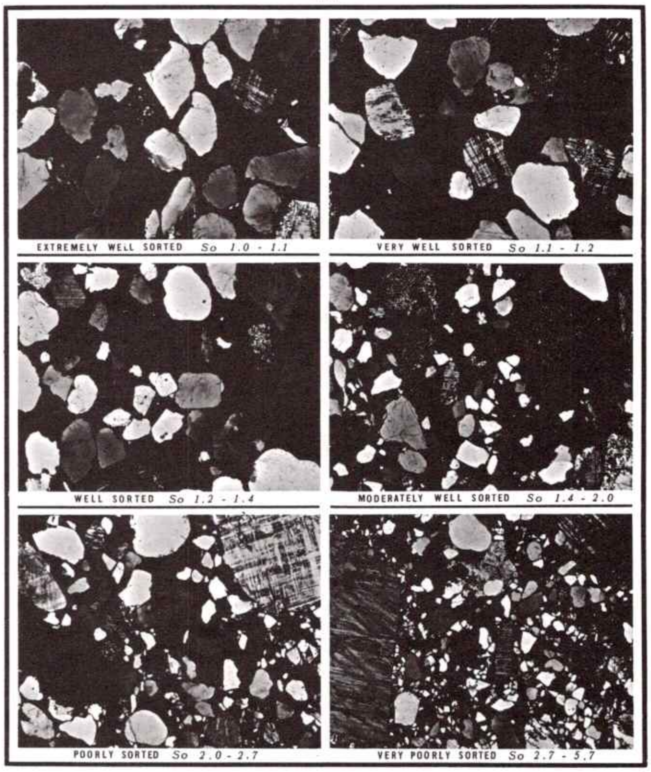
0 1 MM.



UPPER COARSE GRAIN SIZE

MEDIAN DIAMETER 0.840 mm. (●)

0 1 MM.



(from Beard and Weyl)

12.6 Conversion Graph:

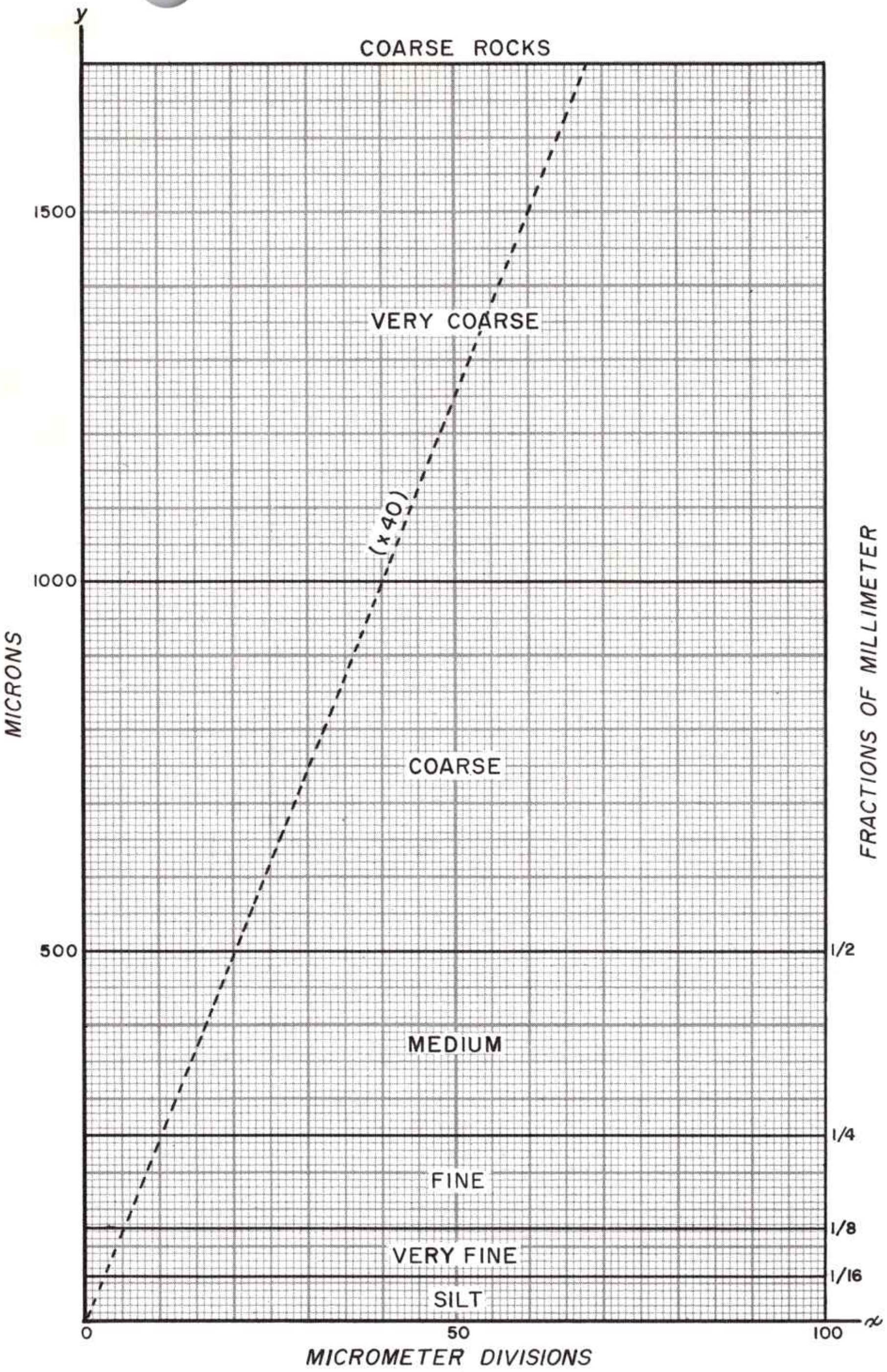
Use: To convert readings on the eyepiece micrometer into metric scale readings.

Take a piece of millimeter paper or a millimeter scale, place it on the microscope stage, and count the number of scale divisions that fall within a convenient number of eyepiece micrometer divisions. If at magnification ×40, for example, 40 subdivisions on the eyepiece micrometer subtend one scale division, plot this on the A conversion graph as follows: Move along the X axis 40 divisions. Then proceed up to the Y axis intercept which represents 1 millimeter, and draw a line from that point through the origin.

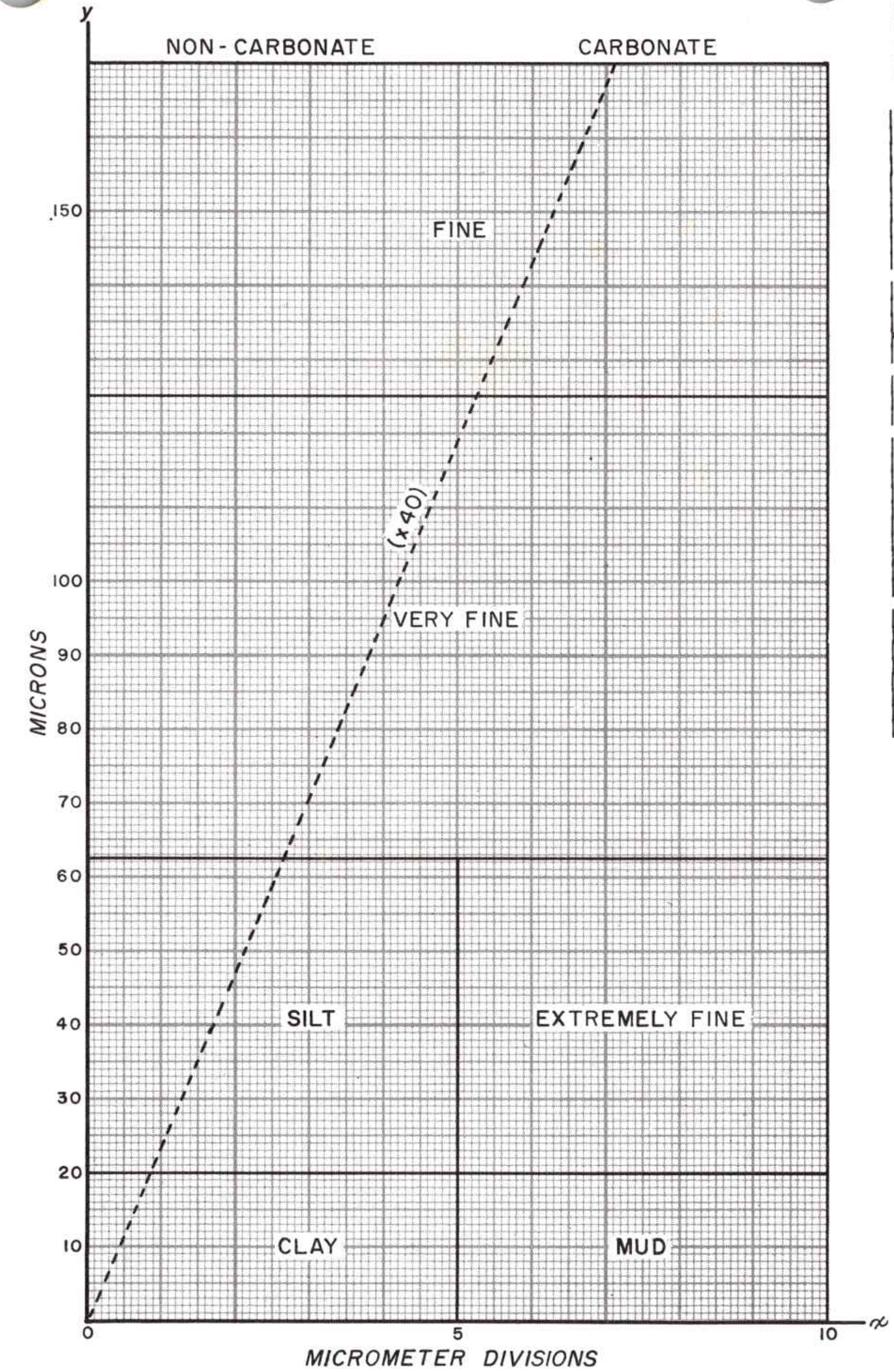
Because the B conversion graph is 1/10 the A graph, then at 4 micrometer divisions you should read 0.1 scale divisions. In most cases this approach will be sufficiently accurate (e.g., 0.1 scale divisions fell at 4.2 micrometer divisions at ×40, when actually measured).

To measure a grain, count the divisions it subtends on the ocular micrometer and, using the graph and appropriate magnification line, read off the size in millimeters, microns or Wentworth class as desired.

12.61 Conversion Graph for Micrometer Eyepiece:



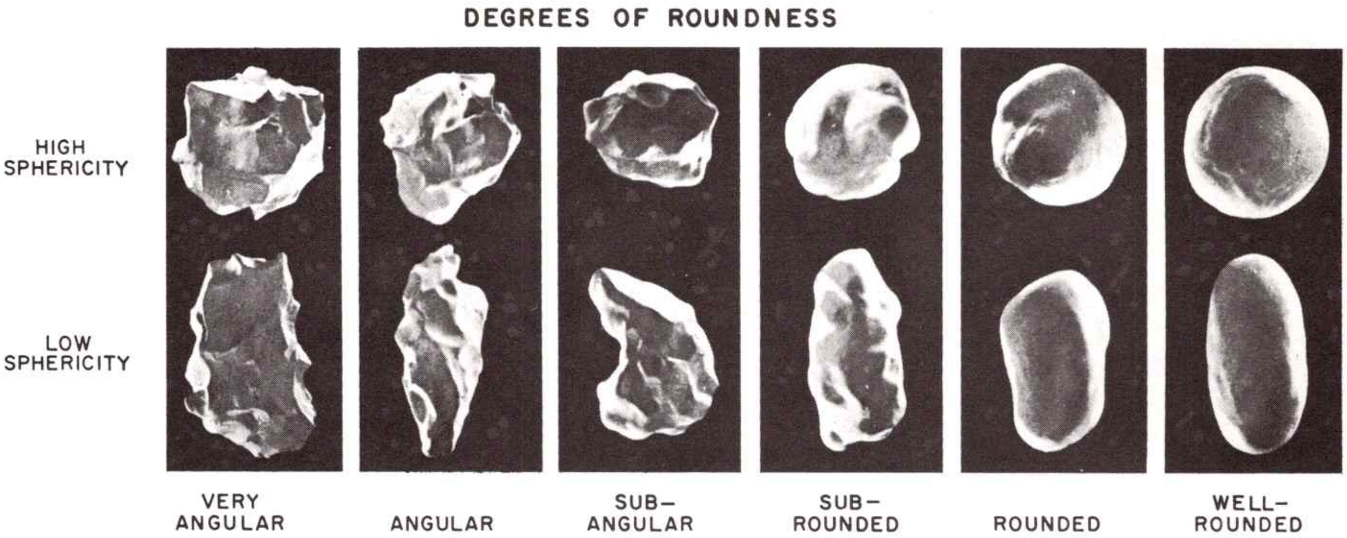
A



B

12.7 Roundness and Spericity:

Roundness refers to the roughness of the surface; Sphericity refers to the shape of the grain. These parameters can be expressed by words or by numerical values as shown in the two charts below.



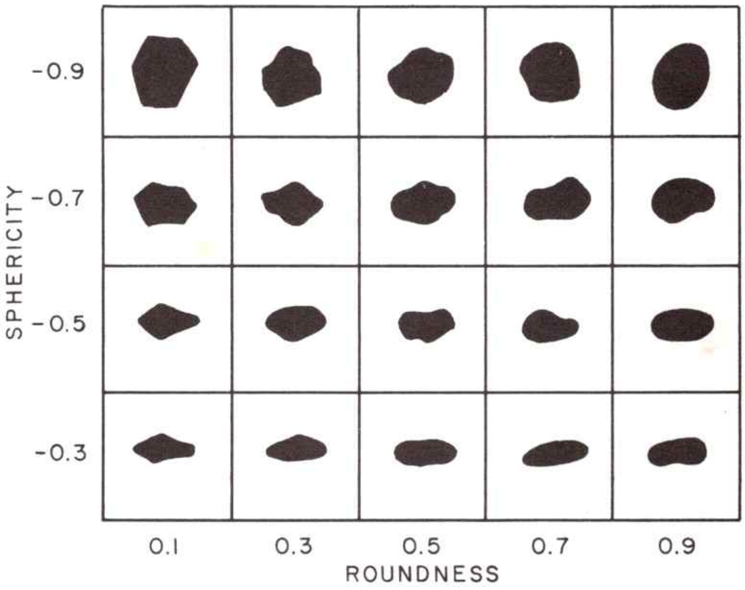
(from Powers, 1953)

SPHERICITY

0.3	LOW
0.5 & 0.7	MODERATE
0.9	HIGH

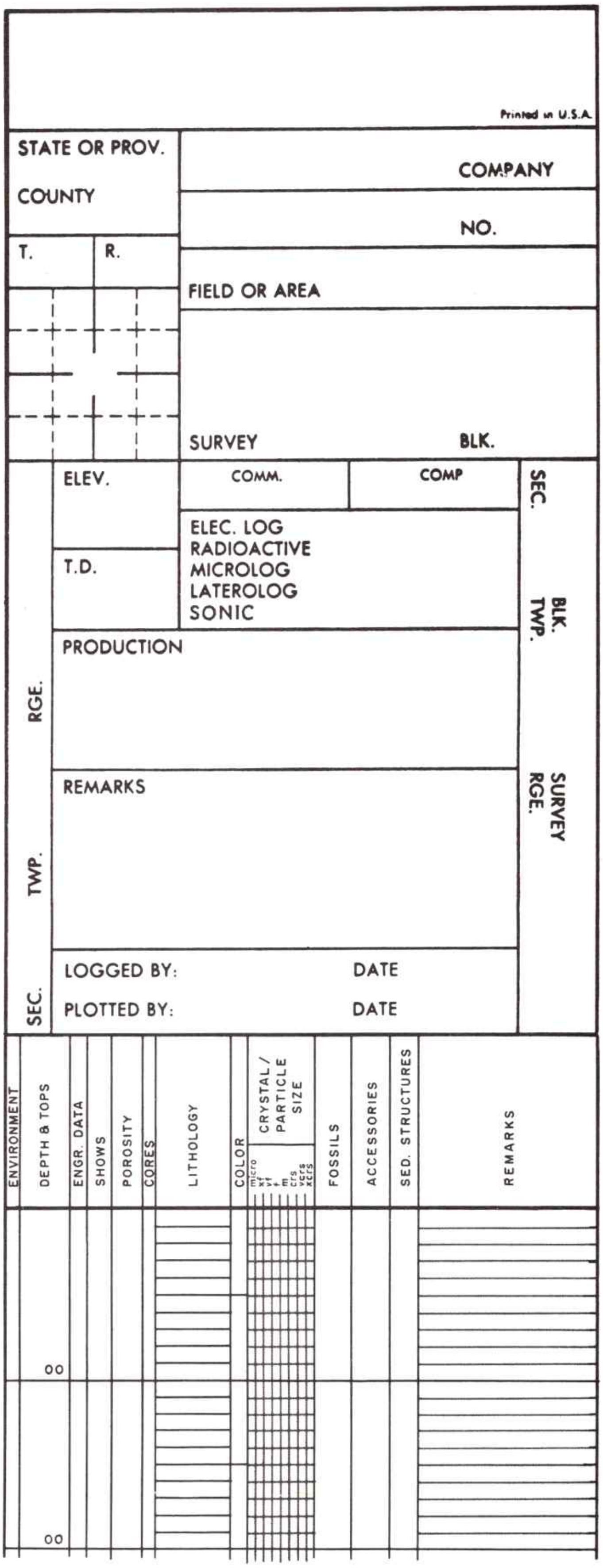
ROUNDNESS

0.1	ANGULAR
0.3	SUBANGULAR
0.5	SUBROUNDED
0.7	ROUNDED
0.9	WELL ROUNDED



13.1 STANDARD LITHOLOGIC LOG FORM

This lithologic log form is the standard for the logging systems presented in the following pages. Refer to Section 2.1 for additional information about the log.



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STATE OR PROV.

COUNTY

COMPANY

NO.

T.

R.

FIELD OR AREA

SURVEY

BLK.

ELEV.

COMM.

COMP

SEC.

T.D.

ELEC. LOG
RADIOACTIVE
MICROLOG
LATEROLOG
SONIC

BLK.
TWP.

PRODUCTION

RGE.

REMARKS

SURVEY
RGE.

TWP.

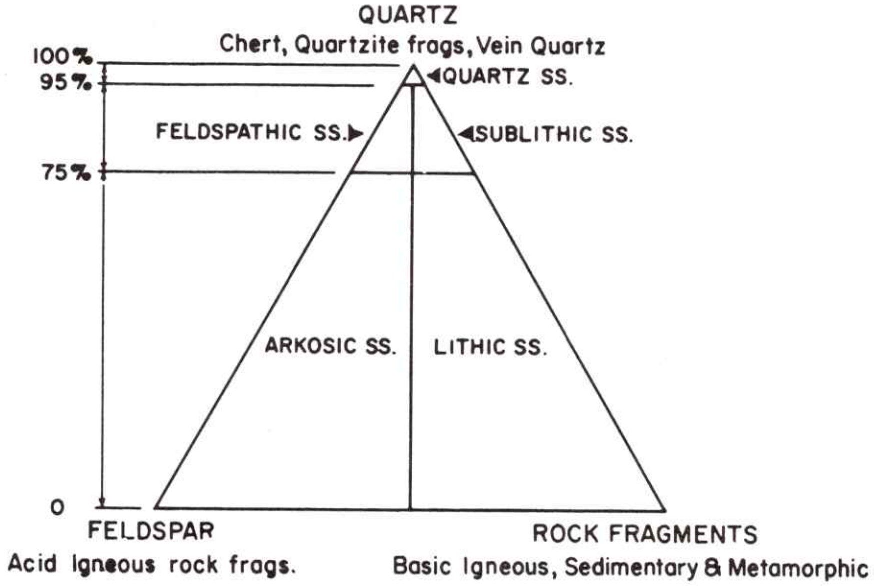
LOGGED BY: DATE

SEC.

PLOTTED BY: DATE

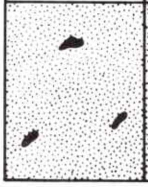
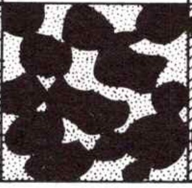
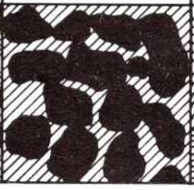
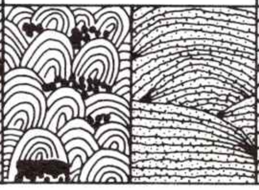
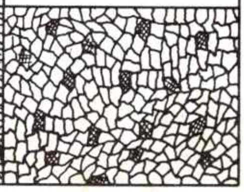
ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL / PARTICLE SIZE micro xf vf f m crs vcrs xcrs	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
	00											
	00											

13.2 CLASSIFICATION OF SILICICLASTIC ROCKS



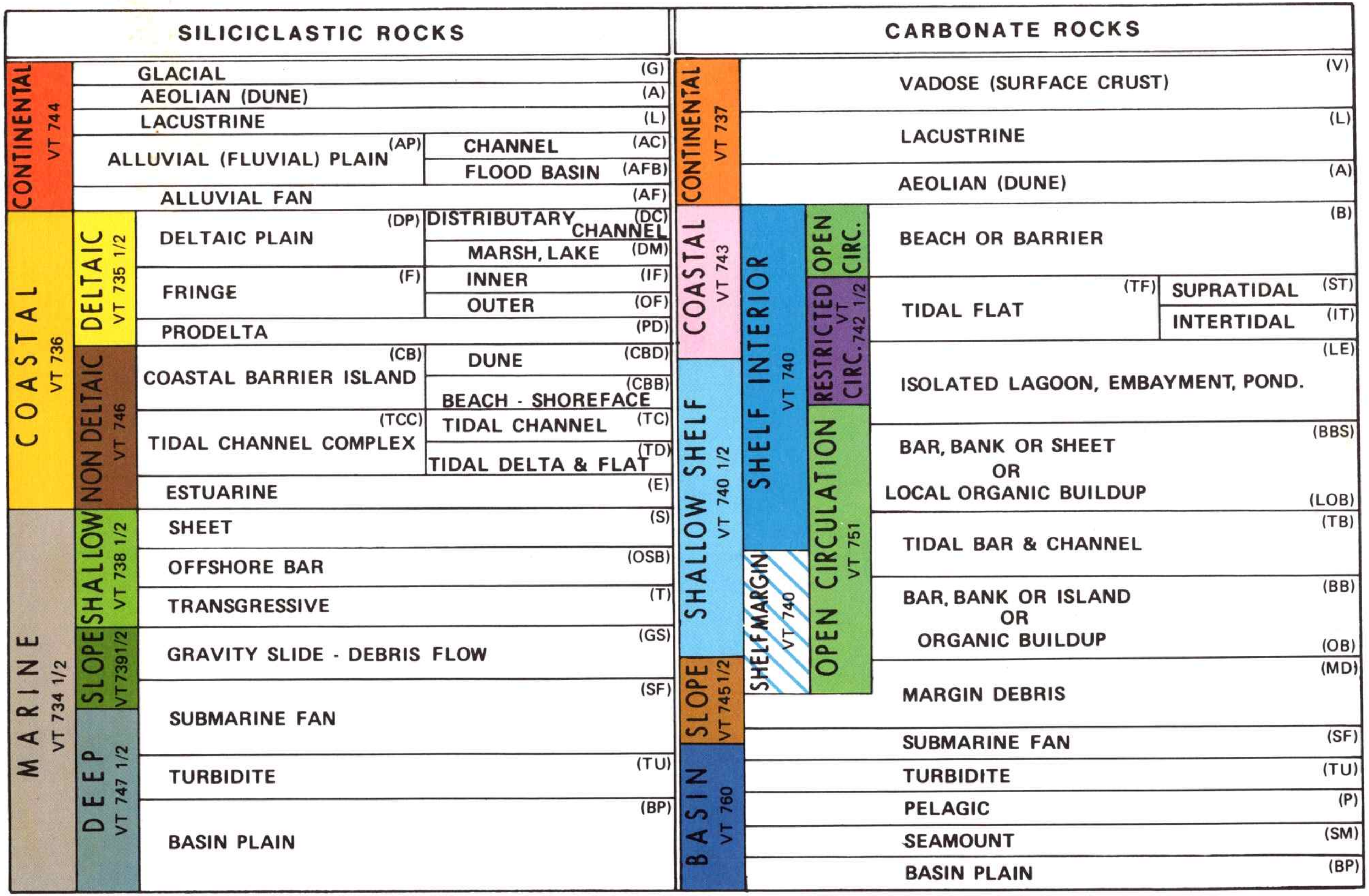
13.3 CLASSIFICATION OF CARBONATE ROCKS ACCORDING TO DEPOSITIONAL TEXTURE

modified after R. J. Dunham 1960

Depositional Texture Recognizable					Depositional Texture Not Recognizable
Original Components Not Bound Together During Deposition				Original components were bound together during deposition, as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.	(Subdivide according to classifications designed to bear on physical texture or diagenesis.)
Contains mud (particles of clay and fine silt size, less than 20 microns)			Grain-supported		
Mud-supported		Grain-supported			
Less than 10 percent grains	More than 10 percent grains	More than* 10 percent mud	Less than* 10 percent mud		
Mudstone	**Wackestone**	**Packstone**	Grainstone	**Boundstone**	**Crystalline Carbonate**
					

***Modification of original Dunham classification by changing percent mud from 1 to 10%**

13.4 CLASSIFICATION OF DEPOSITIONAL ENVIRONMENT AND ENVIRONMENT COLOR LEGEND



SILICICLASTIC ROCKS

CONTINENTAL VT 744		GLACIAL	(G)		
		AEOLIAN (DUNE)	(A)		
		LACUSTRINE	(L)		
		ALLUVIAL (FLUVIAL) PLAIN	(AP)	CHANNEL	(AC)
				FLOOD BASIN	(AFB)
		ALLUVIAL FAN	(AF)		
COASTAL VT 736	DELTAIC VT 735 1/2	DELTAIC PLAIN	(DP)	DISTRIBUTARY CHANNEL	(DC)
				MARSH, LAKE	(DM)
		FRINGE	(F)	INNER	(IF)
				OUTER	(OF)
		PRODELTA	(PD)		
	NON DELTAIC VT 746	COASTAL BARRIER ISLAND	(CB)	DUNE	(CBD)
				BEACH - SHOREFACE	(CBB)
		TIDAL CHANNEL COMPLEX	(TCC)	TIDAL CHANNEL	(TC)
				TIDAL DELTA & FLAT	(TD)
		ESTUARINE	(E)		
MARINE VT 734 1/2	SHALLOW VT 738 1/2	SHEET	(S)		
		OFFSHORE BAR	(OSB)		
		TRANSGRESSIVE	(T)		
	SLOPE VT739 1/2	GRAVITY SLIDE - DEBRIS FLOW	(GS)		
	DEEP VT 747 1/2	SUBMARINE FAN	(SF)		
		TURBIDITE	(TU)		
		BASIN PLAIN	(BP)		

CARBONATE ROCKS

CONTINENTAL VT 737			VADOSE (SURFACE CRUST)	(V)		
			LACUSTRINE	(L)		
			AEOLIAN (DUNE)	(A)		
COASTAL VT 743	SHELF INTERIOR VT 740	OPEN CIRC.	BEACH OR BARRIER	(B)		
		RESTRICTED CIRC. VT 742 1/2	TIDAL FLAT	(TF)	SUPRATIDAL	(ST)
					INTERTIDAL	(IT)
			ISOLATED LAGOON, EMBAYMENT, POND.	(LE)		
SHALLOW SHELF VT 740 1/2		OPEN CIRCULATION VT 751	BAR, BANK OR SHEET OR LOCAL ORGANIC BUILDUP	(BBS) (LOB)		
			TIDAL BAR & CHANNEL	(TB)		
	SHELF MARGIN VT 740		BAR, BANK OR ISLAND OR ORGANIC BUILDUP	(BB) (OB)		
SLOPE VT 745 1/2			MARGIN DEBRIS	(MD)		
BASIN VT 760			SUBMARINE FAN	(SF)		
			TURBIDITE	(TU)		
			PELAGIC	(P)		
			SEAMOUNT	(SM)		
			BASIN PLAIN	(BP)		

Numbers Refer To Eagle Chemi - sealed Verithin Pencils

13.5 Standard Lithologic Legends (General Logging Procedures)

1. Use black, India ink for all notations on the strip log, including overlays and other symbols, except as follows:

   a. Use red India ink for information or symbols pertaining to hydrocarbon shows and engineering data.

   b. Use green India ink for all paleontological determinations (optional).

   c. Use red pencil to designate formation, series, or system tops.

2. Rapidograph pens (#00) or crow quill pens should be used in recording all data on the log.

3. Use Eagle "Chemi-Sealed" Verithin pencils for all color symbols (except where colored ink is designated).

4. Headings on all logs should be filled in as completely as possible (neatly).

   a. Always note the name (or names) of the person (or persons) who completed the log, and the date of completion.

   b. Always include a brief statement about the initial and present production data. A summary of pertinent completion data should be written at the bottom of the log.

   c. Always write the name and location of the well at both the top and bottom of the log to facilitate filing and handling.

5. Lithologic formation tops should be included on all logs. The person making the log is the best qualified to pick the tops. (See Chart VI).

6. If the columns on the log designated for specific information (ex. fossil and accessory column) are not wide enough to plot all the pertinent symbols, the remainder should be logged in the remarks column adjacent to the appropriate interval. Any written description should follow.

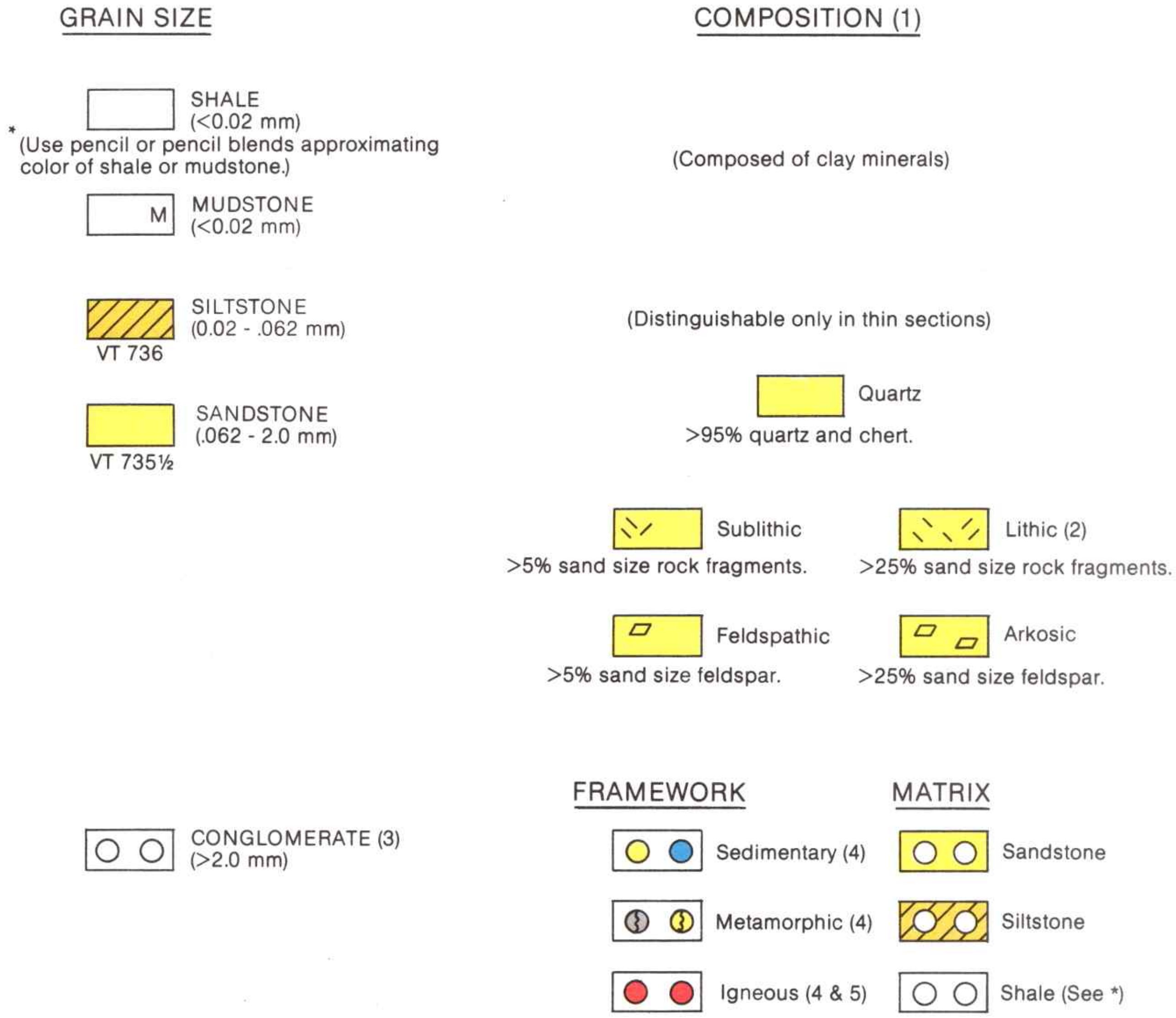
7. A completed log should always be treated with care. It represents valuable and expensive geologic data, and its preservation is important.

8. The symbols and abbreviations presented in the following charts are intended to eliminate lengthy descriptions in the remarks column of the log. Use them accordingly. But if the rock characteristics cannot be illustrated by one or more of the symbols, then they should be supplemented with a written description in the appropriate column.

Chart I: Siliciclastic Rock Types

Siliciclastic rocks are best described on the basis of grain size and composition. Such things as cements and accessories are incidental to the primary description, and should be treated as such.

Special rock types such as "granite wash" and "metamorphic wash" can be defined in terms of grain size and composition, and therefore do not warrant special names.



GRAIN SIZE

SHALE (<0.02 mm)

*(Use pencil or pencil blends approximating color of shale or mudstone.)

MUDSTONE (<0.02 mm)

SILTSTONE (0.02 - .062 mm) VT 736

SANDSTONE (.062 - 2.0 mm) VT 735½

CONGLOMERATE (3) (>2.0 mm)

COMPOSITION (1)

(Composed of clay minerals)

(Distinguishable only in thin sections)

Quartz: >95% quartz and chert.

Sublithic: >5% sand size rock fragments.

Lithic (2): >25% sand size rock fragments.

Feldspathic: >5% sand size feldspar.

Arkosic: >25% sand size feldspar.

FRAMEWORK	MATRIX
Sedimentary (4)	Sandstone
Metamorphic (4)	Siltstone
Igneous (4 & 5)	Shale (See *)

(1) See Chart V for logging of subordinate components and cementing agents.
(2) Term graywacke is abandoned because of its ambiguous definition. Clay admixture (detrital matrix) is logged as matrix.
(3) See Structures, Chart XVIII for logging or breccia.
(4) Lithology of framework constituents should be represented by appropriate rock color symbol.
(5) Use appropriate overlay of igneous rock type from Chart IV.

Chart II: Carbonate Rock Types

The purer carbonate rocks are composed of varying admixtures of particles and matrix. Local production of carbonate particles eliminates effective use of grain size and sorting as significant factors in the vast majority of cases. Therefore, the organization and emphasis of rock types is based dominantly upon the relative abundance of particles, and their packing (See Dunham, R.J., 1962)

Diagenetic processes may change size of component mineral crystals, and destroy component particles as recognizable entities. Any recognizable particles in altered carbonate rocks should be recorded.

TEXTURES (1)

A. PRIMARY DEPOSITIONAL TEXTURES

LIMESTONE (2)	DOLOMITE (2)	
 VT 740	 VT 740½	MUDSTONE - particles <10% (3)
		WACKESTONE - particles 10-30%, mud supported (4)
		WACKESTONE - particles >30%, mud supported (4)
		PACKSTONE - particles in contact, with >10% mud matrix (4 & 5)
		GRAINSTONE - particles in contact, with <10% mud matrix (4 & 5)
		BOUNDSTONE - components bound together during deposition. Can be either particle- or mud-supported

B. DIAGENETICALLY ALTERED ROCKS, LITTLE OR NO DEPOSITIONAL TEXTURES RECOGNIZABLE

		Interlocking crystals
		Sucrosic - crystals in point contact, with intercrystal pores
		With recognizable particles (4)

C. MISCELLANEOUS

		Chalky - soft and porous. Can occur in either primary depositional or diagenetically altered rocks.
 VT 744	 VT 744	Caliche

(1) Average or range of grain or crystal size should be logged in crystal/particle size column.

(2) See Chart V for logging of subordinate components and cementing agents.

(3) Note particles (if any) in fossil-accessory column.

(4) If particles constitute >10% of rock use overlay of appropriate dominant particles. (See fossil symbols Charts XII, XIII and XIV.) All fossil types should be logged in fossil column with indication of abundance. Log only dominant fossil types in lithic column.

(5) Percentage of mud matrix for packstone and cement for grainstone should be indicated by relative width of vertical column.

Chart III: Carbonate Particle Symbols(1)

NON-SKELETAL PARTICLES (excluding nucleus)

⍿ ⍿	Pellets (fecal particles)	
● ●	Pelletoids	pellet-like structureless particles with regular outlines
✛ ✛	Micropelletoids (20-62μ)	
⊖ ⊖	Coated grains	irregularly shaped or elongated particles
⦵ ⦵	Superficial oolites	spherical to ellipsoidal particles 62μ to 2 mm, with single coating
⊙ ⊙	Oolites	spherical to ellipsoidal particles 62μ to 2 mm with multiple concentric coatings
⊚ ⊚	Pisolites	multiple concentrically coated particles > 2mm
⦾ ⦾	Vadose pisolites	
8 8	Grapestone or aggregate grains	

SKELETAL or NON-SKELETAL

⍝ ⍝	Oncolites , rhodoliths or algal balls	crenulated concentric algal or stromatolitically coated particles

SKELETAL PARTICLES (2)

ɓ ɓ	Macrofossil fragments, undifferentiated
ɸ ɸ	Microfossils, undifferentiated
ⓑ ⓑ	Macrofossil fragments, undifferentiated rounded or worn
[ɓ] [ɓ]	Macrofossils undifferentiated - whole

QUESTIONABLE PARTICLES

⊠ ⊠	Particles of indeterminate origin
⁘ ⁘	Obscure particles (fuzzy or clotted)

LITHOCLASTS - fragments of previously lithified carbonate rock (3)

⧖ ⧖	Angular, undifferentiated	
⌛ ⌛	Rounded, undifferentiated	
⌶ ⌶	Intraclasts	locally derived penecontemporaneous fragments
⧓ ⧓	Talus (slope or fore reef detritus)	
◈ ◈	Breccia, solution, collapse	
⟐ ⟐	Breccia, tectonic	

(1) If particles constitute > 10% of rock, use overlay of appropriate dominant particles.

(2) Use fossil symbol overlays shown on Charts XII, XIII, and XIV if skeletal particles are identifiable. Log only dominant particle types in lithic column. Note all particle symbols in fossil-accessory column.

(3) Carbonate conglomerate should be logged using same rules as shown for siliciclastic rocks, Chart I. Flat pebble conglomerates are considered lithoclastic.

Chart IV: Miscellaneous Sedimentary Rock Types, Igneous Rocks, and Metamorphic Rocks

SEDIMENTARY ROCK TYPES

🟪	VT 742½	ANHYDRITE (OR GYPSUM)
🟧	VT 737	CHERT - bedded (refer to "Accessories" for detailed chert symbology.)
⊠	VT 738½	HALITE
▤	VT 744 VT 751	BENTONITE
⬛	VT 747	COAL (Lignite indicated by brown in color column)
▦	VT 738½	POTASSIUM SALTS

IGNEOUS ROCKS (1)

^^^^	VT 750	Igneous, undifferentiated
× × × × ×	VT 750	Extrusive, acid-intermediate, felsic (rhyolite, dacite, tracite, etc.)
+ + + + +	VT 750	Intrusive, acid-intermediate, felsic (granite, diorite, syenite, etc.)
× × × × ×	VT 759	Extrusive, basic, mafic (basalt, andesite, etc.)
+ + + + +	VT 759	Intrusive, basic, mafic (gabbro, diabase, etc.)
Y Y Y Y Y	VT 738	Ultrabasic, ultramafic (peridotite, etc.)
II II II II II	VT 743	Pyroclastic, undiff. (2) (tuff or ash)
⩔ ⩔ ⩔	VT 743	Vitric tuff
◈ ◈ ◈	VT 743	Crystal tuff
⊖ ⊖ ⊖	VT 743	Lithic tuff

METAMORPHIC ROCKS (1)

⫽⫽⫽	VT 750	Metamorphic, undifferentiated
⫽⫽⫽	VT 735½	Quartzite
⫽⫽⫽	VT 734½	Slate, phyllite, etc.
⦚⦚⦚	VT 738	Serpentinite
⫽⫽⫽	VT 740	Marble
⫽⫽⫽	VT 750	Schist and Gneiss
⫽×⫽×	VT 738	Greenstone (altered basalt)

(1) Mixtures of these rock types can be indicated by combining appropriate rock and color symbols.

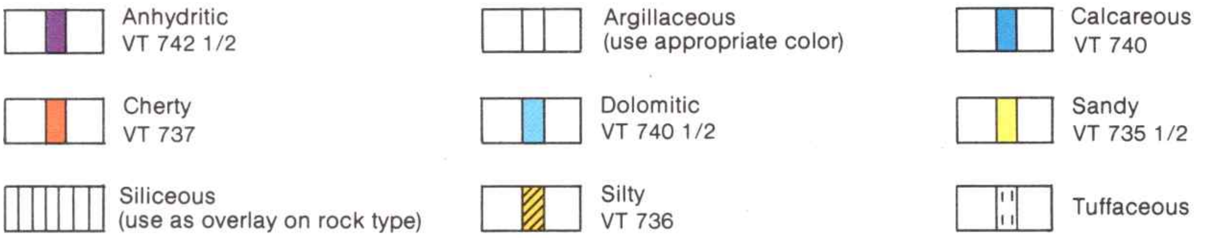
(2) Welded pyroclastics can be indicated by underlining any of the various tuff symbols (Ex. welded tuff, undifferentiated, is $\underline{\text{II}}$).

Chart V: Subordinate Components and Cements

Subordinate Components(1)

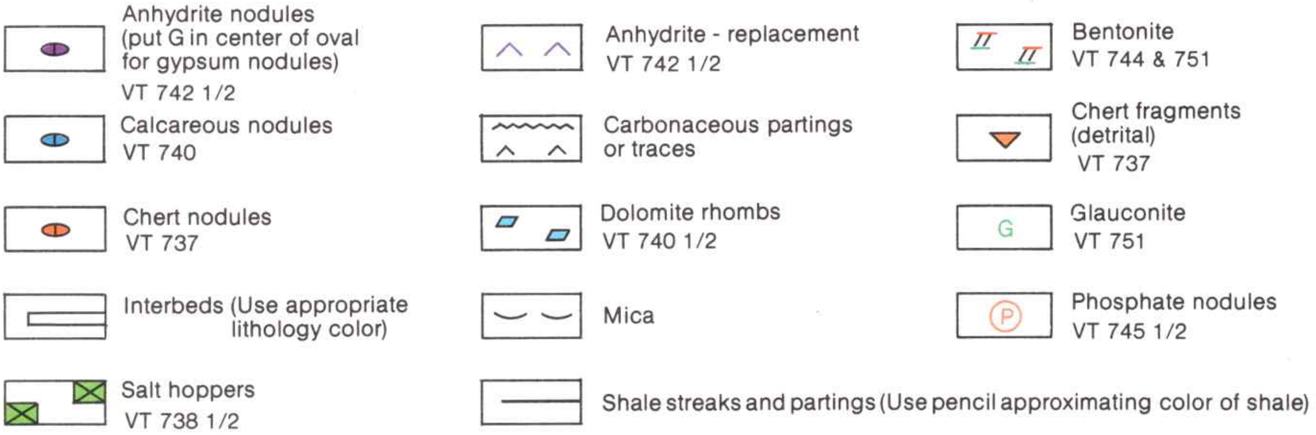
These materials are part of, or replace part of, the original sediment. Included here are minor primary constituents (less than 50%) of a rock, such as clay in argillaceous sandstone or limestone, etc. Also included are partial replacements (such as scattered dolomite rhombs in limestone), or relicts following wholesale replacement (calcareous fossils in dolomite, etc.)

COMMON SUBORDINATE COMPONENTS



- Anhydritic VT 742 1/2
- Argillaceous (use appropriate color)
- Calcareous VT 740
- Cherty VT 737
- Dolomitic VT 740 1/2
- Sandy VT 735 1/2
- Siliceous (use as overlay on rock type)
- Silty VT 736
- Tuffaceous

LESS COMMON SUBORDINATE COMPONENTS (2)

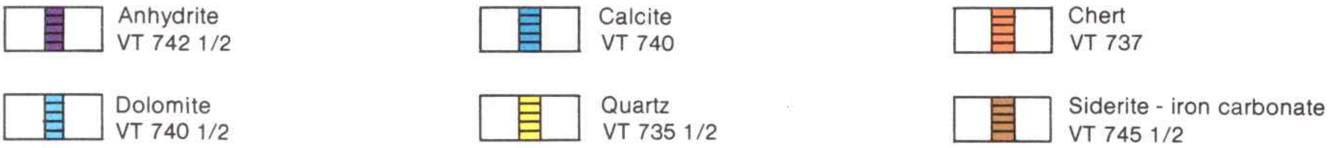


- Anhydrite nodules (put G in center of oval for gypsum nodules) VT 742 1/2
- Anhydrite - replacement VT 742 1/2
- Bentonite VT 744 & 751
- Calcareous nodules VT 740
- Carbonaceous partings or traces
- Chert fragments (detrital) VT 737
- Chert nodules VT 737
- Dolomite rhombs VT 740 1/2
- Glauconite VT 751
- Interbeds (Use appropriate lithology color)
- Mica
- Phosphate nodules VT 745 1/2
- Salt hoppers VT 738 1/2
- Shale streaks and partings (Use pencil approximating color of shale)

Cements(1)

Any mineral precipitated in a pre-existing void; a precipitate which serves directly to reduce porosity. Also could be called "secondary pore filling". This includes not only minerals binding particles (as sandstone cement), but also fillings of solution cavities, fossil molds, primary cavities, etc.

UNDIFFERENTIATED CEMENT FABRICS



- Anhydrite VT 742 1/2
- Calcite VT 740
- Chert VT 737
- Dolomite VT 740 1/2
- Quartz VT 735 1/2
- Siderite - iron carbonate VT 745 1/2

SPECIFIC CARBONATE CEMENT FABRICS (3)

- Blocky
- Fibrous
- Isopachous
- Syntaxial or Overgrowth

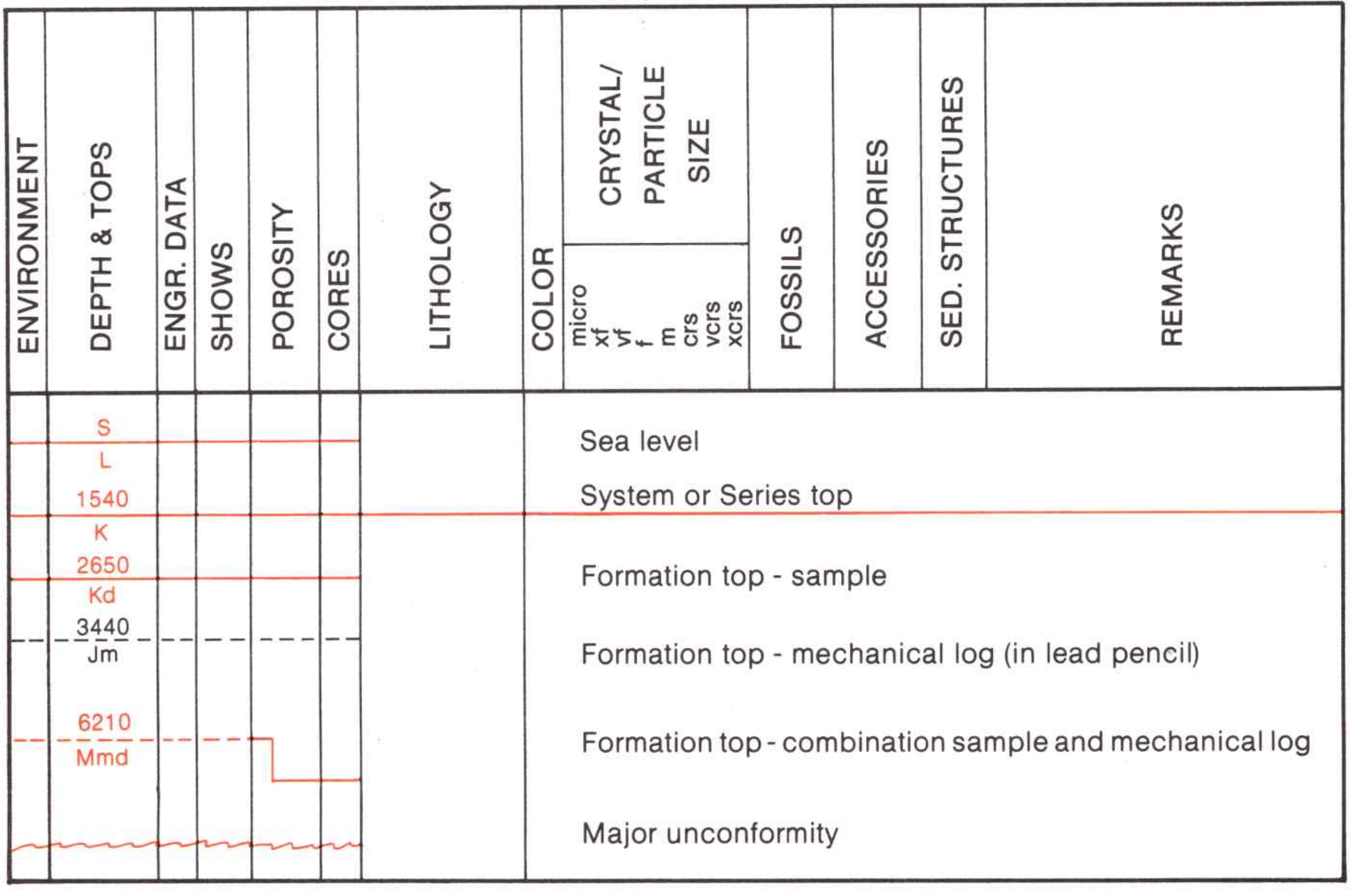
(1) Cement and subordinate components are shown by a vertical band in the center of the lithologic column. Cements are distinguished from subordinate components by horizontal lines (in black ink) over the vertical color strip. The width of the strip denotes the relative abundance of the material and should not exceed 50% of lithic column for any one component. Components are logged from left to right in order of increasing hardness.

(2) If less than 10%, log in accessory column.

(3) Use in place of horizontal black lines over the appropriate vertical color strip for either calcite or dolomite, or for other mineral cements if applicable. (Ex. quartz overgrowth cement)

Chart VI: Tops, Sample Quality, and Thin Sections

Tops(1)



Sea level

System or Series top

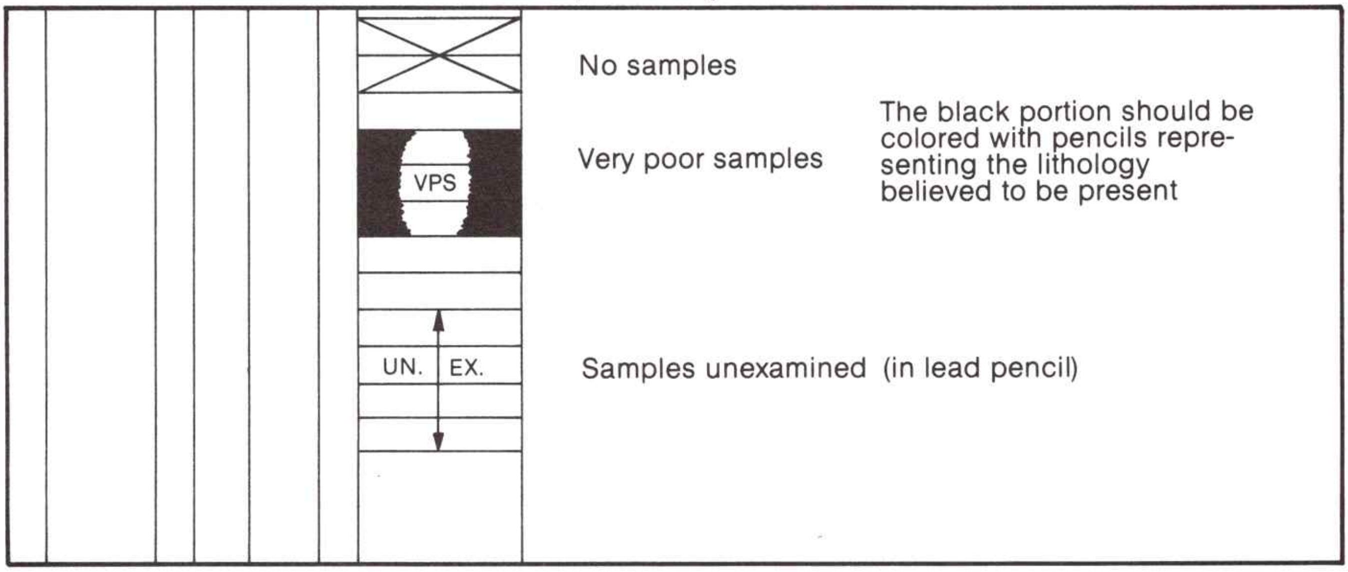
Formation top - sample

Formation top - mechanical log (in lead pencil)

Formation top - combination sample and mechanical log

Major unconformity

Sample Quality Data



No samples

Very poor samples

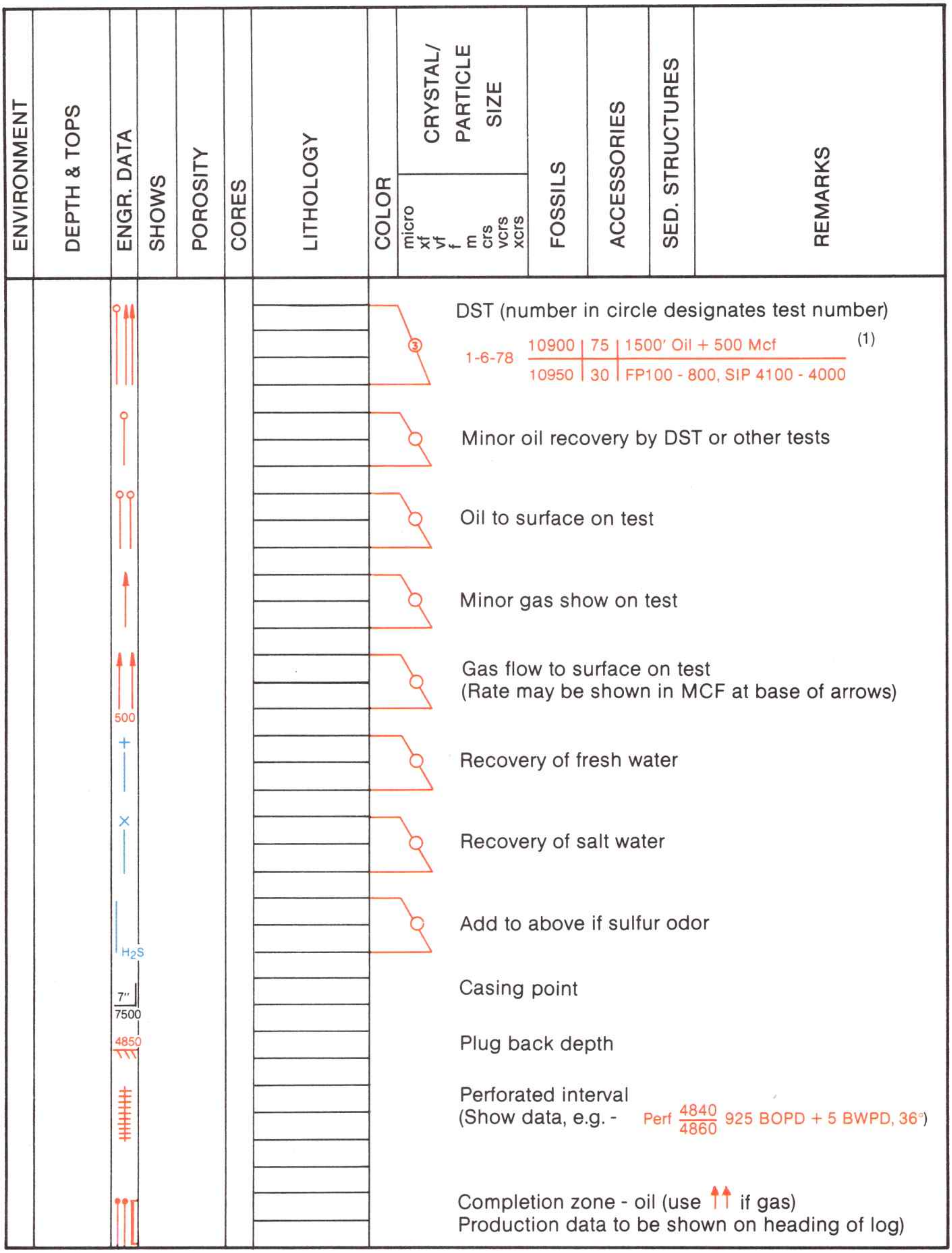
The black portion should be colored with pencils representing the lithology believed to be present

Samples unexamined (in lead pencil)

Thin Sections

(1) Sample tops should be logged in red pencil. Formation name or abbreviation shown below line.

Chart VII: Engineering Data



DST (number in circle designates test number)

1-6-78 10900 | 75 | 1500' Oil + 500 Mcf (1)
10950 | 30 | FP100 - 800, SIP 4100 - 4000

Minor oil recovery by DST or other tests

Oil to surface on test

Minor gas show on test

Gas flow to surface on test
(Rate may be shown in MCF at base of arrows)

Recovery of fresh water

Recovery of salt water

Add to above if sulfur odor

Casing point

Plug back depth

Perforated interval
(Show data, e.g. - Perf $\frac{4840}{4860}$ 925 BOPD + 5 BWPD, 36°)

Completion zone - oil (use ↑↑ if gas)
Production data to be shown on heading of log)

(1) Plot in red ink in remarks column or on bottom of log.

Chart VIII: Hydrocarbon Shows and Other Fluids, and Source Rocks

Hydrocarbon Shows and Other Fluids(1)

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE micro xf vf f m crs vcrs xcrs	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
			●			Poor oil stain						
			●●			Good to excellent oil stain						
			●			Dead oil (hard and brittle)						
			▲			Tarry or gummy oil						
			∘			Oil reaction in acid						
			╭			Faint cut fluorescence						
			ɱ			Strong cut fluorescence						
			●╭			Poor stain, faint cut fluorescence						
			◊			Hydrocarbon odor						
			↑			Gas indications						
			×			Salt water						
			× H_2S			Sulfurous salt water						
			+			Fresh water						
			+ H_2S			Sulfurous fresh water						

Source Rocks(2)

			⚐			Analyzed, organic lean						
	VT745½		⚑			Analyzed, organic rich						
			⚑ 12			Vitrinite values should be recorded under the appropriate source rock symbol, as shown in example						
			⚐ ⚐			Continuous sequence of analyzed samples. Use appropriate source rock symbols						

(1) A detailed description of significant shows should be written in the remarks column. This description should specify (1) quantity (percentage of cuttings with show), (2) color, (3) fluorescence, (4) cut, and (5) cut fluorescence.

(2) Qualifying data of source rock and maturity analysis should be recorded in the remarks column.

Chart IX: Visible Porosity(1)

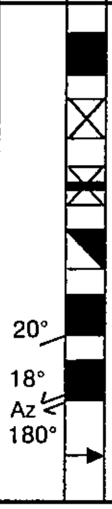
ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE micro xf vf f m crs vcrs xcrs	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
				•				Trace				
				|				Poor		(1-5%)		Intergranular, Interparticle or Intercrystal
				||				Fair		(5-10%)		
				|||				Good		(10-15%)		
				||||				Excellent		(> 15%)		
				V				Trace				Vuggy (Undifferentiated)
				↓				Poor		(1-5%)		
				↓↓				Fair		(5-10%)		
				↓↓↓				Good		(10-15%)		
				↓↓↓↓				Excellent		(> 15%)		
				H↓				Visibly interconnected				
				⊕				Poor		(1-5%)		Moldic, (Undifferentiated)
				⊕⊕				Fair		(5-10%)		
				⊕⊕⊕				Good		(10-15%)		
				⊕⊕⊕⊕				Excellent		(> 15%)		
								Moldic porosity of specific particles can be shown by superimposing the specific particle symbol over the vuggy porosity symbol.				
								For example:				
				⦶⦶⦶				Oomoldic		(15%)		Moldic, (Specific)
				●●				Pelmoldic		(10%)		
				⊕				Fossomoldic, undifferentiated		(5%)		
				⚡				Occasional				Fractures
				⚡⚡				Abundant				
				LC				Lost circulation, possibly porous				
				U?				Free sand grains, possibly porous				
				■				Microporosity, not visibly apparent in cuttings and/or core				

(1) Description of quantity and quality of porous intervals should be recorded in remarks column.

Chart X: Core Data and Textural Chart

Core Data

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE micro xf vf f m crs vcrs xcrs	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS



Core recovered

Core unrecovered

Core partial recovery, position known

Core recovery unknown

Apparent dip from core

Oriented core dip

Sidewall core

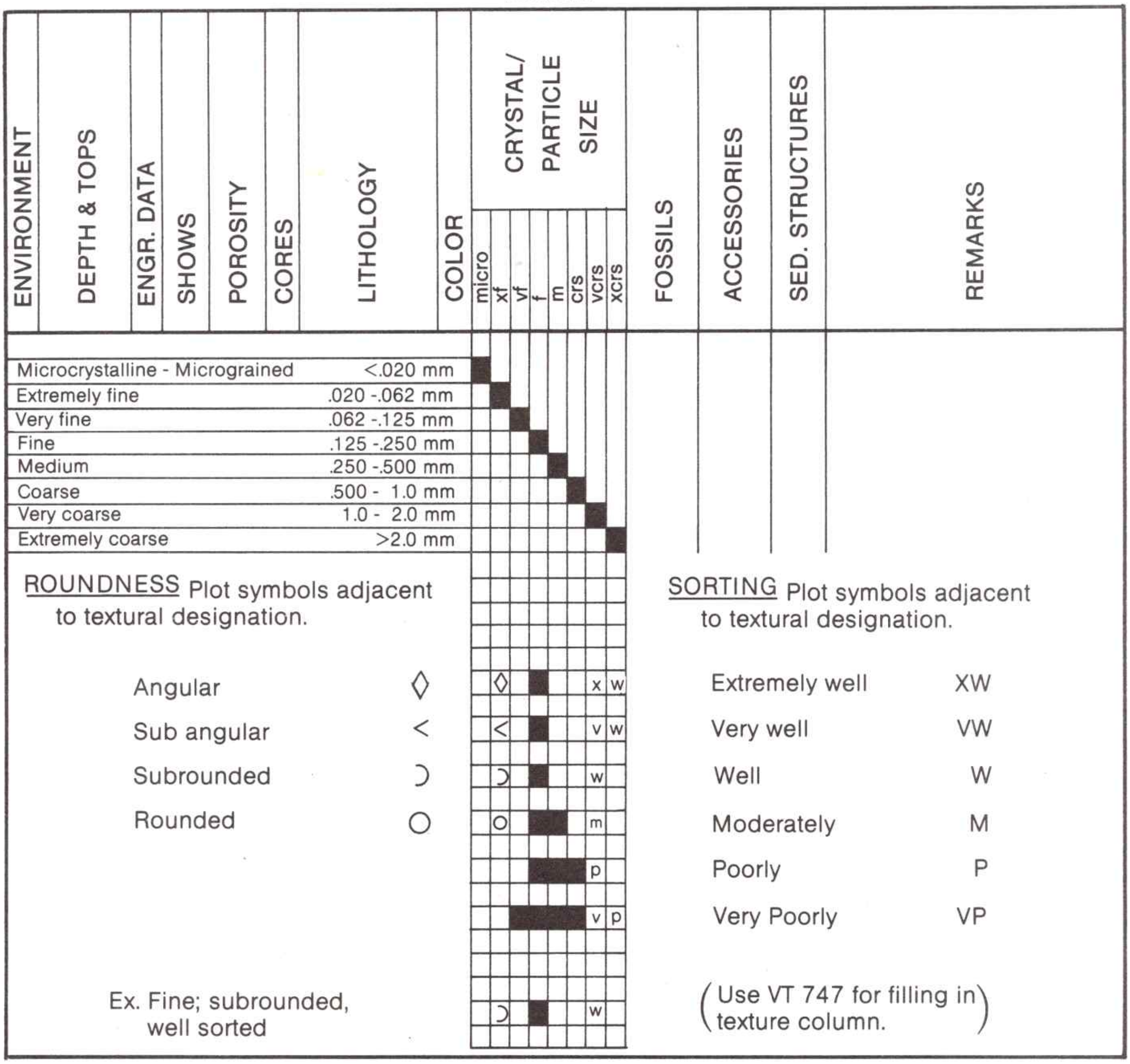
Textural Chart(1)

SILICICLASTIC ROCKS		GRAIN SIZE MILLIMETERS		GRAIN SIZE MICRONS	CARBONATE ROCKS	
Boulder (Bld)					Extremely Coarse (xc)	
		256	256			
Cobble (Cbl)						
		64	64			
Pebble (Pbl)						
		4	4			
Granule (Gran)						
		2	2	2000		
Sand	Very Coarse (vc)				Very Coarse (vc)	
		1	1	1000		
	Coarse (c)				Coarse (c)	
		.5	1/2	500		
	Medium (m)				Medium (m)	
		.25	1/4	250		
	Fine (f)				Fine (f)	
		.125	1/8	125		
	Very Fine (vf)				Very Fine (vf)	
		.062	1/16	62		
Silt					Siltite	Extremely Fine (xf)
		.020	1/50	20		
Mud					Mud	Micro-grained/crystalline (Lithographic/mat)

1) For practical reasons Wentworth's division of the lutites into clay and silt at the 4μ(1/256 mm) boundary has been replaced by the above subdivision into mud and silt at the 20μ boundary.

Chart XI: Texture and Rock Colors

Texture



Microcrystalline - Micrograined	<.020 mm
Extremely fine	.020 -.062 mm
Very fine	.062 -.125 mm
Fine	.125 -.250 mm
Medium	.250 -.500 mm
Coarse	.500 - 1.0 mm
Very coarse	1.0 - 2.0 mm
Extremely coarse	>2.0 mm

ROUNDNESS Plot symbols adjacent to textural designation.

Angular	◊
Sub angular	<
Subrounded	ↄ
Rounded	○

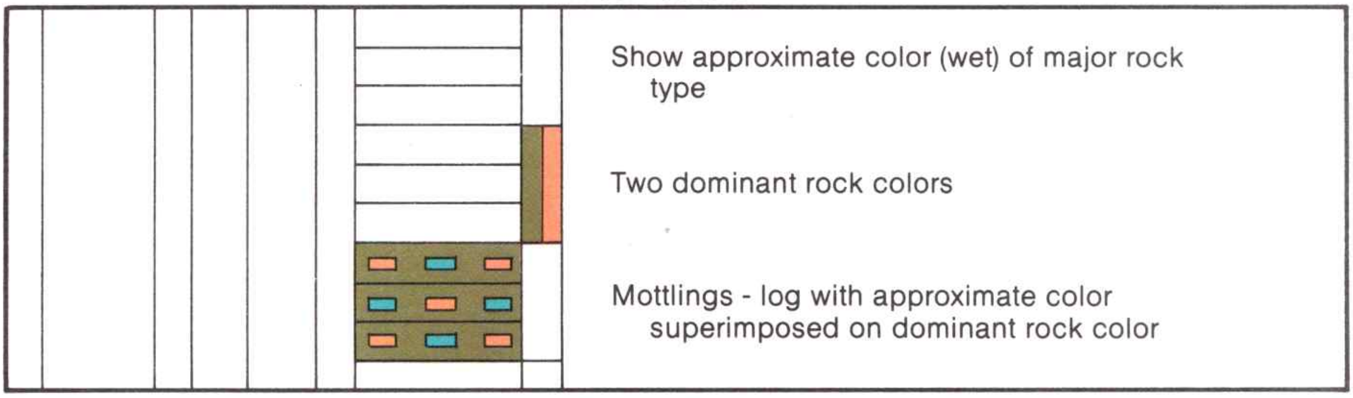
Ex. Fine; subrounded, well sorted

SORTING Plot symbols adjacent to textural designation.

Extremely well	XW
Very well	VW
Well	W
Moderately	M
Poorly	P
Very Poorly	VP

(Use VT 747 for filling in texture column.)

Rock Colors[(1)]



Show approximate color (wet) of major rock type

Two dominant rock colors

Mottlings - log with approximate color superimposed on dominant rock color

---

(1) Use the G.S.A. Rock Color Chart for accurate color designations.

Chart XII: Fossils(1) & (2)

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
								micro xf vf f m crs vcrs xcrs				

FOSSILS

General Symbols

- Macrofossil fragments, undifferentiated
- Macrofossil fragments, rounded
- Macrofossils, whole
- Microfossils, undifferentiated
- Fossils, encrusting

Specific Symbols

- Algae, undifferentiated
- Algae, Red
- Algae, Green
- Algal plates
- Algal balls, oncolites, rhodoliths
- Algal stromatolites
- Brachiopods, undifferentiated
- Brachiopods, phosphatic
- Brachiopods, productid
- Bryozoa, tube-like forms
- Bryozoa, fenestellid forms
- Calcispheres
- Chara
- Conodonts and scolecodonts
- Corals, colonial
- Corals, Chaetetes
- Corals, Syringopora
- Corals, solitary
- Crinoids
- Diatoms
- Echinoderms

Use appropriate fossil symbol within circle or square if fossil identifiable

Use as underline under appropriate fossil symbol. Ex: $\underline{\clubsuit}$ = encrusting foraminifera

VT 744
VT 751

(1) Relative abundance is indicated by dots over symbols

No dot = 0-10%
• = 10-20%
•• = 20-30%
••• = 30%

To be used over fossil symbols
Ex. $\overset{\therefore}{\bigstar}$ = crinoids >30%

or, indicate % above fossil symbol. Ex: $\overset{10}{\bigstar}$

(2) Any of these symbols can be used as overlays in the lithic column, if they represent a major rock constituent.

Chart XIII: Fossils, continued

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
								micro xf vf f m crs vcrs xcrs				

- Fish remains
- Fish scales
- Foraminifera, undifferentiated
- Foraminifera, pelagic
- Foraminifera, small benthonic
    - Miliolids
    - Tubular forams
- Foraminifera, large benthonic
    - Orbitolina
    - Dictyoconus
    - Coskinolina and Coskinolinoides
    - Fusulinids
- Graptolites
- Hydrozoa
- Molluscs, undifferentiated
    - Cephalopods
    - Belemnites
  - Gastropods
  - Pelecypods (clams)
    - Chondrodonta
    - Gryphaea
    - Inoceramus
    - Oysters
- Rudists, undifferentiated
    - Caprinids
    - Caprotinids
    - Monopleurids
    - Requieniids
    - Radiolitids
  - Tentaculites
- Ostracods
- Plant remains
- Silicified wood
- Spicules

Chart XIV: Fossils, continued; and Accessories

Fossils

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE								FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
								micro	xf	vf	f	m	crs	vcrs	xcrs				

Spines	/
Spines, brachiopod	/b
Spines, echinoid	/e
Sponges	⌓
Spores and/or pollen	Sp
Stromatoporoids, undifferentiated	S
Stromatoporoids, lamillar	S
Stromatoporoids, spherical	Ⓢ
Stromatoporoids, hemispherical	S
Stromatoporoids, branching	S
Stromatoporoids, Amphipora, undifferentiated	A
Stromatoporoids, Amphipora, lamillar	A
Radiolarians	⌖
Trilobites	
Worm tubes	
Vertebrates	

Accessories(1) & (2)

Ash	+	VT 751
Chlorite	◡	VT 751
Feldspar	▱	
Glauconite	G	VT 751
Hematite	H	VT 744
Limonite	L	VT 744
Mica	◡	
Phosphate nodules	Ⓟ	VT 745 1/2
Pyrite	#	
Quartz crystals		
euhedral	⬭	
singly terminated	▭	
Quartz grains (floating)	○	VT 735 1/2
Siderite grains	●	VT 745 1/2
Sulfur	S	VT 737
Volcanic glass	V	VT 751

(1) Relative abundance is indicated by dots over symbols (see Chart XII)

(2) Any of these symbols can be used as overlays in the lithic column if they represent a major rock constituent.

Chart XV: (Accessories) Chart(1), (2) & (3)

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE micro xf vf f m crs vcrs xcrs	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
						Mineralization						Use symbol color of mineral present to indicate nature of filling. Examples shown indicate calcite fill. Use VT 743 for hydrothermal mineral fill
						Vug filling				✸		
						Vein or fracture filling				≷		
						CHERT						
						Banded				▽≋		
						Chalk textured (tripolitic)				▽/C		
						Fossiliferous				▽ϭ		Use appropriate fossil symbol
						Granular				▽⁖		
						Milky				▽ M		
						Mottled				▽⋞		make ticks with appropriate color pencil
						Oolitic				▽⊙		
						Opaque				▼		use appropriate color pencil for filling in symbol
						Pelletal				▽o		
						Porcelaneous				▽/		
						Sandy				▽○		
						Spicular				▽⋌		
						Spotted				▽⋋		make ticks with appropriate color pencil
						Subporcelaneous				▽•		
						Translucent				⧨		use appropriate color pencil for filling in or outlining symbols
						Transparent				▽		
						Undifferentiated				▼		VT 737
						Composite symbol (e.g. fossiliferous, oolitic, sandy)				▽ϭ/⊙/○		

(1) Undifferentiated chert symbol is placed in lithology column. Detailed symbology is shown in accessory column.

(2) Chert symbols should be made with colored pencil approximating the color of the chert. White chert symbol should be colored light blue (VT 741 1/2).

(3) Relative abundance is indicated by dots over symbols (see Chart XII).

Chart XVI: Structures (Stratification, Sedimentary, Diagenetic)

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
								micro xf vf f m crs vcrs xcrs				

SYNGENETIC STRUCTURES

A. Stratification

1. Parallel type

Thickness of Bedding

Metric System

millimeter bed	1 mm - 10 mm	mm
centimeter bed	1 cm - 10 cm	cm
decimeter bed	1 dm - 10 dm	dm
meter bed	1 m - 10 m	m

When greater precision is desired, the modal thickness can be indicated, e.g., beds with modal thickness 3 meters. 3m

British System

thin lamina	< 1/10 inch	tnlam
lamina	1/10 - 1/2 inches	lam
very thin bed	1/2 - 2 inches	(tn)
thin bed	2 - 6 inches	tn
medium bed	1/2-1 1/2 feet	med
thick bed	1 1/2 - 5 feet	tk
very thick bed	> 5 feet	tk

2. Cross-bedding
   - in general
   - with angle indicated
   - chevron
   - climbing
   - festoon
   - planar
3. Irregular bedding
4. Graded bedding
5. No apparent bedding
6. Nodular bedding

Chart XVII: Structures and Markings (Stratification, Sedimentary, Diagenetic)

ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE								FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
								micro	xf	vf	f	m	crs	vcrs	xcrs				

B. Current - produced markings

1. Ripple marks
   - asymmetrical
   - interference
   - symmetrical
2. Pull-over flame structure
3. Scour and fill
4. Flute cast
5. Groove cast
6. Striation
7. Parting lineation

C. Organism - produced markings

1. Burrowed
   - slightly burrowed
   - moderately burrowed
   - well burrowed
2. Churned
3. Bored
4. Bored surface
5. Organism tracks and trails
6. Plant root tubes
7. Vertebrate tracks

D. Penecontemporaneous deformation structures

1. Mud cracks
2. Rain or hail prints
3. Pull-apart
4. Slump structures and contorted bedding
5. Convolute bedding
6. Load cast
7. Tepee structure
8. Birdseye, fenestral fabric

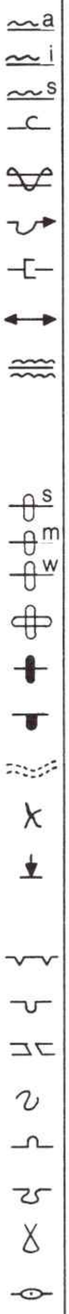


Chart XVIII: Structures (Stratification, Sedimentary, Diagenetic)

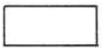
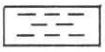
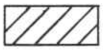
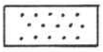
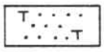
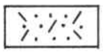
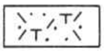
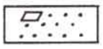
ENVIRONMENT	DEPTH & TOPS	ENGR. DATA	SHOWS	POROSITY	CORES	LITHOLOGY	COLOR	CRYSTAL/ PARTICLE SIZE	FOSSILS	ACCESSORIES	SED. STRUCTURES	REMARKS
								micro xf vf f m crs vcrs xcrs				

	SED. STRUCTURES
EPIGENETIC STRUCTURES	
A. Solution structures	
1. Breccia, solution, collapse	
2. Dissolution - compaction (horse tail)	
3. Stylolite	
4. Vadose pisolite	
5. Vadose silt	
6. Boxwork	
7. Salt hoppers or casts	
B. Tectonic structures	
1. Fractures	
2. Slickensides	
3. Breccia, tectonic	
C. Miscellaneous	
1. Geopetal fabric	
2. Cone-in-cone	
3. Stromatactis	
4. Boudinage, ball and flow structure	

Chart XIX: Black and White Lithologic Symbols

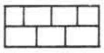
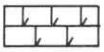
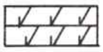
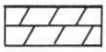
To be used for Stratigraphic Columnar and Cross Sections

SILICICLASTIC ROCK TYPES

	Clay (See symbols for color designations)		Shale (See symbols for color designations)
	Silt		Siltstone
	Quartz sand		Quartz sandstone
	Lithic sand		Lithic sandstone
	Feldspathic sand		Feldspathic sandstone
	Arkosic sand		Arkosic sandstone
	Gravel (undifferentiated)*		Conglomerate (undifferentiated)*

*Use appropriate rock symbol for matrix component surrounding pebbles, cobbles or boulders.

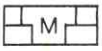
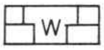
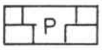
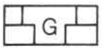
CARBONATE ROCK TYPES

			
Limestone (undifferentiated)	Dolomitic Limestone	Calcareous Dolomite	Dolomite (undifferentiated)

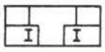
The texture and particle overlays shown below can be used with any of these basic patterns

TEXTURES

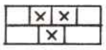
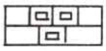
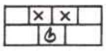
PRIMARY DEPOSITIONAL

	Mudstone
	Wackestone
	Packstone
	Grainstone
	Boundstone

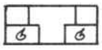
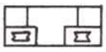
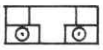
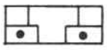
MISCELLANEOUS

	Chalky

DIAGENETICALLY ALTERED

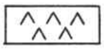
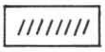
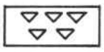
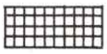
	Crystalline
	Sucrosic
	Crystalline w/recognizable particles*

PARTICLES

	Fossils (undifferentiated)*		Lithoclasts
	Oolites		Pelletoids

*Consult Charts XII, XIII & XIV for appropriate fossil symbols, and Chart III for additional particle symbols.

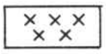
MISCELLANEOUS ROCK TYPES

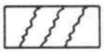
	Anhydrite or Gypsum		Coal
	Bentonite	 L	Lignite
	Chert (dark)		Halite
	Chert (light)		Potassium salt

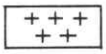
Chert (dark), Chert (light): Type of chert should be designated in margin by appropriate symbols.

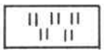
Chart XX: Black and White Lithologic Symbols

IGNEOUS AND METAMORPHIC ROCKS


Extrusive


Metamorphic


Intrusive

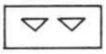

Pyroclastic

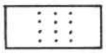
Specific rock types can be designated by using symbols on Chart IV and/or inserting first two letters of rock name in center of lithic column.

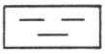
SECONDARY COMPONENTS

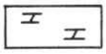
MODIFYING COMPONENTS

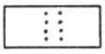

Anhydritic

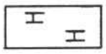

Cherty


Very sandy

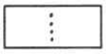

Argillaceous


Dolomitic

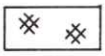

Sandy

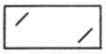

Calcareous


Micaceous


Slightly sandy

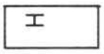

Carbonaceous


Salt hoppers

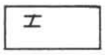

Silty

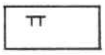
CEMENTS


Anhydrite

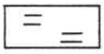

Calcite

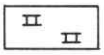

Chert

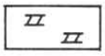

Dolomite

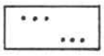

Quartz

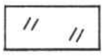
STREAKS AND LENSES


Argillaceous

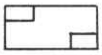

Calcareous

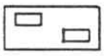

Dolomitic


Sandy


Silty

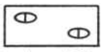
INTERBEDS AND INTERCALATIONS

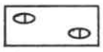


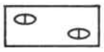


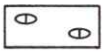
Use same symbols as for streaks and lenses enclosed within above symbols.

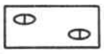
CONCRETIONS AND NODULES


anhy.
Anhydritic


calc.
Calcareous


ch
Cherty or Siliceous


fe.
Ironstone or other ferruginous material


phos.
Phosphatic

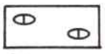

sid.
Sideritic

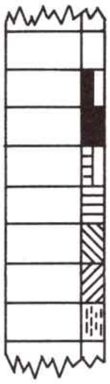
Chart XXI: Black and White Lithologic Symbols

MISCELLANEOUS SYMBOLS

N.S. No sample

☒ No information

Lst
Dol
Ss
} Can be used for long continuous sections of uniform lithology in place of drafted symbols.



COLORS

Color description for shales can be illustrated in column (⅛″) along right margin of log with these symbols.

Symbols to be used for the following data are the same as those given in the Standard Color Lithologic Legend, except as noted. These symbols are to be logged on the right side of the lithic column.

FOSSILS — Same as on Charts XII, XIII & XIV except:

 rd. Red algae  gn. Green algae

ACCESSORIES — Same as Charts XIV & XV except:

⊞ Ash or Tuff  Chlorite ○ Quartz crystals ● Siderite grains

MINERALIZATION

 cal.
 cal.
Type of vein, fracture or vug filling indicated by abbreviation of mineral

CHERTS

 Transparent

 bl
 gy
} Use appropriate chert symbol followed by abbreviation of color.

TEXTURES — Same as on Chart X & XI.

STRUCTURES — Same as on Chart XVI, XVII & XVIII

These symbols to be logged on left side of lithic column.

POROSITY — Same as on Chart IX.

OIL SHOWS — Same as on Chart VIII except all symbols in black.

○ Poor oil stain ○ ○ Good to excellent oil stain ✱ Dead oil stain

ENGINEERING DATA — Same as on Chart VII except all symbols in black.