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The Composite Interpretive Method of Logging Drill Cuttings

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JOHN C. MAHER

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THE COMPOSITE INTERPRETIVE METHOD OF LOGGING DRILL CUTTINGS

JOHN C. MAHER

ABSTRACT

Stratigraphic analysis of sedimentary basins has become an important part of exploration programs in the petroleum industry. The accuracy of the analysis and the conclusions drawn therefrom are affected greatly by the type and quality of well logs used in the analysis. Well logs are prepared in many different ways and for many different purposes. Some are expressed directly in lithologic characteristics; others are expressed in measurements of natural or induced characteristics from which lithologic characteristics or attitudes of strata may be deduced. The first type includes drillers logs and sample logs; the second type includes electric logs, radioactivity logs, drilling-time logs, and many special-purpose logs. At the present time the logs which approach closest to an all-purpose log are the sample log, the electric log, and the radioactivity log. Fortunately all three of these logs may be used together in such a way that the specific weakness of any one is counteracted. A combination of electric- or radioactivity-log data with sample-log data, plotted in lithologic terms, provides what is termed a *composite interpretive log.*

A composite interpretive log is basically a detailed sample log with important refinements adapted from other types of logs. It is primarily a research tool that has been derived from the experience of thousands of geologists, who have used different methods of sample examination and different terminology, abbreviations, and symbols.

In the preparation of a composite interpretive log, the microscope is placed on the left-hand extension leaf of the desk for a right-handed geologist or on the right-hand extension leaf for a left-handed geologist. One or two previously completed sample logs of nearby wells adjusted to proper correlation, side-by-side and overlapped to the well columns, are laid parallel to the edge of the desk, followed by the log form on which the descriptions will be plotted. The electric log or radioactivity log reduced to log scale (1 inch = 100 feet) is then laid alongside the log form but not overlapping it. All logs are weighted or taped in place at the top and bottom. A steel straightedge is laid parallel to the first sample-log column and a six-inch triangle is placed so that it can be slid up and down along the straightedge to maintain correlative points on all logs and to plot the lithology on the log form. This permits the concurrent examination of the samples and logs, the bed-for-bed correction of sample data with the electric or radioactivity log, and the plotting of the adjusted sample data on the log form.

The general examination of the samples is made under the microscope using 6.3× magnification; critical details, minute features, and fine cuttings are examined under 18× or 27× magnification. Special examinations for fine details, such as faint oölites and microfossils, are made with the cuttings placed in a shallow pan of water. The samples are examined, described, and plotted on the log in one operation. The abbreviated description of the sample is lettered with a crow-quill pen and drawing ink at the right of the well column. Following this, symbols both in black ink and color are plotted in the well column and to the left of the column.

In order to avoid the confusion caused by the indiscriminate mingling of rock, particle, and special terms in the description lettered on the log, the writer has found the following order of description to be useful: (1) rock characteristics, (2) particle characteristics, (3) special characteristics. Rock characteristics are described in the following order: (1) ascertainable megafeatures, (2) color pattern and color, (3) accessories, (4) structure, (5) luster, (6) sorting, cementation, and porosity, (7) grain size, (8) composition (x constituent, y constituent, and z constituent [rock type]). The significant particles that are described individually are grains and crystals, chert, oölites and pisolites, fossils, and insoluble residues. The principal characteristics of grains and crystals and the sequence of their description are: (1) staining and color, (2) luster, (3) relief, (4) roundness, (5) sphericity, (6) crystal development, (7) size, (8) composition and particle type. The principal characteristics of chert and the sequence of their description are: (1) color pattern and color, (2) accessories, (3) structure, (4) luster, (5) opacity, (6) texture, (7) composition. The principal characteristics of oölites and pisolites and the sequence of their description are: (1) color, (2) shape, (3) structure, (4) texture, (5) size, (6) composition, (7) particle type. Special characteristics described include oil staining, fluorescence under ultraviolet light, and the condition of the samples.

Importance of Subsurface Data

Recognition of the importance of subsurface data in supplying the third dimension to stratigraphy has come very slowly in the geological literature. This has been due in part to the poor reputation of subsurface geology attained in the days when inaccurate drillers logs were the only sources of subsurface data and in part to the natural reluctance of some stratigraphers to use the unfamiliar methods and data of the petroleum industry. In recent years the petroleum industry has been drilling tens of thousands of deep wells annually and logging these wells by accurate methods and devices, and the effect of these subsurface data on stratigraphic concepts in the literature has been considerable. Krumbein and Sloss (1951, p. 20-21) have summarized this effect in the following succinct statements.

"Practically all of the concepts which modern stratigraphers have inherited from their predecessors are derived from studies of rocks in outcrop. It is obvious, however, that by far the greater volume of the sedimentary rocks is buried and unavailable for surface study. No stratigraphic concept which ignores this great bulk of unexposed strata can be considered complete.

"Each year, tens of thousands of wells are drilled in the search for subsurface mineral resources, particularly oil and gas. Each of these wells adds to our stratigraphic knowledge by revealing previously unavailable data, until today the volume of subsurface stratigraphic information derived from drilling exceeds the studied surface data by a wide margin; and the volume is constantly increased as new areas are explored by the drill, and deeper horizons penetrated.

"It is quickly apparent to the student of subsurface stratigraphy that the unconformities which may serve to subdivide the stratigraphic column in the outcrop belts become less and less distinguishable as they are traced down-dip from outcrops on the margins of sedimentary basins, until, in many cases, the unconformities disappear entirely. In other cases, where rock units are separated in outcrops by abrupt changes in lithology, complete gradations from one rock type to another are found in the subsurface; and no horizon can be selected with certainty as representing the clear demarcation observed in the surface section.

"Moreover, the distinct faunal groupings, compartmented by the extinction and replacement of important faunal elements, disappear or become confused in the sedimentary basins. At the proper stratigraphic position, where the boundary between two systems should be recognizable, the subsurface stratigrapher is likely to encounter a series of transition faunas, including a mixture of supposedly diagnostic elements of both systems. Instead of a sharp break between clearly defined fossil suites, the rocks representing successive periods yield fossils which change gradually from types typical of one period to types indicative of another."

Until the advent of deep drilling by the petroleum industry, stratigraphy was chiefly concerned with outcrops of rocks in gentle upwarps on one side of a basin or in folded and faulted mountain belts on the other. Except in some mining areas, little or no information was available about the deeply buried rocks in the depositional basins. Detailed correlations could not be made across them because of the lithologic, thickness, and faunal dissimilarities of the outcrops on the opposite sides; consequently the geologic history of many basins was poorly understood. As wells were drilled in the basins and well logs were improved, detailed correlations across the basins became possible and the analysis and interpretation of facies and thickness changes of correlative units provided a better basis for reconstructing the geologic history of the basins and delimiting areas most favorable to the accumulation of petroleum. In the past 15 years this type of regional stratigraphic analysis has become an accepted exploratory tool in the search for petroleum.

Importance and Source of Lithologic Details

The stratigraphic analysis of a sedimentary basin may depend upon correlations based upon lithologic, faunal, electric, or radioactivity characteristics, or a combination of different types of characteristics, but the final interpretation of the geologic history must be based upon lithologic types, associated fossils, and implied environments. Therefore the lithologic detail derived from well logs is basically important, and the quality of well logs is an important consideration in preparing any regional stratigraphic analysis.

Well logs are prepared in many different ways and for many different purposes. Some are expressed directly in lithologic characteristics; others are expressed in measurements of natural or induced characteristics from which the lithologic characteristics or attitudes of strata may be deduced. The first type includes drillers logs and sample logs, which are generally implied by the unqualified term "well logs." The second type of logs, generally referred to by specific names, includes electric logs, radioactivity logs, drilling-time logs, drilling-mud logs, temperature logs, dipmeter logs, caliper logs, acoustic logs, total-magnetic-field logs, magnetic-susceptibility logs, dielectric-constant logs, and many special modifications of these logs.

Obviously some of these logs have special uses, and no one log is best for all purposes. Some are very valuable for engineering or well-completion work but have little value by themselves in regional geological work. These include drillers logs, drilling-time logs, drilling-mud logs, caliper logs, and temperature logs. Others are only in the research stage of development or are not in common enough use to provide regional correlations. At the present time the logs that approach closest to an all-purpose log are the sample log, the electric log, and the radioactivity log, and fortunately all three may be used together in such a way that the specific weakness of any one is counteracted. A combination of electric- or radioactivity-log data with sample-log data, plotted in lithologic terms, provides what is termed and described in this report as a *composite interpretive log.*

Purpose of Report

This report has been prepared primarily to provide a reference, a manual, and a set of descriptive standards for subsurface investigations in the Midcontinent region. As a reference, it provides details of commonly used procedures which cannot be fully described in every subsurface report. As a manual, it should aid in orienting or training geologists in subsurface methods. As a set of descriptive standards, it is hoped that it will encourage greater care and standardization in all phases of preparation of sample logs because these logs form the foundation upon which the geologic history of sedimentary basins may be reconstructed.

Specifically this report describes the preparation of composite interpretive logs and presents a system of description including terminology and definitions, abbreviations, and symbols. General discussions of drillers logs, drilling-time logs, electric logs, radioactivity logs, and sample logs are included to explain their supporting role in preparing composite interpretive logs.

A composite interpretive log is basically a detailed sample log with important refinements adapted from other types of logs. It is primarily a research tool that has been derived from the experience of thousands of geologists, who have used different methods of sample examination and different terminology, abbreviations, and symbols. It is not the intent of this report to suggest that composite interpretive logs should replace any other type of log, that the system of description presented will be suitable for all purposes, that the methods described are unique, or that the terminology and definitions of lithologic characteristics used represent an ideal standard. Rather it is intended to show the advantages and limitations of this method, and to define somewhat more specifically the terms that have become firmly established in subsurface work during the past 40 years and are now recorded on hundreds of thousands of well logs in oil-company and government-agency files.

Acknowledgments

The general method and special techniques of sample logging have been developed by petroleum geologists through a process of continuing adaptation over a period of 40 years. This technical know-how has been passed from one geologist to another primarily by personal contact or training so that every geologist that has worked over a microscope has had some part in the evolution of present-day procedures. Those who have contributed to the scant literature on sample-logging methods are mentioned in a section in this report on the development of sample logging.

Persons and firms that have aided in the preparation of this report by reviewing parts of the manuscript include C. R. Ruddick, Schlumberger Well Surveying Corporation; S. W. McGaha and J. D. Cruce, Lane-Wells Company; P. B. Nichols, Geolograph Corporation; L. H. Lukert, The Texas Company; and R. J. Lantz, American Stratigraphic Company. W. H. Freeman and Company kindly gave permission to quote from *Stratigraphy and Sedimentation,* by Krumbein and Sloss. W. L. Adkison prepared the sample logs used in figure 7. The writer is personally indebted to T. C. Peters and the late F. C. Edson, of the Shell Oil Company, for early training in sample examination.

GENERAL DISCUSSION OF LOGS AND LOGGING METHODS

Drillers Logs

A drillers log is the record of the rock penetrated in a well as the drilling progresses. It usually represents the work of several different drillers and helpers with differing degrees of competency. The record is made upon the basis of visual inspection of drill cuttings, the drilling time, and the changes in fluid level, along with the action of the rotary table and mud pump on a rotary rig or the "feel" of the drilling line on a cable-tool rig. The terminology used by a driller in describing the rock types penetrated seldom follows geological classifications, and terms such as "chat," "shale and shells," "gumbo and boulders," "slate," and "hard rock" are common. These terms usually have a rather definite meaning in any one area and sometimes can be translated into proper geological terms in a general way.

The drillers logs for wells drilled by cable-tool methods are usually more reliable and more easily interpreted than those for wells drilled by rotary tools because the drilling is slower and the drill cuttings are not intermixed with mud and recirculated or caved fragments from shallower depths. The logs recorded by experienced drillers who are familiar with both the rig and the local underground conditions are sometimes helpful in so far as the major changes in lithology are concerned. However, not even the best drillers logs are adequate for detailed stratigraphic studies. Consequently, drillers logs are used mainly as a source of completion and testing data.

Drilling-Time Logs

A drilling-time log is a record of the rate of penetration of the rocks by the bit. It may be recorded directly on a log strip by a machine or plotted manually from the record sheets of the driller (fig. 1). It may be expressed either as drilling time (minutes) for each unit of depth (1, 2, 5, or 10 feet) or as penetration (feet) for each unit of time (minutes or hours). The changes in rate of penetration are related generally to the lithologic succession encountered in a well, and major differences in lithology can be accurately noted from the drilling-time record.

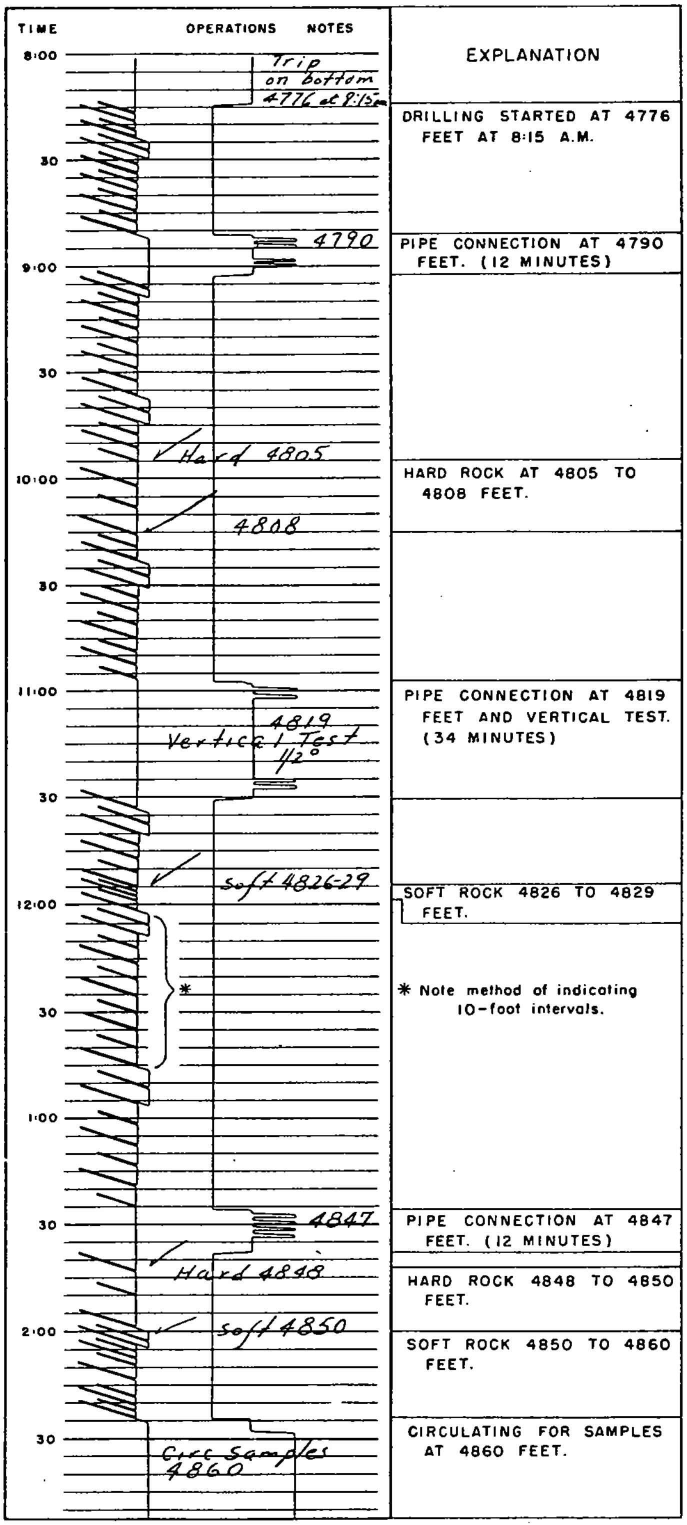
A drilling-time log is valuable as an operational record of a well, but it is most useful before an electric, radioactivity, or sample log is available. During drilling operations, it may serve to indicate when the bit needs to be changed, where drill-stem tests should be made, and where casing and packers may be set to best advantage. Drilling-time logs cannot be used by themselves for regional stratigraphic studies but are aids in correcting sample depths during the examination of well cuttings, particularly if no electric or radioactivity log is available.

Electric Logs

An electric log of a well is a record of the self-potential and apparent resistivity of formations adjacent to the drill hole. These properties are measured in the uncased part of the well and are commonly recorded with drilling mud in the hole. The self-potential is measured in millivolts as the difference of electrical potential between the formations in the hole and a point on the land surface. The apparent resistivity of the formations is measured in ohm-meters squared per meter by sending a current of electricity into the wall of the hole and determining the rate of potential drop. The equipment used in making these measurements consists of a system of electrodes which are lowered into the hole; a multi-conductor cable spooled on a power-driven winch which raises and lowers the electrodes; a measuring device which records the depth of the electrodes; electrical measuring instruments and a source of electromotive force on the land surface connected to the electrodes by the multi-conductor cable; and a plotting mechanism which records measured values of self-potential and resistivity on film. The electric log is printed from this film at scales of 1 inch = 100 feet, 1 inch = 50 feet, and 1 inch = 20 feet. Scales of 1 inch = 100 feet and 1 inch = 50 feet are commonly used for stratigraphic studies.

SELF-POTENTIAL CURVE

The measured self-potential, or record of voltages in the hole, is shown on the left-hand side of the film or electric log (fig. 2) as a single trace, which is termed the self-potential or spontaneous-potential curve, and commonly referred to as the S. P. curve. The self-potential curve is considered to represent the algebraic sum of the natural earth potentials, electrofiltration potentials, and electrochemical potentials. Natural earth potentials generally exist



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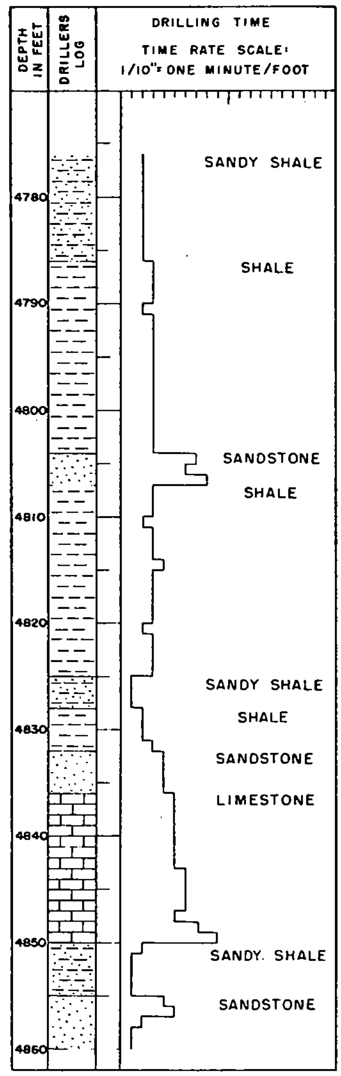

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Figure 1. Two types of drilling-time logs for the same interval.

A. Mechanically recorded drilling-time chart with driller's notes. Explanation at right (adapted from Geolograph).

B. Drilling-time and drillers log plotted from driller's records.

at all geological discontinuities without regard to drilling action, whereas electrofiltration and electrochemical potentials are generated during and after the drilling of the hole.

The electrofiltration potential is derived from the movement of fluid into or out of the formation due to differences in formational pressure and the weight of the mud column in the hole. When an electrolyte, such as the drilling fluid, is caused to flow through a permeable medium, such as a sandstone, an electromotive force is set up in the direction of the flow. This electromotive force is proportional to the pressure differential, to the electrical resistivity of the electrolyte, and inversely proportional to its viscosity.

The electrochemical potential is caused by two electrolytes (drilling fluid and formational water) of different ionic concentration being in contact through a permeable medium, such as a sandstone. The flow of the current is toward the more highly concentrated electrolyte, which may be either the drilling mud or the formational water.

Any one of the potentials composing the recorded self-potential may be either positive or negative under different conditions, and it is difficult to judge the relative magnitude of each. At one time the electrofiltration potential was thought to be dominant, and the self-potential curve was then called the porosity log; in recent years the generally greater effect of the electrochemical action has been realized and the term has been dropped.

RESISTIVITY CURVE

The apparent resistivity is shown on the right-hand side of the electric log as one, two, or three curves (short normal, long normal, and lateral curves in fig. 2), depending upon the number of different electrode arrangements used. These curves describe the formations penetrated by the drilled hole in terms of their resistance to the flow of an electric current. Measurable differences in the character of the formations in this respect are primarily dependent not upon the minerals in the formations, but rather upon their physical characteristics and fluid content. Increases in apparent resistivity are recorded by deflections of the resistivity curves to the right on the electric log. Differences in the magnitude of deflection of the curves in the same formation are the result of differences in their effective penetration, which is relative to the spacing of the electrodes in the hole. The electrode spacings are different in different regions, but those often used are 16 inches, 64 inches, and 19 feet (fig. 2).

The resistivity curve recorded by two electrodes 16 inches apart is called the short normal curve. This accurately indicates the tops and bottoms of formations more than 16 inches thick by abrupt deflections to the right or left. However, it does not give a true idea of the resistivity of the natural formation because of the relatively shallow penetration of the current and the considerable influence of the drilling mud upon it.

The resistivity curve recorded by two electrodes 64 inches apart is known as the long normal curve. It records the formation contacts less accurately but aids in determining the extent of invasion by drilling mud.

The resistivity curve recorded by electrodes generally 16 to 19 feet apart is known as the lateral curve. It provides the greatest penetration of the formations and, as a result, the most accurate recording of the resistivity of the formations and their contents. It does not record abrupt deflections at the tops and bottoms of thick formations because of the wide spacing of electrodes used for this curve.

MICRORESISTIVITY CURVE

Microresistivity curves recorded as Micro-Logs or Contact Impedance Logs by a special electric-logging technique but are commonly printed in combination with other curves on an ordinary electric log (fig. 2). This technique is designed specifically to locate permeable beds by differentiating beds that have been invaded by drilling mud from the relatively impermeable ones that have not. It is most useful in locating thin permeable layers in thick limestone or dolomite beds, which are generally so highly resistive that the self-potential currents are short-circuited around the beds through the mud column and record a highly generalized self-potential curve.

Microresistivity curves are recorded by closely spaced electrodes in an insulating pad which, pressed against the wall of the hole, shields the electrodes from the short-circuiting effect of the drilling mud in the hole. Two electrode systems, one with 1-inch spacing and the other with 2-inch spacing, are generally used in combination to record two curves simultaneously.

High microresistivities are recorded opposite relatively nonporous and impermeable beds, and low microresistivities are recorded opposite permeable beds, which are infiltrated with drilling fluid and caked with mud. Low microresistivities are also recorded opposite shale, claystone, and siltstone, which are porous but relatively impermeable. These can be identified readily by characteristics of the self-potential and lateral curves, and are not easily confused with relatively permeable rocks.

The microresistivity curve made with electrodes 1 inch apart is primarily a measure of the resistivity of the mud cake on the formation face; the curve made with electrodes spaced 2 inches apart generally measures the resistivity of the mud cake and the formation. The difference between the two curves for any one formation is the basis for interpretation and is known as the separation. The separation is positive if the 2-inch curve extends farther to the right than does the 1-inch curve, and negative if the relations are reversed. Positive separation (P.S., fig. 2) indicates that mud has invaded the formation, which in turn suggests an appreciable degree of permeability of the formation. Negative separation indicates that the resistivity of the formation is lower than that of the drilling mud, a rather uncommon circumstance, or that the wall of the hole is too irregular for close contact with the electrode pad, a common circumstance in thick sequences of limestone or dolomite. Lack of separation indicates that little or no mud has invaded the formation and suggests little or no permeability.

Although microresistivity curves indicate permeable beds, they are not a measure of permeability. The curves essentially are a measure of the mud cake on a formation face, and the mud cake generally is thicker opposite slightly permeable formations, which are more effective filters than the more permeable formations. Special microresistivity curves recorded by focusing devices as a MicroLaterolog can be used to calculate porosity.

INTERPRETATION

The complete interpretation of electric logs, particularly when made without detailed sample information, requires a knowledge of numerous variable factors which are reflected in the curves and an understanding of their possible combinations and relative magnitudes. These variables, which have been discussed in detail by Archie (1942), Doll, Legrand, and Stratton (1947), Doll (1948, 1950), and Stratton and Ford (1950), are beyond the scope of this outline. However, certain generalizations about the interpretation of electric logs can be made empirically by comparing an electric log and a sample log of the same well. These generalizations are illustrated in figure 2 by a hypothetical electric log. The curves representing limestone in this figure are typical of highly resistive rock and therefore could represent dolomite, anhydrite, or quartzite as well as limestone. The numbers below refer to examples in this illustration.

1. *Shale* is indicated when the microresistivity curves have little or no separation, and all curves show low readings. The almost straight self-potential curve recorded in shale or clay is sometimes referred to as the shale base. The shale base may drift gently with depth and may shift abruptly between marine and continental sediments, but it remains relatively constant in shale or clay beds of the same origin.

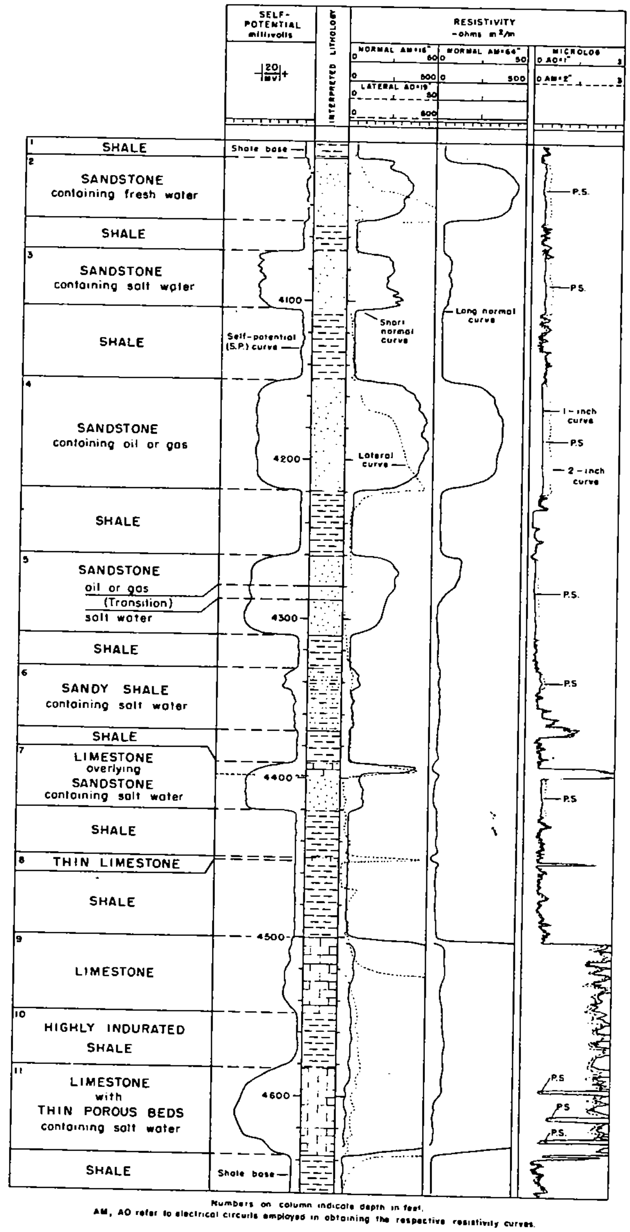


Figure 2. Electric-log curves and their characteristic expression of common lithologies, fluids, and gas. Dolomite, anhydrite, and quartzite record curves similar to those shown for limestone. Permeable beds are indicated by positive separations (P. S.) of microresistivity curves. (Adapted from unpublished diagrams of C. K. Ruddick, Schlumberger Well Surveying Corporation, Tulsa, Oklahoma.)

2. *Sandstone containing fresh water* is indicated by the separation of the microresistivity curves, the large deflections of all resistivity curves to the right, and a moderate deflection of the self-potential curve to either the left or right away from the shale base.
3. *Sandstone containing salt water* is indicated by the separation of the microresistivity curves, the moderate deflection of the short normal curve to the right, the slight deflection of the long normal curve, the left deflection of the lateral curve, and the large deflection of the self-potential curve to the left.
4. *Sandstone containing oil or gas* is indicated by the separation of the microresistivity curves, the large deflections of all resistivity curves to the right, and the shape and large deflection of the self-potential curve to the left.
5. *Sandstone containing oil or gas and salt water* is indicated by the separation of the microresistivity curves, the large deflection of the short and long normal curves at the top and their gradual recession toward the bottom, and the left deflection of the lateral curve in the lower part. Because of the 19-foot spacing of the electrodes recording the lateral curve, the high resistivity of the 20 feet of oil-saturated sandstone is not recorded by the lateral curve as it would be in a thicker zone of oil saturation as is illustrated in no. 4.
6. *Sandy shale containing salt water* is indicated by the lack of separation of the microresistivity curves except at the top where mud has invaded a slightly permeable part, and the slight deflections of the resistivity and self-potential curves.
7. *Limestone overlying sandstone containing salt water* is indicated by this combination of curves. The limestone is suggested by the pronounced deflections and near coincidence of the two microresistivity curves and the similar deflections of the short normal and lateral curves, as well as by the rounded slope of the self-potential curve. The small reverse deflection of the long normal curve is characteristic of a thin highly resistive bed. The underlying sandstone containing salt water is indicated by the separation of the microresistivity curves, the less rounded slope of the base of the self-potential curve, the moderate deflection of the short normal curve, the lack of deflection of the long normal curve, and the reverse deflection of the lateral curve.
8. *Thin limestone* is indicated by the pronounced and nearly coincident deflections of the microresistivity curves, the small reverse deflections of the short and long normal curves, the pronounced deflection of the lateral curve, and the lack of deflection of the self-potential curve. The reverse deflection of the lateral curve for a depth of 19 feet under the limestone and the following small but sharp deflection to the right are due to the 19-foot electrode spacing and shielding effect of the limestone.
9. *Limestone* is indicated by the pronounced deflections of the microresistivity and resistivity curves, and the small rounded deflection of the self-potential curve.
10. *Highly indurated shale* is indicated by the pronounced deflections of the microresistivity and resistivity curves, and the lack of deflection of the self-potential curve.
11. *Limestone with thin beds containing salt water* is indicated by the alternating high and low resistivities recorded by the microresistivity curves, the undulating character of the short normal and lateral curves, and the rounded slope of the top and base of the self-potential curve. The abrupt slope changes in the middle of the self-potential curve are indicative of porous beds, and the positive separation of the microresistivity curves where low resistivities are recorded opposite these beds suggests appreciable permeability.

SPECIAL ELECTRIC-LOGGING TECHNIQUES

Special techniques in electric logging have been developed to overcome logging difficulties due to abnormally high and low conductivities of the drilling mud in the hole. Where thick salt beds are penetrated in drilling, the drilling mud becomes very salty and the resulting high conductivity of the mud permits most of the current introduced to flow up and down the hole rather than into the more resistive formations adjacent to the electrodes. Under these circumstances, the resistivity curves recorded do not reflect the resistivities of the formations. Devices, such as the Guard electrode (McArthur, 1952), the Laterolog (Doll, 1951), and the MicroLaterolog (Doll, 1953), have been developed to overcome this difficulty. These employ an extra electrical circuit which charges the mud above and below the recording sonde and forces the current from the regular circuit to penetrate the formations opposite the sonde. The resulting curves may be interpreted in the same manner as the ordinary lateral and MicroLog curves.

A technique developed to overcome logging difficulties created by low conductivity of the drilling mud is termed induction logging (Doll, 1950). This technique is used in holes drilled with oil-base mud or in holes drilled with cable tools. It does not require any direct contact between the electrode and the drilling mud or formation. The formations adjacent to the sonde are energized by electromagnetic induction. To do this an alternating current of an appropriate frequency is allowed to flow through a coil in the sonde. This current creates an alternating magnetic field which induces eddy currents in the adjacent rocks. These induced currents in the rocks have their own magnetic field, which induces current in a second coil in the sonde. As long as the alternating current is constant, the currents induced in the rocks and received by the second coil are proportional to the conductivity and inversely proportional to the resistivity of the rocks. This electric-logging technique, not in common use in 1956, is used considerably today.

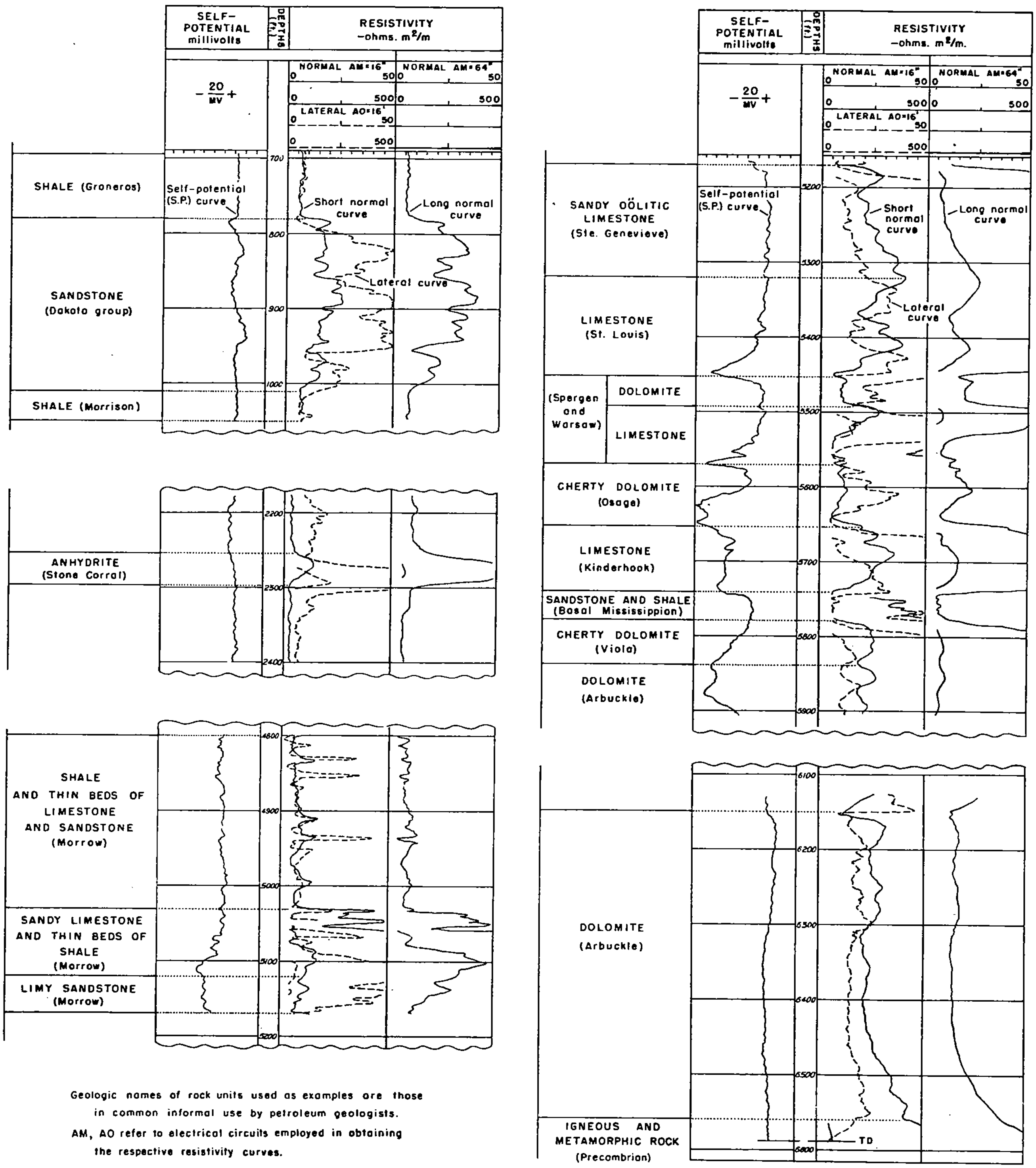


Fig. 3.- Examples of the expression of common lithologies by electric-log curves of wells in southeastern Colorado. Note that some dissimilar lithologies may have similar curves, and that detailed conclusions regarding lithology cannot be derived from the curves alone

USE IN STRATIGRAPHIC STUDIES

Electric logs are extremely valuable in evaluating the oil and gas possibilities of a well, and in making local stratigraphic studies in areas where the detailed stratigraphy has been established previously from lithologic and paleontologic studies. Nevertheless they cannot be used with certainty to interpret lithologic details without reference to well cuttings and cores. A comparison of different lithologies, which were determined from samples, with their corresponding electric-log curves is shown in figure 3. It is readily apparent from this that some dissimilar lithologies have similar curves and that, although the gross aspects of the formations can be interpreted from the curves, detailed conclusions regarding lithology cannot be derived from the curves alone.

Electric logs have a very important use in regional stratigraphic studies as they provide a means of correcting some of the errors inherent in samples from rotary drilling. This use will be discussed in connection with composite interpretive logs.

Radioactivity Logs

A radioactivity log is a record of the relative natural radioactivity of the different formations adjacent to the drill hole and the relative intensity of radiation produced by bombarding these formations with neutrons. This record is in the form of two curves—a gamma-ray curve on the left and a neutron curve on the right (fig. 4)—which are recorded on a scale referable to the percentage of radium per gram of rock. The equipment used in recording these curves utilizes a crystal which flashes light or scintillates under gamma-ray bombardment; the original scintillations are changed to current pulses, which are proportional in number to the intensity of the gamma-ray bombardment. Other equipment includes a conductor cable spooled on a power-driven winch which raises and lowers the instrument in the hole, a measuring sheave which records the depth of the instrument, and a plotting mechanism which traces the curves on a continuous roll of logging paper at scales of 1 inch = 20 feet or 1 inch = 50 feet. Reproductions of these records are made after the logging operation.

Gamma-ray curve

All rocks exhibit measurable amounts of natural radioactivity. The gamma-ray curve measures the relative amounts in different formations by recording variations in conductivity of the gas in the ionization chamber as the instrument is lowered in the hole. These variations are caused by gamma rays of the rocks penetrating the chamber and ionizing the gas, and are directly proportional to the intensity of the gamma rays.

In general, the intensity of radioactivity in sedimentary rocks increases from low values in evaporites, coarse clastics, and carbonates to high values in fine clastics. The following common lithologies are arranged in order of increasing radioactivity as determined empirically: (1) anhydrite, (2) salt, (3) sandstone, (4) limestone, (5) dolomite, (6) shaly sandstone and shaly limestone, (7) sandy shale and calcareous shale, (8) shale, (9) bentonite, volcanic ash, and organic shale. The intensity values determined for each type have considerable range and the general intensity range of one type overlaps another so much that separation of lithologic types having similar radioactivity intensities requires a knowledge of the stratigraphy or a comparison with a sample log. However, the general relationships observed permit interpretation of the gamma-ray curves in terms of general lithology in most areas where the stratigraphy is well established.

NEUTRON CURVE

The neutron curve measures the relative intensity of gamma rays induced in the formations by bombarding them with neutrons from a radium-beryllium mixture in a capsule added to the instrument. The neutrons from this capsule penetrate the adjacent rocks and are captured by the atomic nuclei of certain elements. This capture results in one or more gamma rays being emitted and these induced gamma rays penetrate the ionization chamber of the instrument and are recorded as the neutron curve in the same manner as the natural gamma rays are recorded as the gamma-ray curve. Because of the considerable strength of the neutron source, the induced gamma rays are of greater intensity than the natural gamma rays being emitted spontaneously. This considerable difference of intensity permits the measurements of the induced radiation without interference from the relatively weak natural radiation. Before being captured, the neutrons travel at a high velocity and collide with some atomic nuclei, principally hydrogen, by which they are not captured. These collisions reduce the velocity of the neutrons and accordingly slow the rate of capture upon which depends the intensity of induced gamma rays. In as much as hydrogen is most common in fluids in the rocks, and rocks must be porous to contain fluids, the intensity of the induced gamma rays is an indication of the amount of fluid and porosity in a rock—a high intensity signifies a dry, nonporous formation, whereas a low intensity signifies a porous, fluid-bearing formation.

INTERPRETATION

The proper interpretation of radioactivity logs, particularly when made without detailed sample information, involves the evaluation of several variable factors, some of which are related to drilling operations and some to natural conditions. Complete discussions of these variables have been presented in numerous papers on radioactivity well logging by Russell (1941), Mercier (1950), Downing and Terry (1950), and many others, and the reader is referred to them for details. The following discussion is intended merely to outline the empirical interpretation of radioactivity logs and to point out their usefulness in the detailed examination of drill cuttings.

The main operational variables that affect a radioactivity log are casing, hole size, and fluid level. Although radioactivity logs can be made effectively through one or more strings of casing, a shift of both the gamma-ray and neutron curves may occur at the end of each string of casing. Shifts in the neutron curve generally occur wherever the diameter of the hole has been changed and at the level of any fluid in the hole. These shifts generally are quite apparent on the radioactivity log and, unless they happen to coincide with a decided change in radioactivity in the rocks, cause little difficulty in interpretation. Information about the casing, hole diameter, and fluid level usually can be obtained prior to interpreting the log.

The natural conditions which introduce difficulties in the interpretation are uncommon occurrences of highly radioactive minerals or particles in rocks of low radioactivity. The presence of volcanic ash or bentonite in sandstone or limestone beds may cause the gamma-ray curve to register considerably higher radiation than is typical of sandstones or limestones. Radioactive asphaltic pellets and vugs containing radioactive material in limestones are another source of difficulty. Radioactive ground water and secondary deposits of radioactive minerals in porous sandstones and limestones, and in joints and crevices, may complicate any interpretations made without reference to cuttings or cores. However, all such occurrences are soon recognized in cuttings and cores and thereafter are not unexpected in the particular beds and areas.

If the operational and natural variables of radioactivity logging are taken into account, the gamma-ray curve may be interpreted in terms of lithology and the neutron curve may be used to locate porous zones and to estimate percentage of porosity. These interpretations are made by comparisons of the curve values on the individual logs. The terms low, medium, and high are used to relate the values in this discussion. Gamma-ray curves expressing low values suggest anhydrite, salt, limestone, dolomite, or sandstone; those of medium value suggest shaly limestone, calcareous shale, shaly sandstone, sandy shale, shaly dolomite, or dolomitic shale; and those of high value suggest shale (including siltstone), bentonite, volcanic ash, and granite.

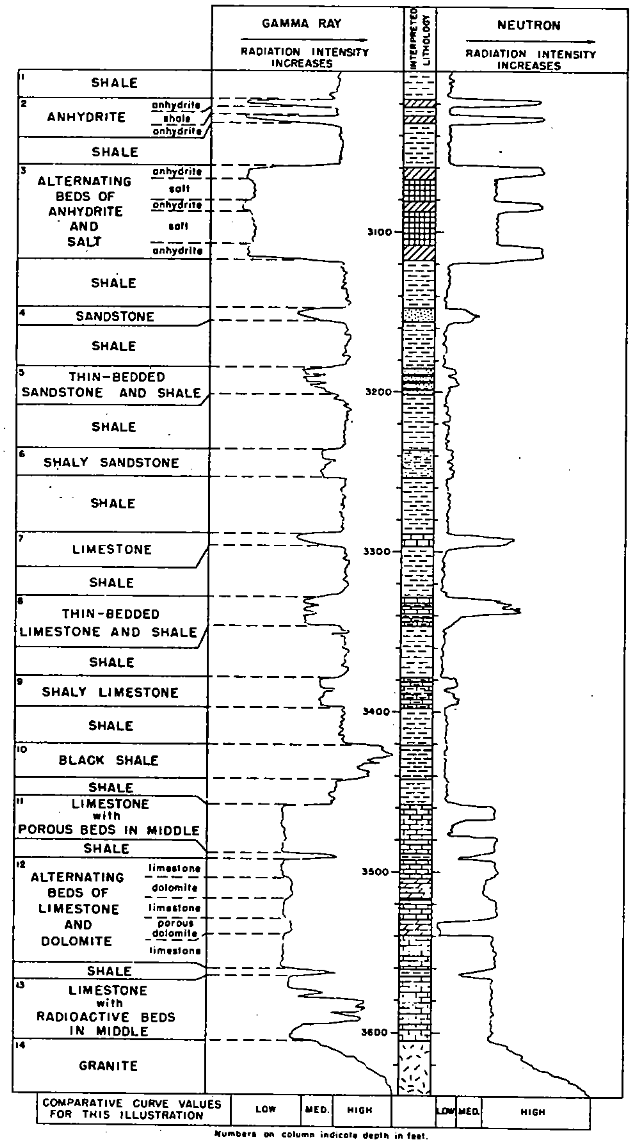


Figure 4. Radioactivity-log curves and their characteristic expression of common lithologies (adapted from Lane-Wells manual, *Radioactivity well logging*).

Neutron curves expressing low values suggest high porosities (although not necessarily effective porosities) such as are ordinarily found in shale, shaly sandstone, and sandstone;

those of medium values suggest medium porosities such as are ordinarily found in calcareous sandstone, dolomitic sandstone, shaly limestone, and shaly dolomite; and those of high values suggest low porosities such as are found in compact limestone, dolomite, salt, anhydrite, and granite.

Interpretations based upon such generalizations are discussed below and illustrated in figure 4 by a hypothetical radioactivity log. The numbers below refer to the examples presented in this illustration.

1. *Shale* is usually indicated by high gamma-ray-curve values and low neutron-curve values. Dark-colored shale ordinarily has a greater radioactivity intensity and consequently a greater gamma-ray-curve value than light-colored shale. Black organic shale records a maximum value. Shale has a minimum response on the neutron curve because of its high porosity and consequent large content of interstitial water.
2. *Anhydrite* usually provides a low gamma-ray-curve value, lower than that of limestone, dolomite, or sandstone, and a high neutron-curve value, which indicates little fluid content and little porosity.
3. *Alternating beds of anhydrite and salt* are suggested by a succession of similar but unequal values in the high range of gamma-ray and neutron curves. The salt beds are generally separable from the anhydrite beds because of their slightly higher gamma-ray-curve values and slightly lower neutron-curve values. Pure salt beds may record gamma-ray-curve values less than those for anhydrite but generally salt beds are not pure.
4. *Sandstone* records a minimum value for the gamma-ray curve and a low to medium value for the neutron curve. Porous limestone or dolomite may create a similar response and may not be distinguished with certainty from sandstone without sample information.
5. *Thin-bedded sandstone and shale* record an alternating succession of high and medium values on the gamma-ray curve and alternating unequal low values on the neutron curve. Porous limestone or dolomite beds and shale beds have similar curve characteristics.
6. *Shaly sandstone* is suggested by medium gamma-ray-curve values and medium to low neutron-curve values. Shaly limestone or dolomite may produce similar curve characteristics.
7. *Limestone* is generally indicated by low gamma-ray-curve values and high neutron-curve values. Dolomite records similar curve values.
8. *Limestone and shale* record alternating unequal low to medium gamma-ray-curve values and irregular high neutron-curve values. Dolomite and shale beds produce similar curves.
9. *Shaly limestone,* like shaly sandstone or dolomite, is suggested by medium gamma-ray-curve values and medium to low neutron-curve values.
10. *Black shale* generally records high to extremely high values on the gamma-ray curve and low values on the neutron curve. Volcanic ash or bentonite in any shale usually causes a similar response.
11. *Limestone with porous beds in middle* is suggested by low gamma-ray-curve values and neutron-curve values ranging from high to low. Dolomite with a zone of porosity produces a similar response, although the neutron-curve values are slightly lower in intensity.
12. *Alternating beds of limestone and dolomite* are suggested by the succession of low but unequal gamma-ray-curve values and alternating high and medium values of the neutron curve. Porous dolomite is indicated by the low neutron-curve value of the lower part of the unit.
13. *Limestone with radioactive beds in middle* is suggested by the low gamma-ray-curve values at the top and base, and the very high gamma-ray-curve values in the middle. Limestones or dolomites recording curves such as these may contain pellets or vugs of radioactive material. Similar gamma-ray-curve deviations are recorded by sandstones containing radioactive minerals.
14. *Granite* and highly radioactive igneous rocks are generally indicated by extremely high gamma-ray-curve and neutron-curve values.

USE IN STRATIGRAPHIC STUDIES

Radioactivity logs are particularly valuable in locating zones of porosity in formations, estimating porosity, and in making local correlations where the stratigraphic section is well known and the relationship of the radioactivity curves to the rocks has been established. They are also useful in regional structural studies wherever a thin radioactive bed extends over a considerable area. As with electric logs, however, they cannot be used safely to interpret lithologic details necessary for detailed thickness and lithofacies maps, nor can they be used to establish detailed regional correlations in relatively unexplored regions.

One of the primary values of radioactivity logs in regional studies lies in accurately determining the tops and bottoms of formations. The contact of any formation is recorded as a gently sloping transition curve covering depth intervals of 5 feet on the gamma-ray curve and 3 feet on the neutron curve. These transition curves represent the passage of the measuring devices, one 3 feet long and the other 1 foot long, by the formation contact. The exact contact is determined by locating the midpoint on the gently sloping transition curves. The contacts determined from the radioactivity log may be used to correct sample determinations, bed by bed, as the lithology is plotted on sample logs. This use is similar to that made of electric logs and will be discussed in connection with composite interpretive logs.

Sample Logs

DEVELOPMENT OF SAMPLE LOGGING

The study of drill cuttings from oil wells dates from at least 1880 when Carll published a remarkable report on the oil regions of Warren, Venango, Clarion, and Butler Counties, Pennsylvania. Even at that early date geologists found it necessary to explain the risks of the infant oil industry to the public as evidenced by the following quotation of J. P. Lesley (Carll, 1880, p. viii) in the letter transmitting Carll's report:

"Seeking for oil in unexplored ground, is like seeking for tobacco in a smuggler's trunk. The traveler and his luggage look suspicious; that is the full extent of the customs officer's knowledge. The tobacco must be found, if at all, with the probe. The officer's instinct *may* be deceived; the trunk *may* have no false bottom; or the false bottom *may* hold no tobacco."

Carll's report is remarkable because it describes for the first time the use of drillers records, drilling time, and samples. Carll plotted drillers records on a scale of 1 inch = 100 feet to make structural cross sections, and prepared drilling-time logs, which he called time sections, on a scale of 1 inch = 100 feet by using elongate diamond shapes to show the footage drilled in 24 hours. He pointed out the need for the careful washing and examination of samples before making a well record and recommended that duplicate sets of "sand-pumpings" be saved for later study. Carll placed his samples in bottles and arranged the bottles horizontally on a shelf according to depth. Each shelf represented a different well; the samples, as seen through the bottles, were correlated by comparison with samples on adjacent shelves. He also described the use of an odometer wheel, or measuring sheave, to measure depths accurately and, in connection with the leakage of water from one formation into another one containing oil, correctly stated many of the principles known to govern water drive in oil reservoirs and now used in water-flooding operations.

Despite Carll's early work, subsurface geology was not regarded as a practical tool in the oil industry until 1917, when the Empire Gas and Fuels Company organized a subsurface branch of their geological department under the direction of Alex McCoy. Trager (1920) of that organization soon published a laboratory method for the examination of cable-tool cuttings, which consisted of the examination and description of the samples (presumably by hand lens), the treating of the samples with acid to determine the percentages of "lime," sand, and shale, and the plotting of these percentages on a strip log. Similar logs were in general use about that time (Miser, 1919), and these were the forerunners of both the percentage-type sample log and the insoluble-residue log now in use. One of the first papers on areal geology based upon sample logs was that of Aurin, Clark, and Trager (1921). Another was published by Goldman (1922), who included a discussion of the microscopic examination of samples and the possibilities of regional environmental studies based upon sample logs. Goldman combined percentage logs made by visual estimates with drillers logs into what he termed "synthetic logs," which appear to have been the first interpretive sample logs.

Rotary drilling methods, which had their first use at the beginning of the century in the Gulf Coast region, began to supersede the cable-tool method in the Midcontinent region between 1922 and 1930. Some geologists believed that the mixed-up rotary cuttings were useless, but a few worked steadily to improve the accuracy of logs of wells drilled with rotary tools. Gilluly and Heald (1923) suggested sampling procedures and binocular study of systematically collected samples, each representing 10 feet of beds. Kraus (1924) also suggested sampling procedures, including circulation without drilling ahead, but surprisingly did not recommend the systematic collection and preservation of samples. Clark, Daniels, and Richards (1928) presented the results of experiments by the Marland Oil Company and the Gypsy Oil Company, which showed that a satisfactory percentage log could be made from rotary cuttings with a microscope. They predicted that eventually samples would be collected as a routine matter on each drilling rig.

In 1932 Whiteside published a paper on geologic interpretations from rotary-tool cuttings. In this he discussed sampling methods, sample washing, and sample examination under a microscope. He presented lithologic classifications and descriptive adjectives, and advocated the preparation of interpretive logs rather than percentage logs. Whiteside stated that samples were being saved from at least 75 percent of the wells being drilled in 1932.

In a review of the development of sample-logging techniques up to 1937, Lukert made the following observation:

"When drill cuttings were first saved they were examined by the naked eye and later by the use of a small hand lens. In cable-tool drilling fairly good results could be obtained in this manner, but when rotary samples were examined in this fashion, a state of confusion arose which would have continued had it not been for the introduction of the microscope. The microscope has long been used by the paleontologists, but the examination of rock fragments under the microscope, as we have it now in the Mid-Continent, is essentially a development of petroleum geology and has no counterpart in practices connected with the science of geology elsewhere."

Lukert outlined current methods, lithologic classifications and descriptive terms, and illustrated lithologic types with photomicrographs. According to his article, percentage sample logs had been abandoned by most geologists in the Midcontinent region by that time in favor of the "nonpercentage" log or interpretive log.

Hills in 1949 published a comprehensive article touching on all phases of sample collecting and examination, with particular emphasis upon the preparation of the percentage-type logs, which are commonly used in West Texas. Photomicrographs were presented to illustrate types of porosity in carbonate rocks, and the use of the rock-color chart and a standard crystallinity scale was recommended. More general discussions of sample-logging methods were published about this time by Greider (1949) and Busch (1950). In 1950 Rittenhouse published a paper on detrital mineralogy, which included an outline of sample-logging procedures. Although this article was mainly concerned with the study of heavy minerals and thin sections under a petrographic microscope, the discussion of various parameters of sediments is particularly useful to the geologist equipped only with a binocular microscope.

Low (1951) published a manual for the examination of well cuttings, which emphasizes the importance of interpretive logs. This manual describes in detail the method of sample logging most generally used in the Midcontinent region and includes lists of equipment and examples of lithologic symbols.

One of the special techniques of sample interpretation is the examination of insoluble residues of drill cuttings. This technique was first discussed by Wethered (1888), but it did not find extensive application until McQueen (1931), Martin (1931a, 1931b), Merritt and Decker (1928; 1931), and Ockerman (1931), demonstrated the usefulness of insoluble residues in subdividing and correlating thick sequences of carbonate rocks in cable-tool wells and outcrops. McQueen and other members of the Missouri Geological Survey made by far the greatest use of this technique at this time. Between 1935 and 1945, many oil-company geologists and research workers in the oil fields of Kansas, Oklahoma, and Texas resorted to insoluble residues in order to develop criteria for subdividing and correlating thick carbonate sequences. Because of economic importance, only a few results were published (Burpee, 1935; Burpee and Wilgus, 1936; Ireland, 1936; Wellman, 1937). Once these criteria were developed by residue studies, most of them could be found in untreated samples by careful examination. This fact, along with the steady decrease in the number of cable-tool wells drilled each year and the difficulties attending the use of rotary-tool samples for residues, tended to place insoluble-residue studies in the role of a special supplementary tool except in Missouri and West Texas, where residue examination is a routine procedure for most wells. The reader is referred to Ireland (1950) for a summary of insoluble-residue procedures.

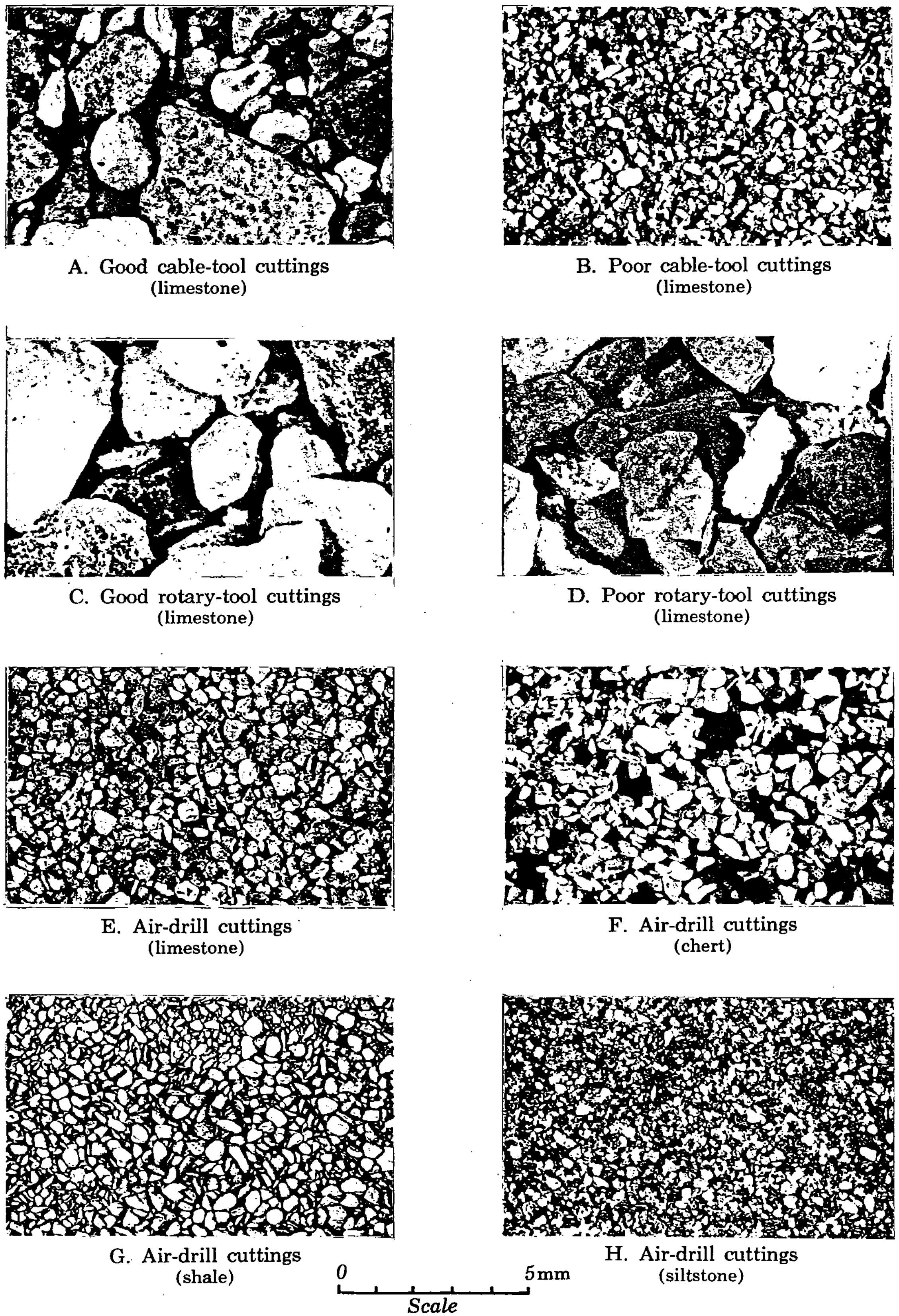
LIMITATIONS OF SAMPLES

Although the quality of a sample log depends to a great extent upon the stratigraphic knowledge and operational skill of the geologist, certain limitations of accuracy are imposed by errors inherent in the drilling and sampling operations. The following discussion contrasts the limitations of cable-tool samples, rotary-tool samples, and core samples.

Cable-Tool Samples

Cable-tool drilling is a percussion method of drilling in which the rock is crushed by successive blows of a heavy bit alternately raised and lowered by a cable. The rock fragments are bailed from the hole at irregular intervals, and portions are saved as samples of the rock penetrated in each interval. Short cores are usually taken from possible oil and gas reservoirs. The hole usually must be cased as the drilling proceeds in order to prevent water from seeping into the hole and the walls from caving onto the tools. This method of drilling is best adapted for penetrating hard rocks, such as limestone and sandstone, and is not well suited for drilling thick beds of soft shale or clay. It has been largely superseded by the faster rotary method since the development of rotary bits capable of cutting hard rock.

Cable-tool samples are usually representative of the interval drilled between bailing operations, although some contamination of the cuttings occurs as rock fragments are knocked from the uncased parts of the hole by the cable. The use of several strings of casing tends to minimize such contamination. The measurement of depth on the drilling cable is relatively easy, but correction by steel-line measurements at intervals is necessary because of the stretching of the cable. The cuttings are generally drilled relatively fine by the crushing action of the bit (fig. 5A) and in some wells the cuttings are ground to powder by the continued use of a dull bit or by drilling with a hole full of water (fig. 5B). The fineness of the cuttings is a distinct disadvantage in determining both the lithology and fossil content. Another disadvantage in logging cable-tool samples is that electric-log data with which to check and supplement the sample interpretation are generally lacking because most holes drilled by cable tools are cased and therefore cannot be easily surveyed electrically. The irregular sequence of cable-tool samples is a minor inconvenience in plotting the log.



A. Good cable-tool cuttings (limestone)

B. Poor cable-tool cuttings (limestone)

C. Good rotary-tool cuttings (limestone)

D. Poor rotary-tool cuttings (limestone)

E. Air-drill cuttings (limestone)

F. Air-drill cuttings (chert)

G. Air-drill cuttings (shale)

H. Air-drill cuttings (siltstone)

Figure 5. Appearance of cable-tool, rotary-tool, and air-drill cuttings under the microscope with 6.3× magnification.

Rotary-Tool Samples

Rotary-tool drilling is a cutting method of drilling in which the rock is cut into small fragments by the rotation of cutting edges on a bit. The bit is rotated on the end of a string of drill pipe while mud fluid is pumped down the drill pipe under considerable pressure. The fluid, or drilling mud, seals the wall of the hole and carries the cuttings to the surface, where they are sampled. Short cores (10 to 20 feet long) are usually cut in possible oil and gas reservoirs. The hole usually is cased through the fresh-water aquifers near the surface but is not cased during deeper drilling unless circulation of the drilling mud is lost in thick beds of salt or permeable rocks. Recent developments in drilling-mud practice have greatly lessened the need for multiple strings of casing in rotary holes. Normally the surface string and the completion string are all that are required.

Rotary-tool samples are usually collected at regular intervals of 5 or 10 feet. This uniform system facilitates the plotting of the sample log and aids in the detection of omissions. The rock fragments in the samples normally range in maximum dimension from 1/16 to 1/2 inch, with most fragments larger than 1/4 inch. Very large fragments can be obtained by reverse circulation. Because of their relatively large size, rotary-tool cuttings usually can be examined rapidly under low magnification and generally provide some whole specimens of any microfossils or microstructures in the rocks. Ordinarily numerous cores are taken in drilling with rotary tools; these may supply important lithologic details and even some megafossils. Most rotary wells are electrically surveyed, and the electric logs are an accurate source of many data not available from samples alone.

Rotary-tool samples usually contain some cavings from above and fragments recirculated by the mud pump (fig. 5C). The proportion of cavings in the samples is large when the viscosity and circulation of the drilling mud has not been properly controlled (fig. 5D). Differential settling rates of the heavy and light fragments in the mud fluid also mix the cuttings from different beds. Because the collection of samples at the surface lags behind the actual cutting of the given bed at depth, the samples usually represent a depth somewhat less than that recorded on the sample sack. This lag may amount to 20 feet in a 5,000-foot hole. It can be eliminated by taking the samples after circulating, without drilling ahead, for a time interval sufficient to permit the latest cuttings to reach the surface, but this delays drilling so much that it is used only for important samples of key beds. Sample depths can be corrected to some extent by timing a round trip of some marker material in the hole and applying a correction factor to the samples. The most accurate bed-for-bed correction can be made with an electric or radioactivity log as the samples are logged in the laboratory.

Recently a special adaptation of the rotary-drilling method called air drilling has proved to be economical in areas underlain by hard formations that contain little water. In this method the exhaust gas from the engine is treated and pumped down the drill pipe to cool the bit and remove the cuttings from the hole in place of the usual drilling mud. The samples obtained by this drilling method seem to have the less desirable characteristics of both cable-tool and rotary-tool cuttings. The principal disadvantage is the extreme fineness of the particles (fig. 5E, F, G, H), few of which are as large as 1/16 inch in diameter.

Cores

Coring is a method of drilling by which cylindrical sections of rock are cut and removed more or less intact from the hole. This can be done with either cable or rotary tools but is more commonly done with rotary tools. When coring is undertaken as an accurate sampling procedure rather than a drilling method, the individual cores generally are less than 4 inches in diameter and 20 feet in length, although short cores as large as 30 inches in diameter have been used in some detailed engineering studies. Recently, complete wells have been drilled by coring with the rotary method as the most economical means in areas underlain by especially hard rocks. Usually diamond bits are used and the core may be 4 to 8 inches in diameter and as long as 50 feet. When complete cores are recovered and several thousand feet of cores are laid out in sequence, the opportunities for detailed study are generally superior to those with drill cuttings or scattered outcrops. The outcrop characteristics, except weathering, are apparent and megafossils may be preserved intact; the location, sequence, and thickness are accurately known. The large cores are sometimes split with a diamond saw and preserved intact. More often, however, the core is described at the well site and then broken into sets of representative chip samples, which can be reexamined in the laboratory at any time.

TYPES OF SAMPLE LOGS

General Form

Sample logs generally are plotted on printed log strips, about 3 inches wide. The log strips have a form heading at the top for the name of the operator, land owner, location, and operational data, and a column, 1/2 to 3/4 inch wide, on the left side (fig. 6). The column is divided into 1/10-inch intervals which are numbered sequentially in units of 100 from top to bottom. The lithology is plotted graphically in this column with color symbols and described in the space at the right. Usually the log is plotted at a scale of 1 inch = 100 feet, although any scale in multiples of 10 can be used conveniently. Two methods are used in plotting the lithology in the well column—the percentage method and the interpretive method—and upon this basis sample logs are classed either as percentage logs or interpretive logs.

Percentage Logs

Percentage logs are prepared by plotting the percentage of each rock type in the sample as a simple bar histogram in the proper interval in the well column (fig. 7B). If the percentage of each rock type in the sample is estimated without regard to the limitations of the samples, the log is called an *unqualified-* or *straight-percentage log.* If the percentage of each rock type thought to represent the sequence drilled is estimated with regard to possible cavings and operational errors, the log is referred to as a *qualified-percentage log.*

The straight-percentage log can be used fairly effectively with cable-tool samples, which usually contain only small percentages of cavings, but cannot be relied upon with rotary samples, which often contain more cavings than representative cuttings. Straight-percentage logs can be mass produced by relatively unskilled help but are little more than improved drillers logs in some cases.

Qualified-percentage logs can be used effectively for both cable-tool and rotary-tool samples. Their preparation requires a skilled microscopist who understands drilling operations and the local stratigraphy. Theoretically all percentage logs record only what is in the samples and leave the translation into layered sequences to the user of the log, who unfortunately may never have seen the rocks. In practice some of this interpretation is in the microscopist's mind as he plots a qualified-percentage log and therefore influences his plotting considerably. The qualified-percentage log is highly recommended and commonly used in some regions, such as West Texas (Hills, 1949, p. 84), but has been largely superseded in the Midcontinent and Rocky Mountains regions by interpretive logs.

Interpretive Logs

An interpretive log is an interpretation of the layered sequence of rocks in a well made

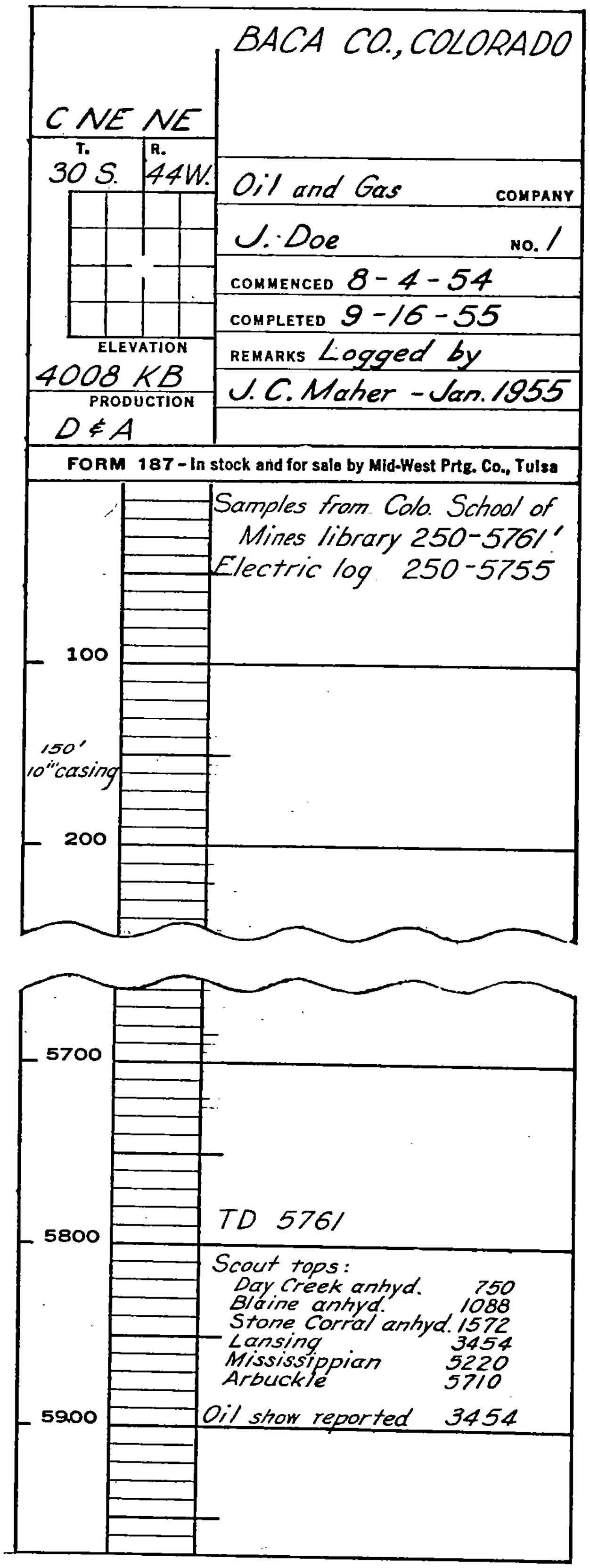


Figure 6. Log form showing heading and supplemental data.

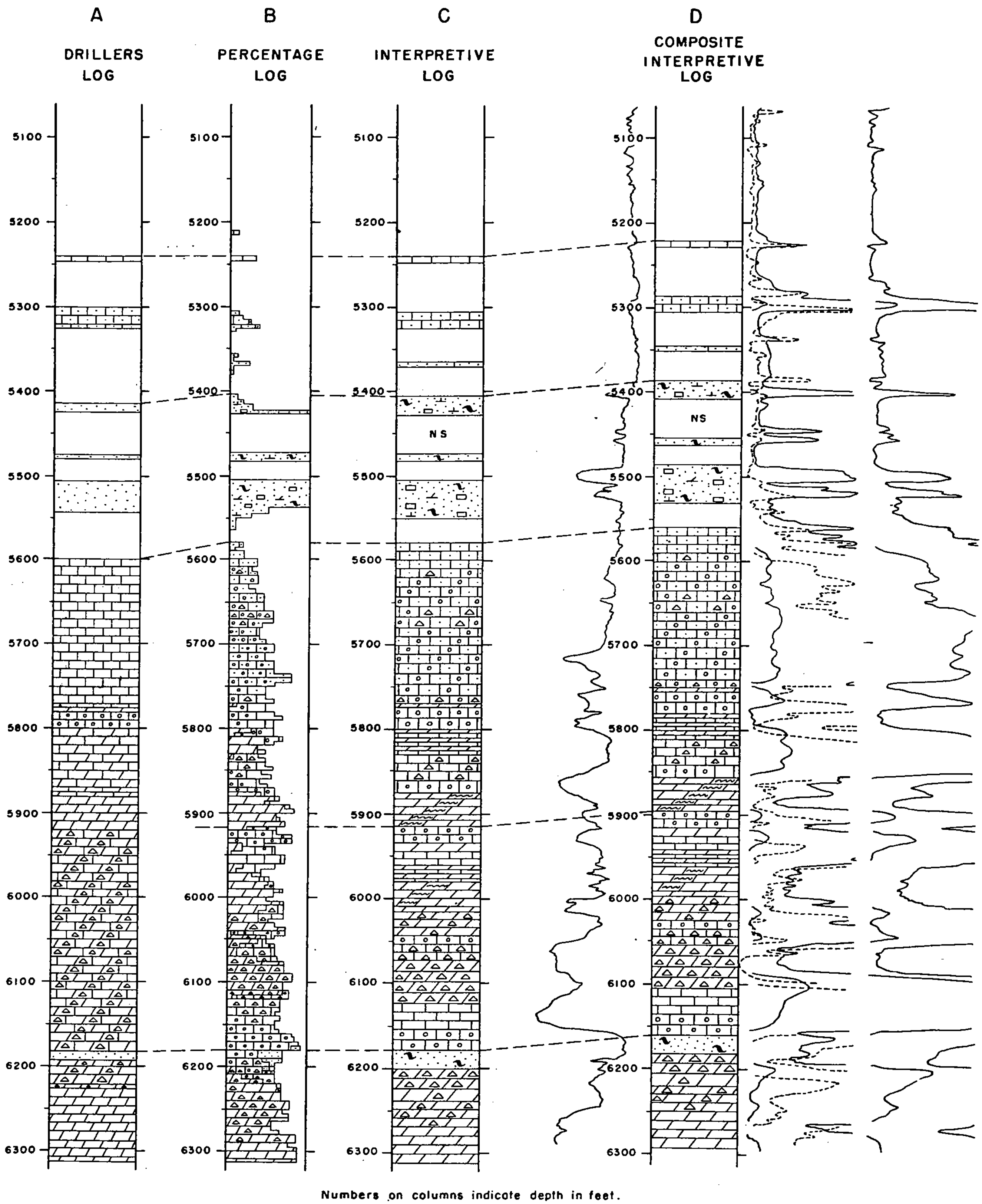


Figure 7. Comparison of drillers log (A), percentage log (B), interpretive log (C), and composite interpretive log (D), of same well. Electric-log curves have been added to (D) to indicate method of correcting log for sample lag. Identical beds have been logged about 20 feet higher in log D than in logs A, B, or C, as indicated by dashed lines. (Logs prepared by W. L. Adkison; see pl. 1 for explanation of lithologic symbols.)

with reference to the drilling operations, the limitations of the samples, the first appearance of specific lithologies and fossils in the samples, and the known stratigraphic sequence in the region. The different rock types in the samples are plotted across the well column of the log strip as individual layers (fig. 7C). Special training and considerable experience are required of stratigraphers who prepare these logs. The primary advantage of interpretive logs over percentage logs is that all interpretations of layered sequences are made by the individual who examines the samples.

Composite Interpretive Logs

In recent years it has become accepted practice to survey electrically most wells upon completion of drilling operations. This has led to the development of a technique of sample examination combining the best features of sample logs and electric logs, and resulting in a composite interpretive log (Maher, 1950). A composite interpretive log is prepared by the examination of samples under the microscope with concurrent reference to the electric or radioactivity log. The sample examination provides lithologic descriptions, including minute details and fossils necessary to correlate with other wells and outcrops, to which the electric log adds depth corrections (fig. 7), establishes the bed-for-bed succession in alternating lithologies, and suggests the content of reservoir rocks. This detail is plotted on a log strip, not the electric log, as a layered sequence with complete printed descriptions. Composite interpretive logs may equal measured outcrop sections of similar thickness in accuracy and lithologic detail. Their principal disadvantage arises from the time required to prepare such logs because a rate of 100 to 150 samples a day is about the optimum speed consistent with thorough examination. Therefore the preparation and use of these logs is limited mostly to detailed stratigraphic research.

PREPARATION OF COMPOSITE INTERPRETIVE LOGS

Equipment and Materials

The low-power binocular microscope is the basic tool of all sample-logging methods and was aptly termed the "present 'work horse' of the oil companies" by Low (1951, p. 1). The writer prefers a tilted-eye-piece model with 9× oculars and 0.7×, 2×, and 3× objectives, and an additional micrometer ocular for grain-size determinations. Combinations of the oculars and objectives listed above will produce 6.3×, 18×, and 27× magnification. A minimum magnification of 10× is commonly used, but the writer prefers 6.3× magnification for routine inspection because it provides a larger field of vision, requires less critical focus, transmits a greater amount of light, and causes less eye strain for the worker. Critical details, minute features, and powdered cuttings may be examined under 18× or 27× magnification.

The illumination used with the binocular microscope is best provided by fluorescent lamps of the type known as a floating fixture because of the mounting on a retractable arm. This type of fixture contains two 18-inch fluorescent tubes. One daylight tube and one white tube may be used in each so that natural colors may be approximated on the samples. Some of the advantages of this fixture over the focusing spotlight and transformer equipment are: (1) it gives off relatively little heat, (2) it leaves the desk top or working surface free of obstacles, and (3) it provides light for both the sample examination and the log plotting so that no desk light is needed. It has the disadvantage of insufficient intensity for magnification of more than 27×.

Other standard accessories are a fluoroscope to detect oil staining, tweezers (surgical grade), needle-pointed prod, sample tray, acid dish, color chart, grain-size slides, and drafting tools. Materials required are electric or radioactivity logs reduced to a scale of 1 inch = 100 feet, 6,000-foot log forms of the best grade, thin nonindelible colored pencils, 6N hydrochloric acid, carbon tetrachloride, lacquer, and brushes.

Procedure

The methods of catching, washing, and cutting samples, which have been fully discussed by Clark, Daniels, and Richards (1928, p. 61-68), Hills (1949, p. 79-83), and others, are well established as routine procedure in the oil industry. Bulk samples for each well drilled are usually provided to a central exchange by the operator or operating company. The washing and cutting of the bulk samples and the distributing of the sample sets is commonly handled by cooperative service organizations and commercial sample laboratories on a subscription basis. Public sample libraries are maintained by most state geological surveys; sample rental libraries are operated by several commercial sample laboratories; and large private sample libraries are kept by most large oil companies. At the present time most samples are filed in 3- by 5-inch manila envelopes and packed in 3½- by 5½- by 30-inch cardboard cartons. Some of the older samples are filed in 2-inch glass vials, which cannot be shipped safely.

In as much as clean samples are essential to detailed sample work, it is often necessary to rewash samples that have become dusty through frequent examination and shipment about the country. Permission should always be obtained from the owner prior to washing borrowed or rented samples.

After procuring a clean set of samples, the next step is to prepare a blank log form. The 6,000-foot log form may be cut and hinged with cloth tape at the 4,000-foot mark in order to assure uniform length of all logs in the log file. The heading (fig. 6) is then completed with the following data:

Names of operator and land owner
Well number
Location of well within section, township, range, county, and state
Altitude of derrick floor (D.F.), rotary table (R.T.), kelly bushing (K.B.), or ground level (G.L.)
Total depth of well (T.D.)
Production
Dates commenced and completed
Casing record
Drilling equipment
Source of samples
Supplementary surveys (electric log, radioactivity log, drilling-time log)
Date of sample examination
Name of sample examiner

Reported formation tops and related geological data may be plotted on the bottom or back of the log strip, and cored intervals marked at the left of the well column. The space provided for description is ruled lightly with a 6-H pencil at intervals corresponding to 5 or 10 feet on the log. These lines serve as guide lines for very small lettering with a crow-quill pen.

After the log form is completed, the microscope is placed on the left-hand extension leaf of the desk for a right-handed geologist or on the right-hand extension leaf for a left-handed geologist. One or two previously completed sample logs of nearby wells adjusted to proper correlation, side by side and overlapped to the well columns, are laid parallel to the edge of the desk, followed by the log form on which the descriptions will be plotted (fig. 8). The electric log or radioactivity log reduced to log scale (1 inch = 100 feet) is then laid alongside the

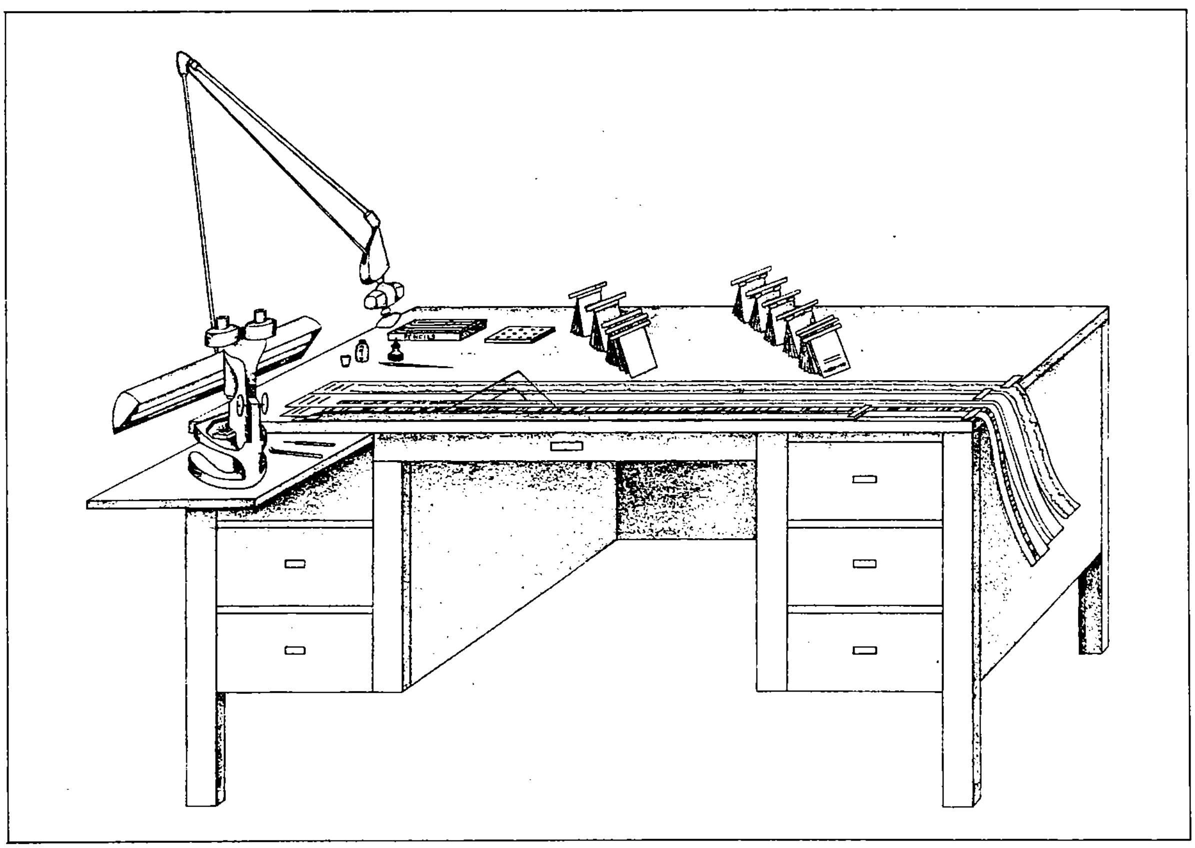


Figure 8. Arrangement of equipment and materials for preparation of composite interpretive logs.

log form but not overlapping it. All logs are weighted or taped in place at the top and bottom. A steel straightedge is laid parallel to the first sample-log column and a triangle is placed so that it can be slid up and down along the straightedge to maintain correlative points on all logs and to plot the lithology on the log form. This permits the concurrent examination of the samples and logs, the bed-for-bed correction of sample data with the electric or radioactivity log, and the plotting of the adjusted sample data on the log form. The entire procedure generally cannot be used in examining cuttings from a drilling well either at the well site or in the laboratory because the electric or radioactivity log ordinarily is not made until drilling is complete.

The general examination of the samples is made under the microscope using 6.3× magnification; critical details, minute features, and fine cuttings are examined under 18× or 27× magnification. Special examinations are made by examining the cuttings in a shallow pan of water in order to observe better the fine details, such as faint oölites and microfossils. The samples are examined, described, and plotted on the log in one operation. The abbreviated description of the sample is lettered with a crow-quill pen and drawing ink at the right of the well column. Fine lettering, carefully done, will permit considerable data to be recorded in this manner. Following this, symbols both in black ink and color are plotted in the well column and in the narrow marginal space to the left of the column.

Systematic Description of Samples

The classification and terminology of rocks in well samples do not correspond exactly to those used in outcrop descriptions or in theory because of the limitations imposed on samples by drilling procedures. Many distinctions and measurements that can be made on the outcrop cannot be made from drill cuttings. Generally the megafeatures of rocks such as weathering, bedding, and induration can only be surmised from the completed log; and most statistical measurements, such as grain-size analyses, are not feasible with rotary cuttings. On the other hand, microfeatures of the rocks probably are described qualitatively better in cuttings than in outcrops or hand specimens because of the enormous surface area presented by cuttings. The following discussion of sample description defines the terms as commonly used in subsurface geology, explains and reconciles the differences of usage in theory and practice, and systematizes the descriptive terms already in use as much as possible without proposing new names or scales.

In order to avoid the confusion caused by the indiscriminate mingling of rock, particle, and special descriptive terms on the log, the writer has found the following order of description to be useful: (1) rock characteristics, (2) particle characteristics, (3) special characteristics. The listing of these items does not imply that each item must be described for each sample but that, if the item is described, it should be in the order indicated. Complete petrographic descriptions with quantified data would be ideal, but unfortunately neither time nor space on the log will permit more than basic qualitative descriptions emphasizing the exceptional or significant features. Training, experience, and a detailed knowledge of local stratigraphy are necessary guides in the selection of the significant rock characteristics.

ROCK CHARACTERISTICS

The order of description of rock characteristics is as follows: (1) ascertainable megafeatures, (2) color pattern and color, (3) accessories, (4) structure, (5) luster, (6) sorting, cementation, and porosity, (7) grain size, (8) composition (x constituent, y constituent, and z constituent [rock type]). The descriptive adjectives and abbreviations for each characteristic are listed in table 1 under three general categories: (A) fine-grained siliceous clastics, (B) medium- and coarse-grained siliceous clastics, and (C) precipitates and nonsiliceous clastics. Nonsiliceous clastics (e. g., clastic limestones) are arbitrarily grouped with precipitates because the clastic particles in nonsiliceous clastic rocks are generally so intimately mixed with precipitated particles that distinctions are difficult and mean-size determinations are impossible under a binocular microscope. The rock characteristics and the accepted meanings, defined or implied, of descriptive terms used in the oil industry are discussed in the following pages.

Ascertainable Megafeatures

Most of the gross features of rocks penetrated in wells cannot be observed, but some of them can be seen in cores and a few can be inferred from cuttings and electric logs. These features include weathering, bedding, and induration.

Weathering, such as took place at major unconformities, can be detected in the cuttings and cores of some wells by the presence of leached limestone and chert fragments, variegated shale, red- to yellow-tinged rounded rock fragments, abraded fossils, and concentrations of pyrite and phosphate. Induration can be judged from cores and, to some extent, from large fragments in the cuttings. Usually the degree of induration is indicated by the terms hard, soft, tough, and brittle.

Bedding can be determined accurately from cores, and estimated fairly well from microresistivity curves of electric logs, but neither cores nor microresistivity curves are generally available. Fissile and platy bedding can be recognized in cuttings. Gross interpretations of bedding in alternating lithologies can be made from an ordinary electric log, but the minimum bed thickness accurately recorded is limited by the smallest electrode spacing used, which is about 16 inches in ordinary equipment. In practice the interpretation of bedding characteristics in wells is made by the geologist using the completed sample log and is not described in words on the sample log unless fissile or platy bedding can be seen in the samples. The bedding classification used in describing drill cuttings, cores, and outcrop samples is as follows:

Fissile, less than 1/16 inch thick.

Platy, 1/16 to 1/2 inch thick.

Very thin-bedded, 1/2 to 2 inches thick.

Thin-bedded, 2 to 4 inches thick.

Medium-bedded, 4 to 12 inches thick.

Thick-bedded, 12 to 36 inches thick.

Massive, more than 36 inches thick.

Color Pattern and Color

Color patterns of sedimentary rock fragments may be due either to primary features such as mineral composition or microstructure of the original sediments, or to secondary alteration of the rocks by weathering, leaching by ground water, recrystallization or replacement of minerals, and other metamorphic processes. Thus some color patterns reflect features described under other physical attributes, such as weathering, bedding, structure, cementation, and composition. Details of color patterns are seldom significant in stratigraphic correlation but may be helpful in locating unconformities or porous zones in rocks of similar composition. Comparative descriptions, such as "salt and pepper," may be useful in some cases but in general should be avoided as nonobjective. Color patterns generally can be simply classified as staining, speckling, spotting, mottling, or banding. These terms are defined as follows:

Staining refers to either a surficial color or an uneven color of obviously secondary origin in porous rocks.

Speckling refers to disseminated fine spots of color in a differently colored background with relatively clear boundaries.

Spotting refers to scattered medium to large spots of color with relatively clear boundaries.

Mottling refers to two or more colors with irregular and gradational boundaries.

Banding refers to two or more colors with relatively parallel, regular, and distinct boundaries.

Attempts to standardize the usage of rock-color descriptions in the geological profession were not very successful prior to 1948, when the Rock-color Chart prepared by the Rock-color Chart Committee (1948) was issued by the National Research Council. Since that time the rock-color standards have been accepted as the ideal system, even though they have not been used in detail for commercial work. Four reasons for the little use of the chart for routine sample examination are apparent: (1) considerable time is necessary to make effective use of the color chart, (2) color details are not diagnostic in subsurface correlations, (3) color details cannot be consistently determined because of variations in intensity and color of light on the samples, in the size, thickness, and grain-size of the fragments, in the magnification used, in the moisture content of the samples, and in the eyes of the observer, and (4) each company or laboratory has used its own semistandardized terminology since the beginning of intensive sample examinations in 1930, and these early descriptions on hundreds of thousands of logs will not match the later ones made with the Rock-color Chart.

Nevertheless the Rock-color Chart* has been adopted for many special research studies and has exerted considerable influence toward standardization by making the wide divergence of individual concepts of color apparent to all. More general use of the Rock-color Chart is recommended, if only during the training of subsurface geologists. After becoming familiar with the colors and terms it is not necessary to match each sample with the Rock-color Chart. The inexact color terms in general use may refer to a wide range of color, as is indicated in the following comparisons of some of these terms with colors on the Rock-color Chart.

Cream-colored includes very pale-orange (10YR 8/2), pale yellowish-orange (10YR 8/6), grayish-yellow (5Y 8/4), and yellowish-gray (5Y 8/1).

Khaki-colored approximates light olive-brown (5Y 5/6).

Light-buff includes light olive-gray (5Y 6/1) and grayish-orange (10YR 7/4).

Buff includes dark yellowish-orange (10YR 6/6) and dusky yellow (5Y 6/4).

Dark-buff approximates moderate yellowish-brown (10YR 5/4)

Maroon includes moderate-red (5R 4/6), very dark-red (5R 2/6), and dark reddish-brown (10R 3/4).

Black includes grayish-black (N2) as well as black (N1).

*Also the Munsell Soil Color Charts, which permit more exact color determinations in the hues 10R, 2.5YR, 7.5YR, 10YR, 2.5Y, and 5Y.

TABLE 1.—DESCRIPTIVE SEQUENCE, TERMINOLOGY, AND ABBREVIATIONS USED IN LOGGING ROCK TYPES IN DRILL CUTTINGS AND CORES

	1	2	3	4	5
	ASCERTAINABLE MEGAFEATURES	COLOR PATTERN AND COLOR	ACCESSORIES	STRUCTURE	LUSTER
A. FINE-GRAINED SILICEOUS CLASTICS	WEATHERING Fresh (fr.) Leached (lchd.) INDURATION Hard (hd.) Soft (sft.) Tough (tgh.) Brittle (brit.) BEDDING Fissile (fis.) (<1/16 in. thick) Platy (pl.) (1/16-1/2 in. thick) Alternating (alt.)	Stained (stn.) Speckled (speck.) Spotted (spot.) Mottled (mot.) Banded (bnd.) (See Rock-color Chart for color terms.)	Micaceous (mic.) Feldspathic (feld.) Pyritic (pyr.) Glauconitic (glauc.) Sideritic (sid.) Limonitic (lmn.) Sphaleritic (sphal.) Bentonitic (bent.) Siliceous (sil.) Carbonaceous (carb.) Bituminous (bit.)	Plastic (plas.) Varved (vrvd.) Laminated (lam.) Foliated (fol.) Splintery (spl.) Flaky (flky.) Jointed (jtd.) Fractured (frac.) Fossiliferous (fos.)	Dull Earthy (ear.) Resinous (res.) Waxy (wxy.) Greasy (gsy.) Sooty
B. MEDIUM- AND COARSE-GRAINED SILICEOUS CLASTICS	WEATHERING Fresh (fr.) Leached (lchd.) INDURATION Hard (hd.) Soft (sft.) Friable (fri.) BEDDING Alternating (alt.) Platy (pl.) (1/16-1/2 in. thick) Very thin bedded* (v.thn.bd.) (1/2-2 in.thick) Thin bedded (thn.bd.)* (2-4 in.thick) Medium bedded (m.bd.)* (4-12 in.thick) Thick bedded (thk.bd.)* (12-36 in.thick) Massive (mass.)* (>36 in.thick) Cross-bedded (x.bd.)*	Stained (stn.) Speckled (speck.) Spotted (spot.) Mottled (mot.) Banded (bnd.) (See Rock-color Chart for color terms.)	Micaceous (mic.) Feldspathic (feld.) Pyritic (pyr.) Glauconitic (glauc.) Sideritic (sid.) Limonitic (lmn.) Sphaleritic (sphal.) Bentonitic (bent.) Siliceous (sil.) Carbonaceous (carb.) Bituminous (bit.)	Laminated (lam.) Foliated (fol.) Oölitic (ool.) Pisolitic (piso.) Fossiliferous (fos.) Jointed (jtd.) Fractured (frac.) Crinkled (crink.)	Dull Resinous (res.) Vitreous (vit.)
C. PRECIPITATES AND NONSILICEOUS CLASTICS	WEATHERING Fresh (fr.) Leached (lchd.) INDURATION Hard (hd.) Soft (sft.) BEDDING Alternating (alt.) Platy (pl.) (1/16-1/2 in.thick) Very thin bedded* (v.thn.bd.) (1/2-2 in.thick) Thin bedded (thn.bd.)* (2-4 in.thick) Medium bedded (m.bd.)* (4-12 in. thick) Thick bedded (thk.bd.)* (12-36 in.thick) Massive (mass.)* (>36 in.thick) Cross-bedded (x.bd.)*	Stained (stn.) Speckled (speck.) Spotted (spot.) Mottled (mot.) Banded (bnd.) (See Rock-color Chart for color terms.)	Micaceous (mic.) Feldspathic (feld.) Pyritic (pyr.) Glauconitic (glauc.) Sideritic (sid.) Limonitic (lmn.) Sphaleritic (sphal.) Bentonitic (bent.) Siliceous (sil.) Carbonaceous (carb.) Bituminous (bit.)	Stylolitic (sty.) Oölitic (ool.) Pisolitic (piso.) Oömoldic (oom.) Fossiliferous (fos.) Algal (alg.) Crinkled (crink.) Banded (bnd.) Concretionary (conc.) Jointed (jtd.) Fractured (frac.) Fibrous (fib.)	Dull Earthy (ear.) Resinous (res.) Vitreous (vit.) Pearly (prly.) Silky (slky.) Greasy (gsy.)

* Determinable only from cores, electric logs, and radioactivity logs.

6	7	8		
		COMPOSITION		
SORTING, CEMENTATION, AND POROSITY	MEAN GRAIN SIZE OR CRYSTALLINITY	X-CONSTITUENT ADJECTIVE[1] (X<Y)	Y-CONSTITUENT ADJECTIVE[1] (Y<Z)	Z-CONSTITUENT ROCK TYPE
(Sorting and porosity of fine-grained siliceous clastics are not usually determined or estimated; cementation usually is treated as X or Y constituent, or an accessory.)	(Mean grain size of fine-grained siliceous clastics is recorded by constituent terms, but sometimes coarse silt (1/32-1/16 mm) is differentiated from finer silt.)	Clayey (cly.) Silty Shaly (shly.) Sandy (sdy.) Conglomeratic (congl.) Limy Dolomitic (dolic.) Anhydritic (anhyd.) Gypsiferous (gyps.) Cherty (chty.) Arkosic (ark.)	Clayey (cly.) Silty Shaly (shly.) Sandy (sdy.) Conglomeratic (congl.) Limy Dolomitic (dolic.) Anhydritic (anhyd.) Gypsiferous (gyps.) Cherty (chty.) Arkosic (ark.)	INDURATED AGGREGATES Claystone (clyst.) Siltstone (sltst.) Shale (sh.) Mudstone (mdst.) NONINDURATED AGGREGATES Clay Silt
SORTING Well sorted (w. srtd.) Medium sorted (m. srtd.) Poorly sorted (p. srtd.) CEMENTATION Silica-cememted (sil. cem.) Lime-cemented (ls. cem.) Dolomite-cemented (dol. cem.) Iron-cemented (Fe cem.) POROSITY Nonporous (n. por.) Slightly porous (sl. por.) Porous (por.) Very porous (v. por.)	Mean grain sizes above 2 mm given in mm. Very coarse grained (v. c. gr.) (1-2 mm) Coarse grained (c. gr.) (1/2-1 mm) Medium grained (m. gr.) (1/4-1/2 mm) Fine grained (f. gr.) (1/8-1/4 mm) Very fine grained (v. f. gr.) (1/16-1/8 mm)	Clayey (cly.) Silty Shaly (shly.) Sandy (sdy.) Conglomeratic (congl.) Limy Dolomitic (dolic.) Anhydritic (anhyd.) Gypsiferous (gyps.) Cherty (chty.) Arkosic (ark.)	Clayey (cly.) Silty Shaly (shly.) Sandy (sdy.) Conglomeratic (congl.) Limy Dolomitic (dolic.) Anhydritic (anhyd.) Gypsiferous (gyps.) Cherty (chty.) Arkosic (ark.)	INDURATED AGGREGATES Sandstone (ss.) Conglomerate (congl.) NONINDURATED AGGREGATES Sand. (sd.) Gravel (gvl.)
POROSITY Nonporous (n. por.) Slightly porous (sl. por.) Porous (por.) Very porous (v. por.) Vuggy (vug.) Tubular (tub.) Cavernous (cav.)	Very coarse grained (v. c. gr.) (1-2 mm) Coarse grained (c. gr.) (1/2-1 mm) Medium grained (m. gr.) (1/4-1/2 mm) Fine grained (f. gr.) (1/8-1/4 mm) Very fine grained (v. f. gr.) (1/16-1/8 mm) Micrograined (micgr.) (1/256-1/16 mm) Cryptograined[3] (crpgr.) Note: The term crystalline may be used in lieu of grained for obviously crystalline rocks--e. g., very finely crystalline, microcrystalline.	Clayey (cly.) Silty Shaly (shly.) Sandy (sdy.) Conglomeratic (congl.) Limy Dolomitic (dolic.) Anhydritic (anhyd.) Gypsiferous (gyps.) Cherty (chty.) Arkosic (ark.)	Clayey (cly.) Silty Shaly (shly.) Sandy (sdy.) Conglomeratic (congl.) Limy Dolomitic (dolic.) Anhydritic (anhyd.) Gypsiferous (gyps.) Cherty (chty.) Arkosic (ark.)	CARBONATES, CHERT, AND EVAPORITES Limestone (ls.) Dolomite (dol.) Chert (ch.) Anhydrite (anhy.) Gypsum (gyp.) Salt[4]

[1]Adverbs "very" and "slightly" may be used with constituent adjective to express extremes.
[2]Silica cement assumed if not mentioned specifically.
[3]This includes lithographic limestone.
[4]Salt is logged but seldom can be described in rotary-drill cuttings.

Accessories

Accessories are those constituent particles which make up a minor, yet meaningful, part of the rock. Usually they constitute less than 1 percent of the rock and consist of either grains or crystals. In many regions the accessories in thick sequences of similar rocks are important in establishing detailed correlations. They also provide significant clues as to the source, mode of origin, transportation, deposition, and diagenesis of the rock. Some of the more common accessories are mica, feldspar, pyrite, glauconite, siderite, limonite, sphalerite, bentonite, silica, carbon, and bitumen. Ordinarily the accessories are identified in the rock description by simple modifying adjectives, as is shown in column 3 of table 1. If a detailed description of any accessory seems warranted, it should follow the rock description as a particle description in order to avoid complicated phrasing.

Structure

The structures normally evident in drill cuttings and cores are fossils, oölites, pisolites, oömolds, stylolites, concretions, joints, fractures, foliation, lamination (including varves), banding, and crinkling. These are indicated in the rock description by the general adjectives listed in column 4 of table 1. Specific descriptions of significant structures are made as particle characteristics (table 5) or special characteristics following the rock description. Fossils, oölites, pisolites, and oömolds are particularly important not only as a basis for detailed correlations but also as indicators of possible oil and gas reservoirs. Joints and fractures are significant because of their effect on the permeability of the rocks; fine banding and crinkling, stylolites, and concretions are important in identifying certain formations. Other structural features commonly are of less importance in regional stratigraphic work.

Luster

The luster of a rock is its appearance due to the effect of light upon it. Ordinarily luster is omitted from rock descriptions unless it is an uncommon type. Resinous dolomites, waxy shales, and earthy limestones are examples of rocks which have distinctive lusters useful in matching rock sequences. Some of the more common adjectives of luster and their meanings are listed below:

Sooty - having the light-absorption qualities of soot.
Earthy - having the dull nonreflective surface of earth.
Resinous - having the appearance of resin.
Greasy - having the resemblance of rock covered with a thin film of grease or oil.
Waxy - having the semishiny reflective surface of wax.
Silky - having the sheen of silk from fine fibrous structure.
Pearly - having the iridescent appearance of a pearl.
Vitreous - having the reflective surface of broken glass.

Sorting, Cementation, and Porosity

Sorting is an expression of the range of grain-size classes represented by the constituent particles of a rock. It is best evaluated by determining the coefficient of sorting from sieve or other grade-size analyses. Such analyses cannot be readily made with drill cuttings and are seldom made from cores except in engineering studies. However, exceptional degrees of sorting noted under the microscope should be recorded qualitatively on the log. The following terms adapted from Payne (1942, p. 1707) are useful in this respect:

Well-sorted - 90 percent of particles concentrated in 1 or 2 size classes.
Medium-sorted - 90 percent of particles distributed in 3 or 4 size classes.
Poorly sorted - 90 percent of particles scattered in 5 or more size classes.

The character and composition of cementing materials of rocks are important in the completion of oil wells, in reservoir behavior studies, and in the interpretation of the depositional history and lithification of sediments. However, the cementing material of a rock, particularly a clastic carbonate rock, can only be described completely by means of thin sections and a petrographic microscope. Time does not permit this in most regional stratigraphic studies so the cementing material is not described unless it is obvious under the binocular microscope. Usually these descriptions concern either sandstones or conglomerates most commonly cemented with silica, calcite, dolomite, and iron oxides. Other less common cementing materials include pyrite, siderite, sulphates, and phosphates. Clay and silt form the matrix of many sandstones and conglomerates, but these are usually described as rock constituents rather than cement.

Porosity, which is the percentage of total volume of a rock not occupied by mineral components, is directly related to sorting, cementation, size, and shape of constituent particles. Porosity can be determined from a core or computed from an electric log, but it can only be estimated roughly from drill cuttings. Rough estimates of porosity can be made from drill cuttings by comparing the rock chips with cores for which the porosity has been determined. Even less exact descriptions are usually made, using the qualitative terms *nonporous*, *slightly porous*, *porous*, and *very porous*. The term *pinpoint porosity* is commonly applied to a special type of porosity in carbonate rocks in which fine pores are widely scattered.

Grain Size

A grain-size classification for rock types in drill cuttings is given in table 2. The adjective *grained* is used in this table to describe any rock composed of grains, either detrital grains or crystals, as suggested by DeFord (1946, p. 1922). The size scale and most terms correspond with those of the Wentworth grade scale except that the size scale expresses the mean grain size of the rock fragments in the drill cuttings, whereas the Wentworth size scale refers to the actual size of an individual grain.

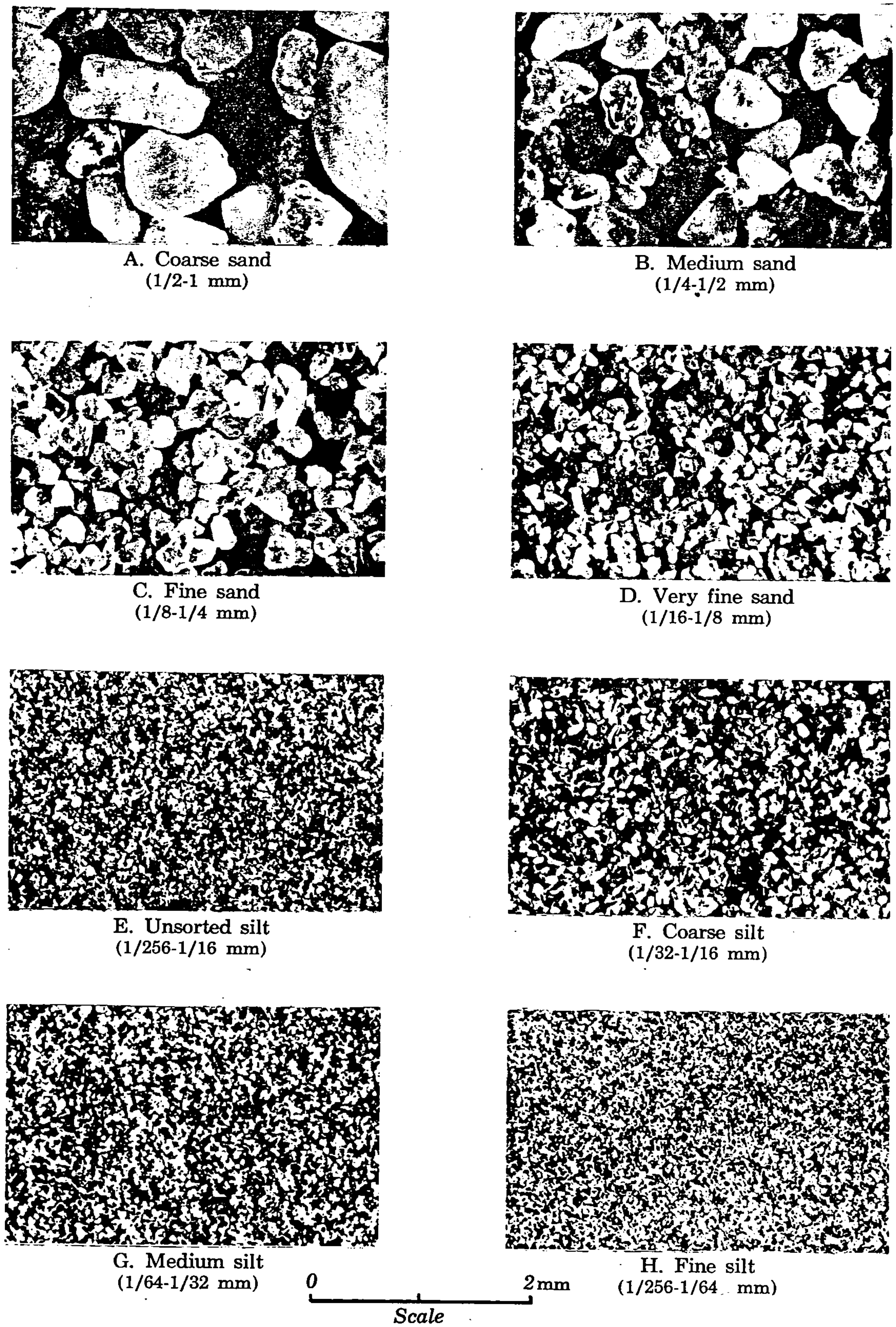
Any description of grain size of rocks in rotary-tool cuttings involves a progressive series of estimates—(1) size of individual grains, (2) mean size of grains in individual fragments, and (3) mean size of grains in all fragments of the same lithology. The determination of mean grain size by sieve or other grain-size analyses is not feasible for most drill cuttings; measurements of grain sizes by means of a micrometer ocular are too time consuming for routine practice and are made only for special rocks, such as possible reservoirs. This means that most grain-size determinations in drill cuttings are relatively inaccurate and that the terms are used in a comparative sense. Slides containing examples of size classes for comparison with the drill cuttings are very helpful in maintaining consistency in the use of these terms. A general rule of thumb helpful, though somewhat inaccurate, in judging grain sizes is that detrital grains or crystals larger than 1/16 mm are clearly visible to the naked eye; those between 1/16 and 1/64 mm in diameter are visible under 6.3× magnification; those between 1/64 and 1/256 mm are indistinctly visible under 6.3× magnification; and those smaller than 1/256 mm are invisible under 6.3× magnification.

Figures 9 and 10 picture the appearance of different sizes of sand and silt under the microscope. Comparison of the appearance of unsorted particles (E) with sorted particles (F, G, and H) in figure 10 suggests the difficulty of estimating mean grain size of particles in rocks in drill cuttings.

TABLE 2.—GRAIN-SIZE CLASSIFICATION FOR ROCK TYPES IN DRILL CUTTINGS

Mean size (mm)	*Relationship of size to visibility of grains*	*Siliceous clastics*	*Undifferentiated precipitates and nonsiliceous clastics*[1]	*Precipitates*[2]
2	Individual grains visible without magnification	(Granule to boulder)	(Mean size in mm)	(Mean size in mm)
1-2	" "	Very coarse-grained	Very coarse-grained	Very coarsely crystalline
1/2-1	" "	Coarse-grained	Coarse-grained	Coarsely crystalline
1/4-1/2	" "	Medium-grained	Medium-grained	Medium-crystalline
1/8-1/4	" "	Fine-grained	Fine-grained	Finely crystalline
1/16-1/8	" "	Very fine-grained	Very fine-grained	Very finely crystalline
1/256-1/16	Individual grains visible to indistinctly visible with 6.3× magnification	Silt	Micrograined	Microcrystalline[3]
1/256	Individual grains not visible with 6.3× magnification	Clay	Cryptograined[4]	Cryptocrystalline[4]

[1]Precipitates and nonsiliceous clastics seldom can be distinguished in carbonate rocks without use of thin sections.
[2]Obviously crystalline rocks. Use of terms optional.
[3]Carbonates of this size range have indistinct crystal faces under 6.3× magnification. Common practice has been to refer to such rocks as very finely granular. The term "sublithographic" has been applied to nonsiliceous rocks of this grain size with the connotation of even texture.
[4]The term "dense" is commonly applied to rocks of this grain size; the term "aphanitic" is less commonly used. The term "lithographic" has been applied with the connotation of even texture.



A. Coarse sand (1/2-1 mm)

B. Medium sand (1/4-1/2 mm)

C. Fine sand (1/8-1/4 mm)

D. Very fine sand (1/16-1/8 mm)

E. Unsorted silt (1/256-1/16 mm)

F. Coarse silt (1/32-1/16 mm)

G. Medium silt (1/64-1/32 mm)

H. Fine silt (1/256-1/64 mm)

Figure 9. Appearance of different sizes of sand and silt under the microscope with 6.3× magnification.

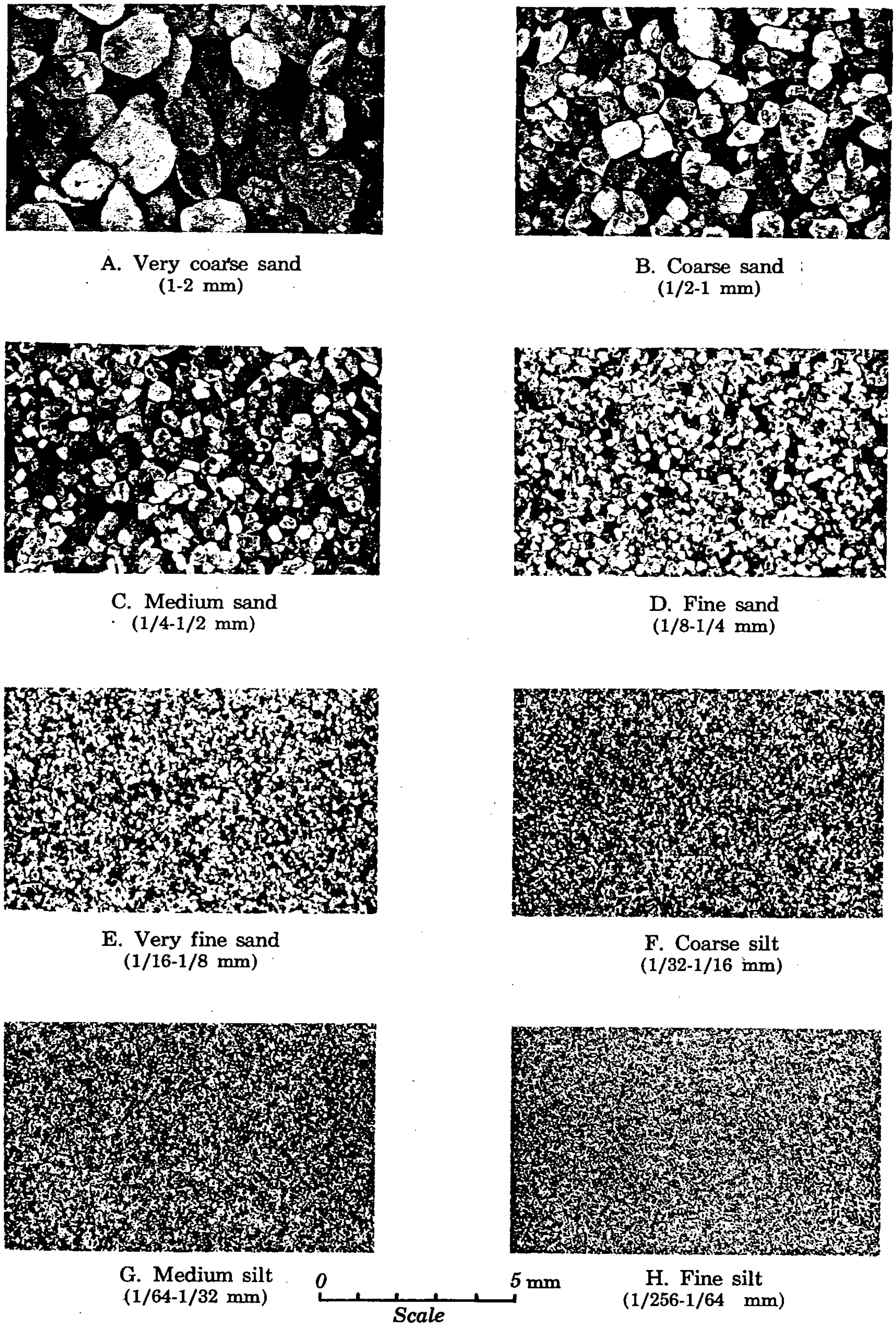


Figure 10. Appearance of different sizes of sand and silt under the microscope with 18× magni-

silt (F, G, H).

Siliceous clastics. The subdivisions of the grain-size range for fine siliceous clastics are clay size (1/256 mm) and silt size (1/256-1/16 mm). The silt size can be further subdivided by pipette or elutriation analysis into fine (1/256-1/128 mm), medium (1/128-1/64 mm), and coarse (1/64-1/16 mm) fractions. Although the coarse-silt size (fig. 9F) can be readily recognized under a low-power binocular microscope, the fine- and medium-silt sizes cannot be separated from each other (fig. 9G, H) or from the clay size in a consistent manner. As a result, the size subdivisions of fine-grained siliceous clastics are commonly ignored in describing drill cuttings by using the term "shale" for any fine-grained siliceous clastic rock with or without bedding. This problem will be discussed further under Composition.

The subdivisions of the medium-size range (1/16-2 mm) of siliceous clastics can be recognized more accurately under the binocular microscope than those in the fine or coarse ranges. However the fact that grains of coarse-silt size (1/64-1/16 mm) are readily visible under low-power magnification has caused many geologists to regard rocks of coarse-silt size as very fine-grained sandstone (1/16-1/8 mm) or to describe them as such as a matter of convenience. Also, the difficulty in estimating accurately the mean grain size of rock fragments composed of both silt-size and very fine grains has resulted in the common use of straddling descriptions such as "siltstone to very fine-grained sandstone" or "very fine-grained to silty sandstone." This cannot always be avoided in logging drill cuttings, even though it is not very definite.

Coarse-grained siliceous clastics, or conglomerates, are classed both as to mean grain size, usually in the sandstone range, and the maximum grain size. The maximum size is expressed by the modifier *granule* (2-4 mm), *pebbly* (4-64 mm), *cobbly* (64-256 mm), or *bouldery* (256 mm). An example of this dual size terminology is "coarse-grained pebbly conglomerate" which indicates a mean grain size between 1/2 and 1 mm and a maximum grain size between 4 and 64 mm. In practice it is extremely difficult to determine the maximum grain size of the fragments in a conglomerate as the drill cuttings are seldom representative in this respect, so most conglomerates are described only as to mean grain size.

Precipitates and nonsiliceous clastics. Little agreement exists among geologists as to the best classification of mean grain size of precipitates and nonsiliceous clastics, the most common of which are the carbonates. Classifications useful for thin sections under a petrographic microscope (Alling, 1943; Pettijohn, 1949, p. 73) are not appropriate for drill cuttings under a binocular microscope. Those proposed for drill cuttings differ considerably (Payne, 1942, p. 1706; DeFord, 1946, p. 1927; Krynine, 1948, p. 142; Wengerd, 1948, p. 2198; Hills, 1949, p. 86; Low, 1951, p. 18).

The classifications most commonly used in the petroleum industry in the past 40 years have been based on the Wentworth grade scale. This grade scale probably provides more size classes than can be determined accurately in most precipitate and nonsiliceous clastic rocks under a binocular microscope, but the scale may be abridged when necessary by giving the mean-size range—e.g., very fine to fine. This expedient permits the rapid description of rocks in which grain size is not particularly important, yet allows the examiner to be more exact where necessary. Use of the Wentworth grade scale for precipitate and nonsiliceous clastic rocks has the practical advantage of providing a single-size scale for all rocks in the drill cuttings. This advantage is considerable in any work in which time does not permit measurements or constant comparisons with grain-size slides or charts.

In recognition of the fact that many carbonate rocks are composed of clastic rather than precipitated particles, the terms *granular* and *crystalline* commonly have been used by petroleum geologists with the Wentworth grade-scale adjectives *very fine, fine, medium, coarse,* and *very coarse.* However, the separation of clastic and precipitated carbonate particles in a limestone or dolomite under a low-power binocular microscope is extremely uncertain. Carbonates exhibiting distinct crystal faces can be readily classed as crystalline; those with fine indistinct faces, mixed clastic and crystal particles, or well-cemented clastic particles cannot be readily classed as either crystalline or granular.

Table 2 presents an adaptation of the Wentworth grade scale to precipitate and nonsiliceous clastic rocks. The adjective *grained* is applied to precipitates as well as to clastic rocks, but the adjective *crystalline* is retained for optional use with obviously crystalline rocks. Measurements rather than descriptive size terms are suggested for precipitates and nonsiliceous clastics in the coarse range (2 mm). The adjective *rhombic* has been used locally to indicate dolomite crystals in the coarse-size range but this is not a proper size term. The adjective *granular* which was proposed by Payne (1942, p. 1706) for granule-size (2-4 mm) crystals has not been adopted generally because the term *granular* has been used with the meaning of noncrystalline in many regions.

Grain-size terms for precipitates and nonsiliceous clastics in the fine range of the Wentworth grade scale are not agreed upon even by geologists who attempt to use the same limiting sizes. Carbonates composed of clay-size particles have been termed *dense, lithographic, mat, aphanitic,* and *cryptocrystalline;* those of silt-size particles have been termed *very finely granular, sublithographic, subcrystalline,* and *microcrystalline.* The terms *cryptograined* and *micrograined* for undifferentiated precipitates and nonsiliceous clastics, and the terms *cryptocrystalline* and *microcrystalline* for obviously crystalline precipitates are recommended in lieu of better terms at the present time. The term *dense,* despite the fact that it does not refer to specific density, is a useful synonym for cryptograined or cryptocrystalline because of its long and common usage in the petroleum industry.

Composition

Most rocks observed in drill cuttings consist of a mixture of one major constituent and not more than two minor constituents, which make up about 99 percent of the rock, and one or more accessories, which make up about 1 percent. The minor and major constituents are recorded on the log as the last or x, y, z terms of the rock-description sequence shown in table 1. These are recorded in accordance with their relative proportions in the mixture—the proportion of y constituent being more than that of x constituent and less than that of z constituent. Adjectives are used to denote the minor constituents (x, y) and a rock-type name is used to classify the major constituent (z)—for example, (x) sandy, (y) dolomitic, (z) limestone.

In binary mixtures, which consist of a major and only one minor constituent, the major constituent (z) composes at least 51 percent of the rock; in ternary mixtures, the major constituent (z) composes at least 34 percent of the rock. Gravel and conglomerate are exceptions as shown in table 3. The most common constituents of the mixtures are 8 in number—clay, silt, sand, gravel, calcite, dolomite, anhydrite, and chert—which correspond to 8 simple rock types—claystone, siltstone, sandstone, conglomerate, limestone, dolomite, anhydrite, and chert.

TABLE 3.—MINIMUM PERCENTAGES OF THE MAJOR CONSTITUENT IN DRILL CUTTINGS OF BINARY AND TERNARY ROCKS

Rock types		*No. of constituents*	*Particles in rock*							
Consolidated aggregate	*Unconsolidated aggregate*		*Clay*	*Silt*	*Sand*	*Granule to boulder*	*Calcite*[1]	*Dolomite*	*Anhydrite or gypsum*	*Chert*
Shale[2]		2 3	51 34							
Claystone	Clay	2 3	51 34							
Siltstone	Silt	2 3		51 34						
Sandstone	Sand	2 3			51 34					
Conglomerate	Gravel	2 3			41 24	10 10				
Limestone		2 3					51 34			
Dolomite		2 3						51 34		
Anhydrite or gypsum		2 3							51 34	
Chert		2 3								51 34

[1]Also includes aragonite.

[2]Bedding seldom is determinable in drill cuttings and the term "shale" is used without structural implication for rocks composed of silt and clay.

Binary mixtures of the 8 constituents provide 56 combinations, and ternary mixtures provide 336 combinations. These with the 8 simple rock types result in 400 possible rock types from the 8 constituents. If clay and silt are not differentiated and claystone and siltstone are treated as shale, the number of possible rock types is reduced to 259.

The commonly associated rock types are illustrated by tetrahedral diagrams in figures 11, 12, and 13. The corners of the tetrahedrons represent the simple rock types; the edges represent the binary mixtures; and the triangular faces represent the ternary mixtures. The accuracy with which rocks may be placed in this classification ranges from a probable error of less than 2 percent in separating relatively insoluble from soluble particles (e. g., sand and calcite) to as much as 10 percent in separating relatively soluble constituents (e. g., calcite and dolomite) from one another, or fine-grained from medium-grained clastics (siltstone and very fine-grained sandstone). The separation of claystone from fine-grained siltstone cannot be accomplished satisfactorily under the low-power binocular, and no estimate of probable error can be made.

The following discussion attempts to define the common terms used for particles and rock types in drill cuttings, and to explain and reconcile, as much as possible, the differences in the theoretical and practical usage of these terms. No attempt is made to utilize the more systematic terms of the classifications by Grabau (1904), Shrock (1948), Pettijohn (1949, p. 191-194), and others, which are superior for outcrop and thin-section work but have not been adopted by many subsurface geologists because they are not readily adaptable to the special limitations of drill cuttings and the binocular microscope. Probably the classification system long in use in the petroleum industry is closer to that of Krynine (1948), with the "end-member" concept, than to other published systems. Restricted meanings and adaptations of standard definitions which have proved useful in practice are explained, but no revisions of standard definitions are suggested or implied.

As a matter of practical convenience the sedimentary rocks commonly observed in drill

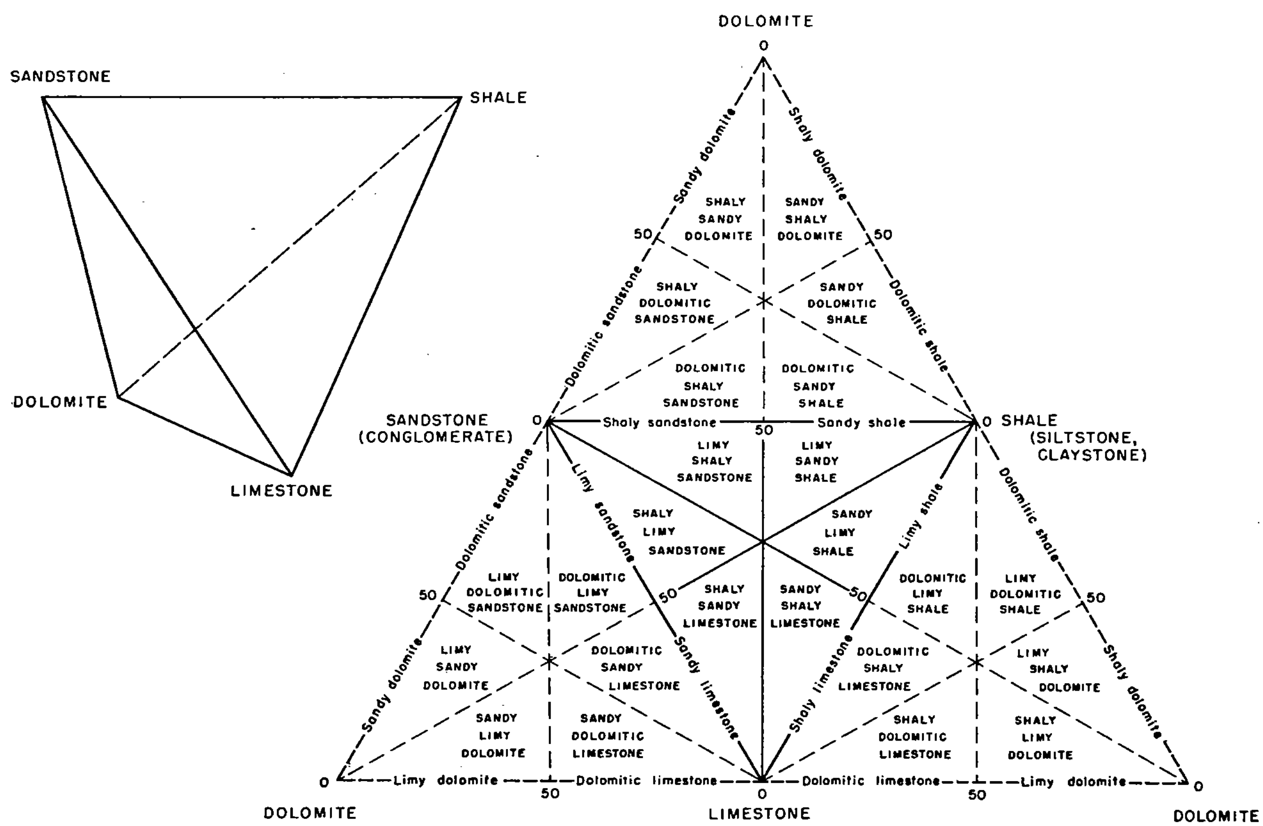


Figure 11. Tetrahedral diagram illustrating classification of commonly associated carbonate and siliceous clastic rocks in drill cuttings.

cuttings may be divided into (1) fine-grained siliceous clastics, (2) medium- and coarse-grained siliceous clastics, and (3) precipitates and nonsiliceous clastics. The adjective "siliceous" is used in the chemical sense in this classification to include not only free silica (quartz) but silica in undecomposed silicates as well. The grouping of nonsiliceous clastics with precipitates, despite the well-known fact that many carbonate and some evaporite rocks are clastic or partly clastic in origin, is necessary because the clastic and precipitated particles in most drill cuttings commonly cannot be distinguished or measured under a binocular microscope.

Table 4 presents the classification of siliceous clastic particles in accordance with the Wentworth grade scale and the corresponding classification of unconsolidated aggregates and consolidated aggregates of these particles. The particle terms with adjectival endings are used to describe the minor or x and y constituents (table 1); the unconsolidated and consolidated aggregate terms are used for the major, or z-constituent, rock type. Unconsolidated aggregates, which usually are found only at or near the land surface, are not sampled as a general practice in drilling oil wells, but the distinction between terms for consolidated and unconsolidated aggregates should be maintained in the description.

Fine-grained siliceous clastics. Fine siliceous particles, which are less than 1/16 mm in size, are divided into clay (1/256 mm) and silt (1/256-1/16 mm). *Clay* is an unconsolidated aggregate of mineral particles, mostly siliceous (Pettijohn, 1949, p. 269, 270), more than 50 percent of which are less than 1/256 mm in diameter. According to Pettijohn (1949, p. 269), clay minerals compose only 10 to 20 percent of the aggregate. *Claystone* is indurated clay. *Silt* is an unconsolidated aggregate of mineral particles, mostly siliceous, more than 50 percent of which range between 1/256 mm and 1/16 mm in diameter. *Siltstone* is indurated silt.

The consistent separation of clay and silt or claystone and siltstone is very difficult under a low-power binocular microscope. The coarse fraction of silt or siltstone (1/64-1/16 mm) can be readily recognized as separate from clay or claystone, but mixtures of smaller sizes of

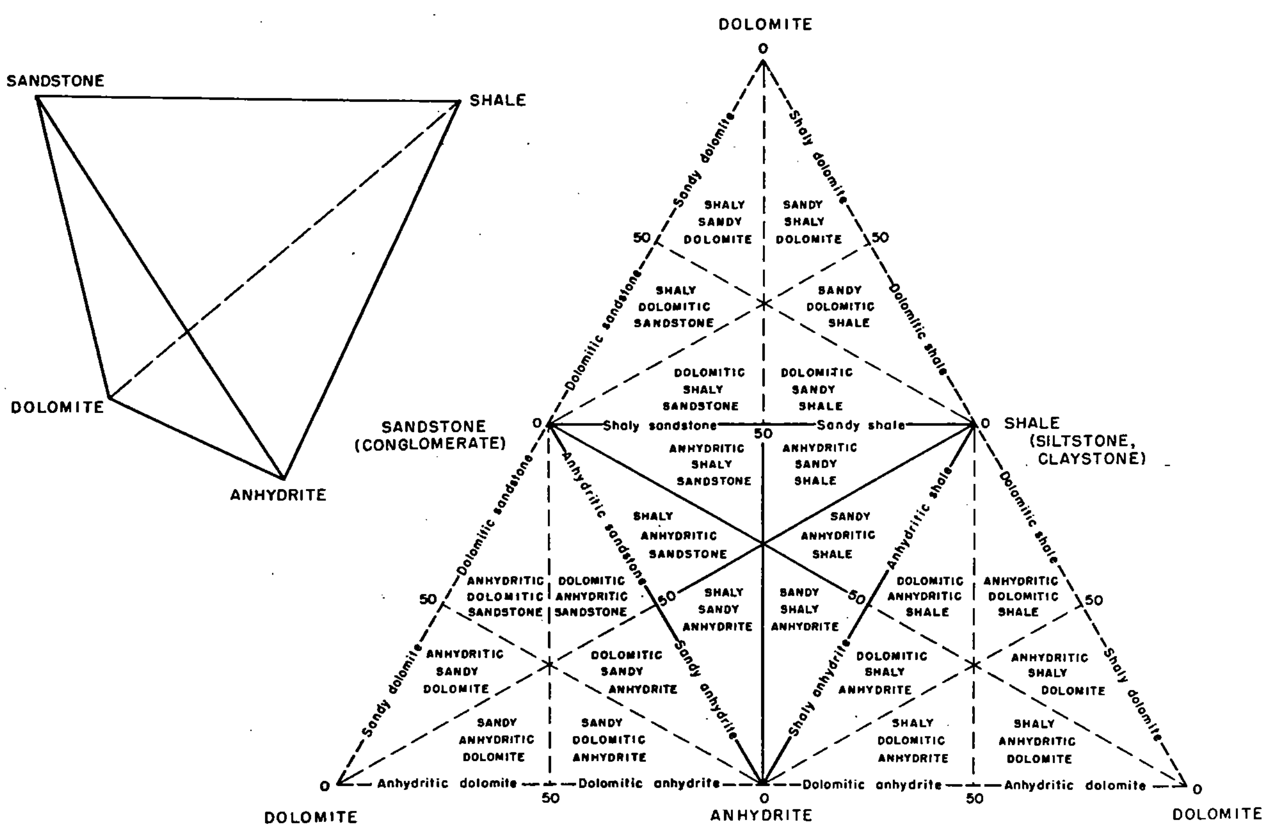


Figure 12. Tetrahedral diagram illustrating classification of commonly associated evaporite and siliceous clastic rocks in drill cuttings.

TABLE 4.—WENTWORTH PARTICLE-SIZE CLASSIFICATION AND CORRESPONDING ROCK TERMS FOR SILICEOUS CLASTICS IN DRILL CUTTINGS

Particle	*Size limit (mm)*[1] *Lower*	*Upper*	*Unconsolidated aggregate*	*Consolidated aggregate*	
Boulder	256		Boulder gravel	Boulder conglomerate	
Cobble	64	256	Cobble gravel	Cobble conglomerate	
Pebble	4	64	Pebble gravel	Pebble conglomerate	
Granule	2	4	Granule gravel	Granule conglomerate	
Very coarse sand	1	2	Very coarse sand	Very coarse-grained sandstone	
Coarse sand	1/2 (0.500)	1	Coarse sand	Coarse-grained sandstone	
Medium sand	1/4 (0.25)	1/2 (0.5)	Medium sand	Medium-grained sandstone	
Fine sand	1/8 (0.125)	1/4 (0.25)	Fine sand	Fine-grained sandstone	
Very fine sand	1/16 (0.062)	1/8 (0.125)	Very fine sand	Very fine-grained sandstone	
Silt	1/256 (0.0039)	1/16 (0.062)	Silt	Siltstone	Shale
Clay		1/256 (0.0039)	Clay	Claystone	

[1]Mean-size range of aggregates.

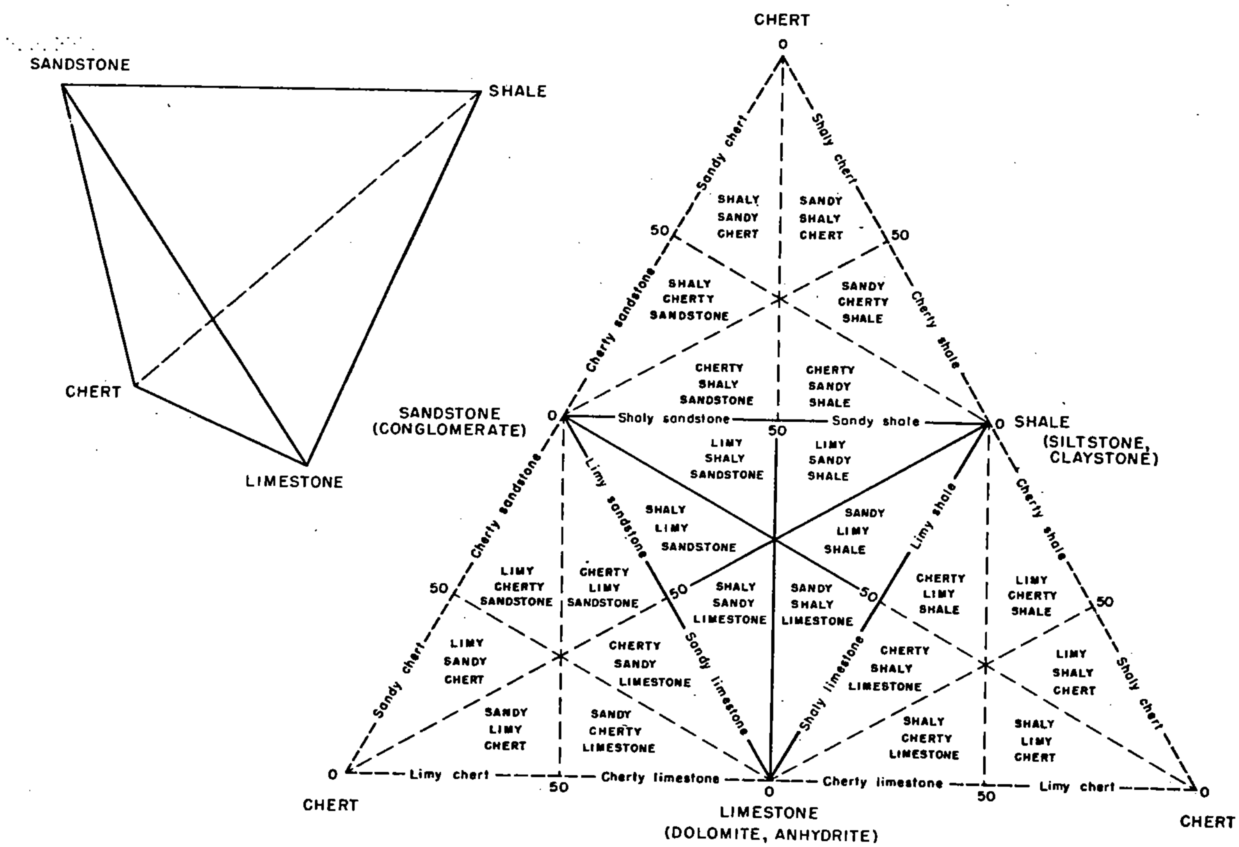


Figure 13. Tetrahedral diagram illustrating classification of commonly associated precipitate and siliceous clastic rocks in drill cuttings.

grains are indistinct. Because of this, the term *shale*, which is defined as a laminated or fissile aggregate, more than 50 percent of which is clay and silt, is commonly used for consolidated aggregates of clay or silt, or both, in drill cuttings with the assumption that the bedding, indeterminate in most fragments, is fissile or laminated. Judged from cores, this assumption of fissile or laminated bedding in deeply buried fine-grained siliceous clastics in the Midcontinent regions is generally though not always true. Therefore the term "shale" is used essentially without structural implication in the petroleum industry as a matter of practical necessity. This usage is followed in this report because of lack of a better term to indicate indeterminate mixtures of clay and silt with indeterminate bedding.

One of the common inconsistencies in describing fine-grained clastics in drill cuttings results from the fact that coarse-silt grains (1/64-1/16 mm) are individually visible under low-power magnification. The usual tendency of the sample examiner is to describe this fraction as "very fine-grained sandstone," "silty very fine-grained sandstone," or "siltstone to very fine-grained sandstone" unless direct comparison to a grain-size chart is made. This error is not altogether without recompense as it serves to separate coarse siltstone from shale in the color column of the log because shale, silt, or clay is represented by its natural color, whereas sandstone is generally shown in yellow. In matching logs of thick units of shale, the presence of coarse siltstone beds may provide important clues as to correlations and facies changes, and these beds may be overlooked if coarse siltstone is symbolized on the log by the same color as shale. Possibly the general adoption of the siltstone symbol shown in plate 1 would serve to emphasize the presence of coarse siltstones and yet differentiate them from sandstone.

Medium- and coarse-grained siliceous clastics. Siliceous particles of the medium-size range (1/16-2 mm) are classed as very fine, fine, medium, coarse, and very coarse sand (table 4). *Sand* is an unconsolidated aggregate of mineral or rock particles, more than 50 percent of which range between 1/16 mm and 2 mm in diameter. *Sandstone* is indurated sand. Siliceous particles of coarse size (2 mm) are classed as granules, pebbles, cobbles, and boulders (table 4). These mixed with sand are the constituents of gravel and conglomerate. *Gravel* is defined as an unconsolidated aggregate of medium- and coarse-sized mineral and rock particles, more than 10 percent of which are larger than 2 mm in diameter. *Conglomerate* is indurated gravel.

Special terms applied to sandstones and conglomerates of exceptional mineralogical composition are quartzose sandstone, arkose, and graywacke. The term *quartzose sandstone* is applied to a well-sorted sandstone, more than 95 percent of which consists of quartz grains, generally of medium or coarse size, not cemented with silica. A similar sandstone cemented with silica may be termed a *quartzitic sandstone*. *Arkose* is a sandstone or conglomerate, more than 25 percent of which is composed of feldspar grains. Drill cuttings of sandstone containing 1 to 25 percent of visible feldspar grains are usually logged as *feldspathic sandstone*, although a lower limit of 10 percent is observed by some geologists. The term *graywacke* has been little used in subsurface work because of the numerous and widely differing published definitions (see Pettijohn, 1949, p. 243-245, for discussion of usage), some of which emphasize characteristics that ordinarily cannot be determined by routine sample examination. The term, if used for drill cuttings, is applied to a dark-colored poorly sorted sandstone, with more than 20 per cent clayey matrix, containing angular rock fragments and grains of quartz, chert, and perhaps feldspar. Probably the presence of rock fragments and considerable matrix material is the common criterion.

Precipitates and nonsiliceous clastics. The most common precipitate and nonsiliceous clastic rocks drilled in wells are limestone, dolomite, chert, anhydrite (or gypsum), and salt. *Salt* is rarely found in rotary samples because it is dissolved by the drilling mud. Its presence in the rocks is usually apparent from the molds of salt crystals in associated anhydrite and shale fragments in the drill cuttings. These are commonly called salt hoppers. Thick or numerous beds of salt generally cause the hole to cave considerably and poor samples result. No difficulty is experienced in recognizing salt in cable-tool samples because much less solution takes place. *Anhydrite*, which is commonly associated with salt, is considered to be a rock, a part of which may be gypsum but at least 50 percent of which is anhydrite. Anhydrite is harder than gypsum and may be readily distinguished from it by general appearance. Both may be distinguished from limestone and dolomite by their insolubility in cold dilute hydrochloric acid. *Chert* is a rock, more than 50 percent of which is chalcedony and cryptocrystalline quartz. Some geologists consider chert as a minor or modifying constituent in a rock until it exceeds 90 percent, possibly in recognition of the secondary origin of some chert. *Limestone* is a rock, more than 50 percent of which is composed of carbonate minerals, mostly calcite or aragonite. *Dolomite* is a rock, more than 50 percent of which is composed of carbonate minerals, mostly dolomite.

Limestone and dolomite are easily identified and separated by texture and relative solubility in acid, but their mixtures are more difficult to recognize. Limestone, dolomitic limestone, calcareous dolomite, and dolomite may be separated roughly upon the basis of their reaction in cold 6N hydrochloric acid. A limestone fragment dropped in a small glass of acid will immediately effervesce vigorously and bob about in the acid; a dolomitic limestone fragment effervesces briskly at once, emitting a continuous stream of bubbles and moving slowly about on the bottom of the glass; a calcareous dolomite fragment emits a steady stream of bubbles but does not move about on the bottom of the glass; a dolomite fragment displays no immediate reaction but may slowly begin to emit small bubbles at a rate that permits them to be counted. The shape, size, and porosity of each fragment cause differences in reaction as will different temperatures of the acid. These facts should be considered in making this test. Differences in reaction due to impurities such as silica, silt, clay, and anhydrite can be recognized by allowing the fragments to dissolve completely and observing the residue. Stain tests (LeRoy, 1950, p. 195-196) may be used to differentiate calcite and dolomite in rocks if greater accuracy is needed.

PARTICLE CHARACTERISTICS

Usually time restrictions and the small space on a sample log will not permit the description of all particles of a rock nor the full description of a single particle. Therefore the description of rock particles must be limited to the more significant particles having characteristics that deviate from the usual. Particles are divided in the following discussion into detrital grains and crystals, chert, oölites and pisolites, and fossils and insoluble residues for the purpose of outlining the description of their more important characteristics.

Detrital Grains and Crystals

The principal characteristics of detrital grains and crystals and the sequence of their description are (1) staining and color, (2) luster, (3) relief, (4) roundness, (5) sphericity, (6) crystal development, (7) size, (8) composition and particle type. The adjectives used in describing these characteristics are listed in table 5.

Staining and color. The staining on a detrital grain or crystal may be described either by color (e. g., red-stained), or by composition of the staining material (e. g., iron-stained) if this is reasonably certain. The Rock-color Chart should be followed in determining the color of the stain. Chemical tests may be made to determine the composition of the staining material but usually the composition is omitted if it is not obvious from visual examination. The color of a detrital grain or crystal is described from the Rock-color Chart unless staining masks the true color.

Luster. Luster, which relates to the diffusion or reflection of light on a surface, may be described simply for grains as *dull* or *polished.* The luster of crystals observed in the cuttings is not ordinarily noted, but the luster adjectives defined under rock characteristics are applicable.

Relief. The surface relief of detrital grains is closely related to their luster because of its effect upon the reflected light. It may be either *smooth* or *rough.* If it is rough, it may be described as *striated, faceted, frosted, etched,* or *pitted.* Crystals may be described as to relief in the same manner although this is seldom done.

Roundness. The roundness of a detrital grain is the record of its abrasion and refers to the sharpness or roundness of edges and corners without regard to the sphericity of the grain. An elongate grain having extremely unequal dimensions may exhibit a greater degree of roundness than some grains having equal dimensions. Roundness may be expressed mathematically as the ratio of the average radius of curvature of the corners or edges to the radius of curvature of the maximum inscribed sphere (Wadell, 1932, p. 448; Pettijohn, 1949, p. 50).

Five grades of roundness have been devised on the basis of these ratios (Russell, R. D., and Taylor, R. E., 1937, p. 239, 248; Pettijohn, 1949, p. 51) using the terms *angular, subangular, subrounded, rounded,* and *well rounded.* Single grains can be fairly accurately placed in these five grades by visual inspection but drill cuttings usually contain many grains of different sizes in many rock fragments for which an average roundness must be estimated. This estimate cannot be very exact and the use of five grades of roundness implies finer distinctions than can be made consistently under usual circumstances. Therefore the usual practice in routine sample examination has been to use four grades—*angular, subangular, subrounded,* and *rounded.* Some geologists have simplified this further to angular, subangular, and rounded (Rittenhouse, 1950, p. 136), obviating any uncertain and time-consuming decisions between the subangular and subrounded classes.

The terms and definitions of Williams, Turner, and Gilbert (1954, p. 282) given below are in accord with the common usage in subsurface work in the Midcontinent region (fig. 14).

Angular—all corners sharp, having radius of curvature equal to zero; surface not abraded.

Subangular—corners not sharp but have small radius of curvature; most of surface not abraded.

Subrounded—corners noticeably rounded but surface not completely abraded.

TABLE 5.—DESCRIPTIVE SEQUENCE, TERMINOLOGY, AND ABBREVIATIONS USED IN LOGGING SIGNIFICANT PARTICLES IN DRILL CUTTINGS AND CORES

	1	2	3	4	5	6	7	8
	STAINING AND COLOR	LUSTER	RELIEF	ROUNDNESS	SPHERICITY	CRYSTAL DEVELOPMENT	SIZE	COMPOSITION AND PARTICLE TYPE
A. DETRITAL GRAINS AND CRYSTALS	(See Rock-color Chart for color terms.)	Dull Polished (pol.)	Smooth (sm.) Striated (str.) Faceted (fac.) Frosted (fros.) Etched (etch.) Pitted (pit.)	Angular (ang.) Subangular (subang.) Subrounded (subrd.) Rounded (rd.)	Equant (eqnt.) Elongate (elong.)	Secondarily enlarged (sec. enl.)	Size range or median diameter in mm or Wentworth grade terms.	Mineral or sand grain (sd. gr.) Mineral or rock granule (gran.) Mineral or rock pebble (peb.) Mineral or rock cobble (cob.) Mineral or rock boulder (bldr.)
						Anhedral (anhed.) Subhedral (subhed.) Euhedral (euhed.) (Crystal form may be given if significant.)	Size range in mm.	Mineral crystal (xl.)

	COLOR PATTERN AND COLOR	ACCESSORIES	STRUCTURE	LUSTER	OPACITY	TEXTURE	COMPOSITION	
B. CHERT	Stained (stn.) Speckled (speck.) Spotted (spot.) Mottled (mot.) Banded (bnd.) (See Rock-color Chart for color terms.)	Silty (slty.) Sandy (sdy.) Limy (lmy.) Dolomitic (dolic.) Dolocastic (dolct.) Dolomoldic (dolmd.) Glauconitic (glauc.) Pyritic (pyr.)	Fractured (frac.) Brecciated (brec.) Figured (fig.) Crinkled (crink.) Banded (bnd.) Drusy (drsy.) Botryoidal (bot.) Oölitic (ool.) Oölitoid (ooltd.) Oömoldic (oom.) Pisolitic (piso.) Fossiliferous (fos.) Spicular (spic.) Bryozoan (bry.) Crinoidal (crin.) Fusulinid (fus.)	Dull Waxy (wxy.) Greasy (gsy.) Vitreous (vit.) Porcellaneous (porc.)	Translucent (transl.) Subtranslucent (subtransl.) Opaque (op.)	Chalky (chky.) Granular (gran.) Smooth (sm.)	Chert (ch.) Tripolitic chert (trip. ch.) Opaline chert (opal. ch.) Quartzose chert (qtzose. ch.) Chalcedonic chert (chalc. ch.) Jasperoid chert (jasp. ch.)	

	COLOR	SHAPE	STRUCTURE	TEXTURE	SIZE	COMPOSITION	PARTICLE TYPE	
C. OÖLITES AND PISOLITES	(See Rock-color Chart for color terms.)	Round (rd.) Ellipsoidal (ellip.) Irregular (irreg.) Flattened (flat.)	Massive (mass.) Radiate (rad.) Concentric (concen.) Sand-centered (sd. cent.)	Drusy (drsy.) Smooth (sm.)	Size range in mm or Wentworth grade terms.	Siliceous (sil.) Calcareous (calc.) Dolomitic (dolic.) Hematitic (hem.) Sideritic (sid.) Baritic (bar.)	Oölite (ool.) Pisolite (piso.) Oömold (oom.) Oölitoid objects (ooltd. obj.)[1] Shadow oölites (shad. ool.)[2]	

[1]The term "oölitoid" is used to indicate oölite-shaped objects that cannot be identified without thin sectioning.
[2]The term "shadow oölites" refers to faint outlines of oölites in dolomitized limestone.

Rounded—entire surface abraded; radius of curvature of sharpest edges about equal to radius of maximum inscribed circle.

Sphericity. Sphericity and roundness of detrital grains have not been carefully differentiated in routine descriptions of drill cuttings. Sphericity refers to the shape of the entire grain and should not be described in terms of roundness (angular, subangular, subrounded, and rounded), which refer only to the shape of the edges or corners of the grain. Sphericity is a measure of the volume occupied by a grain in relation to the volume of a sphere having a diameter equal to the maximum dimension of the grain. Sphericity can be measured mathematically according to an equation developed by Wadell (1932, p. 445), or it can be described by shape terms (Zingg, 1935; Krynine, 1948). These measurements and terms are useful in detailed studies of coarse clastics but are too exact to be applied consistently to fine- and medium-grained clastics seen only in two dimensions under a binocular microscope. The terms *equant* and *elongate* adapted from Krynine (1948, p. 142) probably are sufficient for the purposes of most sample logs. These are defined below and illustrated in figure 14.

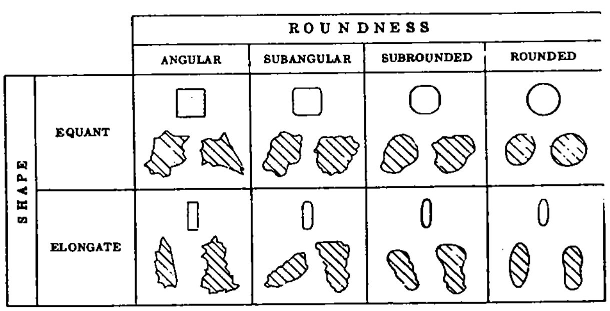


Figure 14. Roundness and shape classification of grains as seen in two dimensions (adapted from Williams, Turner, and Gilbert, 1954).

Equant—length of grain is less than 1½ times its width.

Elongate—length of grain is more than 1½ times its width.

Crystal development. Secondary enlargement of detrital grains should be noted as such. The development of crystal faces of minerals may be indicated as follows:

Anhedral—no crystal form developed.

Subhedral—crystal forms partly developed.

Euhedral—doubly terminated crystals.

Size. The size of detrital grains and crystals may be indicated by Wentworth grade-scale terms, or by giving either the size range or median diameter in millimeters.

Composition and particle type. The mineral or rock composition of a particle is given last combined with a particle-type term such as crystal, sand grain, granule, and pebble. Examples are sphalerite crystal, quartz sand grain, and granite pebble.

Chert

Different characteristics of chert provide important criteria for stratigraphic correlations within thick sequences of carbonate rocks, particularly in the Midcontinent region. The principal characteristics of chert and the sequence of their description are (1) color pattern and color, (2) accessories, (3) structure, (4) luster, (5) opacity, (6) texture, (7) composition. The adjectives used in describing these characteristics are listed in table 5.

Color pattern and color. The color patterns of chert may be placed in the same categories that are defined under Rock characteristics—*staining, speckling, spotting, mottling,* and *banding.* The colors of chert may be described with reference to the Rock-color Chart.

Accessories. Some of the accessory particles commonly found in chert are silt, sand, glauconite, and phosphate grains, and calcite, dolomite, and pyrite crystals. Small calcite and dolomite crystals are difficult to detect in chert unless it is leached in acid. The observation of accessory particles may provide important clues for correlation or separation of similar beds containing chert — for example, glauconite grains in chert serve to differentiate cherty beds of Mississippian age from cherty beds of Ordovician age in western Kansas and eastern Colorado.

Structure. The common structures noted in chert are fracturing, brecciation, crinkling, banding, druses, botryoidal forms, oölites, oömolds, pisolites, and fossils. The fossils most commonly observed in chert are spicules, bryozoans, crinoids, and fusulinids and other foraminifers. Oölites, oömolds, and fossils are particularly important crtieria for correlation purposes. Chert with distinct but unidentifiable fine figuring is usually noted as figured chert.

Luster. Luster, which is a function of surface texture, can be described for chert as *dull, waxy, greasy, vitreous,* and *porcellaneous.* The terms "waxy," "greasy," and "vitreous" have been defined under rock characteristics. Dull is applied to chert which does not reflect much light; porcellaneous is applied to a chert with a shiny smooth surface and an even fracture resembling that of porcelain.

Opacity. The light transmissibility of an object is known as its transparency; the interference offered by an object to the transmission of light is its opacity. Many cherts are opaque but none are transparent, so the term "opacity" is used here to describe an important characteristic of chert. The thickness of a chert fragment and the lighting conditions affect the determination of opacity and must be taken into account in describing chert. Ordinarily the thinnest edges of each fragment are observed under side lighting and classified roughly as *opaque, subtranslucent,* or *translucent.* These are only relative terms as no standards have been devised.

Texture. Texture refers to the size, shape, and arrangement of component particles. Surface texture and luster are so closely related that one cannot be easily described without reference to the other. The following general textural terms are used for chert:

Chalky—the chert has an uneven or rough fracture surface with a dull luster resembling chalk and may be finely porous.

Granular—the chert is compact and homogeneous with grains of uniform size and has a rough or uneven fracture and a dull to vitreous luster.

Smooth or *dense*—the chert has a smooth surface, an even to conchodial fracture, and usually a waxy, greasy, or porcellaneous luster.

Composition. Chert includes all cryptocrystalline varieties of quartz without regard to color but is composed mainly of chalcedony and quartz particles. The exact composition of chert cannot be determined under a binocular microscope; therefore, the classification of chert into tripolitic, opaline, quartzose, chalcedonic, and jasperoid types, as shown in table 5, is based entirely on previously described characteristics, mainly color, luster, opacity, and texture. These types emphasize certain combinations of characteristics, which are listed below, and may be noted either with or in lieu of more detailed characteristic descriptions, as the individual may choose.

Tripolitic chert—generally light colored, dull, opaque, porous, chalky to granular.

Opaline chert—generally banded, light colored, waxy to vitreous, subtranslucent to translucent, and smooth, commonly with botyrodial structure.

Quartzose chert—generally dull to vitreous, opaque to subtranslucent, and granular, commonly with quartz druses.

Chalcedonic chert—generally mottled or banded, waxy, greasy or porcellaneous, opaque to subtranslucent, and smooth.

Jasperoid chert—generally red, yellow, brown or black, iron stained or spotted, dull, opaque, and granular.

Grains, nodules, and geodes of chert can be recognized in cores and some samples, but generally the chert in drill cuttings is too fragmentary to be classified in this manner.

Oölites and Pisolites

The terms "oölite" and "pisolite" have been used both as aggregate terms and particle terms. To eliminate this dual usage, terms such as "oölith," "pisolith," and "oöid" have been suggested for the particles. However, the use of "oölite" and "pisolite" for particles as well as aggregates is so firmly established in the literature (Twenhofel, 1939, p. 570; Pettijohn, 1949, p. 75; Kuenen, 1950, p. 218) and in subsurface work that such use is continued in this discussion.

Oölites, as defined by Pettijohn (1949, p. 75), are small spherical or subspherical, accretionary bodies, 0.25 to 2.00 mm in diameter. This definition is followed in this report except that the minimum diameter is considered to be 1/8 mm rather than 1/4 mm. *Pisolites* are similar bodies more than 2.00 mm in diameter. Both oölites and pisolites have considerable diagnostic value in establishing stratigraphic correlations in thick sequences of carbonate rocks, such as those present in the Midcontinent region.

The principal characteristics of oölites and pisolites and the sequence of their description are (1) color, (2) shape, (3) structure, (4) texture, (5) size, (6) composition, (7) particle type. The adjectives used in describing these characteristics are listed in table 5.

Color. The color of oölites and pisolites can be determined by comparison with the Rock-color Chart.

Shape. Oölites and pisolites are usually *round* or *ellipsoidal* in shape. Some are modified to *irregular* and *flattened* shapes.

Structure. The internal structure of oölites and pisolites may be described as *massive, radiate, concentric,* and *sand-centered.* Usually the structure cannot be determined without thin sections.

Texture. The surface texture of oölites and pisolites may be *drusy* (commonly called "fuzzy") or *smooth.*

Size. The size range or mean diameter of oölites can be measured and stated in millimeters or, as is more commonly done, the size range of the oölites can be estimated in terms of the Wentworth grade scale (e.g., very fine to fine). Pisolites, which are granule to pebble size, are usually measured and their size range given in millimeters.

Composition. Oölites and pisolites are commonly composed of silica, calcite, dolomite, hematite, siderite, or barite.

Particle type. Oölites and pisolites are small spherical or subspherical, accretionary bodies of radial or concentric structure. Oölites range from about 1/8 to 2 mm in diameter; pisolites exceed 2 mm in diameter. Similar bodies of different origin and without radial or concentric structure are termed spherulites. Ordinarily these cannot be distinguished from oölites or pisolites in drill cuttings. Oömolds left by the solution of oölites are not described except for size. Indistinct objects resembling oölites are termed oölitoid objects. Faint oölites in dolomite are termed shadow oölites.

Fossils and Insoluble Residues

Fossils and insoluble residues are listed last in the description of particles. Unfortunately most samples are nonfossiliferous, except perhaps for spores, pollen, and other microfossils too small to be visible under low-power magnification. Whole megafossils are found in some cores but usually only fragments are present in drill cuttings and these fragments cannot be specifically identified. Whole specimens or identifiable fragments of microfossils, such as fusulinids, may be found in both cores and drill cuttings. General identifications of fossils are lettered and symbolized in black ink on the log. A few representative specimens of these fossils may be selected and sent to a paleontological laboratory for specific identifications and age determinations. If the samples are borrowed or rented, permission of the owner should be obtained to remove these specimens and in no case should all the specimens be removed if the samples are to be preserved for the use of other geologists. Specific identifications and age determinations from paleontological laboratories are lettered in red ink opposite the appropriate depth on the log if space permits, or at the bottom of the log.

Insoluble-residue determinations and descriptions usually are not included in the examination of drill cuttings except for special correlation problems involving thick sequences of carbonate rocks. Outcrop and cable-tool samples are well adapted to insoluble-residue techniques (McQueen, 1931) but rotary cuttings are not because of the large amount of caved material in the sample. Generally insoluble-residue studies are needed only to establish criteria for correlation; thereafter careful examination of the cuttings without acidization will reveal these criteria. If insoluble residues of some intervals are useful, the description of significant parts may be lettered in red ink opposite the appropriate depth on the log. A complete list of descriptive terms for insoluble residues has been published by Ireland and others (1947) and by Ireland (1950, p. 146-148).

SPECIAL CHARACTERISTICS

Special characteristics include oil staining, fluorescence under ultraviolet light, and the condition of samples. Oil staining and fluorescence can be roughly described as slight, moderate, and intense. The condition of samples and information on drilling operations that affect the reliability of samples may be noted in parentheses. A few of the terms and abbreviations commonly used include cavings (cvgs.), poor samples (p. spls.), circulated samples (circ. spls.), mixed samples? (mx. spls?), missing samples (skip), powdered samples (pdr. spls.), underreaming samples (ur. spls.), core (cr.), and coring samples (crg. spls.).

PLOTTING

The painstaking examination of drill cuttings by the composite interpretive method is made in vain unless the same painstaking effort is devoted to plotting the resulting detail on the log. Carefully plotted composite interpretive logs should be second only to logs of cores in detail and accuracy. Carelessly plotted logs, some of which are termed "three-pencil" logs because only three colors are used in their plotting, are little better than drillers logs for stratigraphic detail.

Sample logs in general are plotted either directly from the cuttings or indirectly from notes made during the examination. Direct plotting offers the following advantages: (1) the colors of shale and pencil colors may be matched more closely, (2) the correction for sample lag may be easily made by bed-for-bed comparison with the electric or radioactivity log, (3) possible sources of suspected cavings in the samples may be rapidly checked, (4) comparisons of the lithologic sequence already plotted with equivalent sequences on logs of nearby wells allow the examiner to anticipate and search the drill cuttings for key detail and successions of lithologies, to note facies changes and changes in thickness of units adjacent to unconformities, and in general to interpret the cuttings in terms of depositional processes. Indirect plotting from notes has only one advantage—the log may be typed easily.

Composite interpretive logs are plotted concurrently with the inspection of the drill cuttings, the logs of nearby wells, and the electric or radioactivity log. The descriptions are lettered in ink with a crow-quill or similar fine pen between penciled guide lines opposite the proper interval on the well column. The descriptions are lettered in the following order: (1) rock characteristics, (2) particle characteristics, (3) special characteristics (tables 1, 5) with semicolons separating the different units of description.

Both normal and reverse word order are used by geologists in describing surface and subsurface rocks. Each has certain advantages and disadvantages. The reverse word order consists of identifying the rock type first, and then the color and other characteristics in normal sentence order. This style generally is used in drillers' records and descriptions of outcrops, wherein each unit has been selected on the basis of contrast in gross lithology, hardness, bedding, or weathering with that of overlying and underlying beds. The reverse word order of description is an aid in plotting logs from drillers' records or very simple sample descriptions, and in reidentifying on the outcrop the contrasting units of described sections. Reverse word order offers no advantages in preparing or using a composite interpretive log of rotary-tool cuttings because (1) the log is not plotted from notes but directly from the samples, (2) the samples being described have not been taken on the basis of contrasting lithology but at regular depth intervals of 5 or 10 feet and in some regions a single rock type (e.g., limestone) may be present in as many as 100 samples, (3) several rock types (e.g., limestone, shale, and sandstone) may be present in almost equal proportions in any one sample so that reversing the order for one rock type and not the others presents a false impression and confusing punctuation.

Normal word order is recommended for composite interpretive logs because (1) the log is plotted directly from the samples, (2) contrast between different lithologies is supplied by the adjacent color symbols, (3) the abbreviated descriptions are easier to punctuate and to read, (4) a system of description with quantitative connotations in the order of constituents can be maintained, (5) the color symbols generally are plotted in parallel fashion to normal word order—that is, the symbolic color for the principal rock type is the last symbol plotted because most ink symbols and small color symbols for accessories and minor constituents cannot be placed satisfactorily over the color representing the major lithologic type.

The lettering on a log must be very small and uniform; the description must be significant, factual, and concise. Usually some or all of the descriptive terms must be abbreviated. The abbreviations should be clearly understandable and used uniformly where needed. Abbreviations of common descriptive terms are listed in table 6.

After the sample description has been lettered on the log, the accessories and minor constituents are plotted in the well column and at the left side using the symbols and combinations of symbols for strip logs shown in plate 1. Most accessory symbols are plotted in black ink and most minor constituents are shown by short dashes of color. The major rock type is indicated by filling the remainder of the interval in the column with the color symbolic of the rock type. The amount of each accessory and each minor constituent is depicted by the relative number of symbols. As an example, a slightly cherty rock is indicated by one triangular symbol in the interval, a cherty rock by two, and a very cherty rock by three or more. This use of symbols hardly represents a quantitative estimate but it does help in correlating logs prepared in a similar fashion.

Color symbols for the main rock types have not been standardized by geologists but those shown on plate 1 have been satisfactory for most purposes. Limestone is represented by blue, sandstone by yellow, dolomite by blue-green (viridian), anhydrite by violet and diagonal lines, and salt by purple. The shales are represented by colors approximating their true color—usually some shade of black, gray, green, brown, or red. Only nonindelible colors are used as the log is coated with industrial lacquer after completion and the indelible colors run into each other. The following is a list of colored pencils found satisfactory for this purpose; similar pencils by other manufacturers may serve equally well.

Dixon Thinex—viridian 414 (dolomite)
Venus Unique—blue 1206 (limestone)
Venus Unique—purple 1210 (salt)
Venus Unique—violet 1230 (anhydrite)
Venus Unique—yellow 1229 (sandstone)
Venus Unique—red 1227 (shale)
Venus Unique—maroon 1219 (shale)
Venus Unique—black 1213 (shale)
Venus Unique—brown 1212 (shale)
Venus Unique—green 1208 (shale)
Venus Coloring—gray 200 (shale)
Venus Drawing—gray 6H (shale)

Upon completion of the plotting, the colored well column is coated with clear industrial lacquer to preserve the colors. Slightly thinned lacquer and a small brush are recommended for this. Spraying of lacquer or fixative solutions on the entire log is not suggested as the lacquer interferes with changes in or additions to the lettered description. The log then may be compared with logs of nearby wells and the tentative correlations, which were made in pencil as the samples were examined, may be reconsidered, revised, and finally inked in red. A straight red line is drawn from the well column to the left edge of the log at the top of each unit correlated. This facilitates correlation of a number of logs overlapped upon each other. The name of the unit correlated and the exact depth of its top are lettered in red beneath each correlation line. Unit names generally must be abbreviated. Sea level may be indicated on the log by a black-ink line drawn entirely across the log and marked "M.S.L." This permits the rapid alinement of many logs on sea-level datum plane in order to determine the structural relationships between wells.

TABLE 6.—SUGGESTED ABBREVIATIONS FOR COMMON WORDS USED IN LITHOLOGIC DESCRIPTIONS[1]

Word	*Suggested Abbreviation*[2]	*Word*	*Suggested Abbreviation*[2]
About	abt	Conchoidal	conch
Above	abv	Concretion, concretionary	conc
Abundant	abnt	Conglomerate	cgl
Acicular	acic	Conodont	Cono
Agglomerate	aglm	Contact	ctc
Aggregate	agg	Contorted	cntrt
Algae, algal	Alg	Coquina	coq
Altered, altering	alt	Covered	cov
Amorphous	amor	Crenulated	cren
Amount	amt	Crevice	crev
Angular	ang	Crinkled	crnk
Anhedral	anhed	Crinoid, crinoidal	Crin
Anhydrite, anhydritic	anhy	Cross-bedded, cross-bedding	xbd, xbdg
Apparent	apr	Cross-laminated	xlam
Appears	aprs	Cross-stratified	xstrat
Approximate, approximately	aprox	Cryptocrystalline	crpxl
Aragonite	arag	Cryptograined	crpgr
Arenaceous	aren	Crystal, crystalline	xl
Argillaceous	arg	Cuttings	ctgs
Arkose, arkosic	ark	Dark	dk
Asphalt, asphaltic	asph	Dead	dd
At	@	Debris	deb
Average	av	Decrease, decreasing	decr
Band, banded	bnd	Dendritic	dend
Barite, baritic	bar	Dense	dns
Basalt	bas	Determine	dtrm
Bed	bd	Detrital, detritus	dtrl
Bedded	bdd	Diameter	dia
Bedding	bdg	Difference	dif
Bentonite, bentonitic	bent	Disseminated	dism
Biotite	biot	Dolocast, dolocastic	dolc
Bitumen, bituminous	bit	Dolomite, dolomitic	dol
Black	blk	Dolomold, dolomoldic	dolmd
Block, blocky	blky	Druse, drusy	drsy
Blue, bluish	bl	Earthy	rthy
Botryoidal	btry	Echinoid	Ech
Boulder	bldr	Elliptical	elip
Brachiopod	Brac	Elongate	elg
Breccia, brecciated	brec	Embedded	embd
Bright	bri	Enlarged	enl
Brittle	brit	Equivalent	equiv
Brown	brn	Euhedral	euhed
Bryozoa	Bry	Evaporitic	evap
Calcite, calcareous	calc	Expose, exposed, exposure	exp
Carbonaceous	carb	Extrusion, extrusive	extr
Cavernous	cav	Faceted	fac
Caving	cvg	Faint	fnt
Cement, cemented	cmt	Fair	fr
Center, centered	cntr	Fault	flt
Cephalopod	Ceph	Fauna	fau
Chalcedony	chal	Feldspar, feldspathic	fld
Chalk, chalky	chk	Ferruginous	Fe
Chert	cht	Fibrous	fib
Cherty	chty	Figured	fig
Chitin, chitinous	chit	Fine, finely	f
Clastic	clas	Fissile	fis
Clay, clayey	cly	Flaggy	flgy
Claystone	clyst	Flake	flk
Clean	cln	Flaky	flky
Clear	clr	Flat, flattened	flat
Cluster	cls	Floating	fltg
Coarse, coarsely	c	Fluorescence	flor
Cobble	cbl	Foliated	fol
Color, colored	col	Foraminifera	Foram
Common	com	Formation	fm
Compact	cpct	Fossil, fossiliferous	fos
Concentric	cncn	Fracture, fractured	frac

[1]Compiled by the A. A. P. G. Committee on Stratigraphic Correlations.
[2]Plural of noun may be indicated by adding "s" to abbreviation.

TABLE 6 (Cont'd.)

Word	*Suggested Abbreviation*[1]	*Word*	*Suggested Abbreviation*[1]
Fragment, fragmental	frag	Light, lighter	lt
Fresh	frs	Lignite, lignitic	lig
Friable	fri	Limestone	ls
Frosted	fros	Limonite, limonitic	lmn
Fusulinid	Fus	Limy	lmy
Gabbro	gab	Lithic, lithology, lithographic	lith
Gastropod	Gast	Little	ltl
Glassy	gl	Long	lg
Glauconite, glauconitic	glau	Loose	lse
Gloss, glossy	glos	Lower	low
Gneiss	gns	Lumpy	lmpy
Good	g	Luster	lstr
Grade, grades, graded	grd	Magnetic	magn
Grading	grdg	Marlstone	mrlst
Grain, grained	gr	Maroon	mar
Granite	grnt	Massive	mas
Granular	gran	Material, matter	mat
Granule	grnl	Matrix	mtx
Graptolite	Grap	Maximum	max
Gravel	gvl	Median	mdn
Gray	gy	Medium	m
Graywacke	gywke	Member	mbr
Greasy	gsy	Metamorphic	meta
Green	gn	Mica, micaceous	mica
Gritty	grty	Microcrystalline	micxl
Gypsum, gypsiferous	gyp	Microfossil, microfossiliferous	micfos
Hackly	hky	Micrograined	micgr
Hard	hd	Micro-micaceous	mic-mica
Heavy	hvy	Middle	mid
Hematite, hematitic	hem	Mineral, mineralized	mnrl
Hexagonal	hex	Minimum	min
High	hi	Minor	mnr
Horizontal	hztl	Minute	mnut
Hydrocarbon	hydc	Moderate	mod
Igneous	ig	Mollusca	Mol
Imbedded	imbd	Mottled, mottling	mot
Impression	imp	Mudstone	mdst
Intrusion, intrusive	incl	Muscovite	musc
Increase, increasing	incr	Nacreous	nac
Indistinct	indst	No, non-	n.
Indurated	ind	Nodule	nod
Interbedded	intbd	Numerous	num
Intercalated	intcl	Object	obj
Intercrystalline	intxl	Ochre	och
Interfingered	intfr	Odor	od
Intergranular	intgran	Oil	o
Intergrown	intgwn	Oil sand	o. sd
Interlaminated	intlam	Oil stain	o. stn
Interstitial	intstl	Olive	olv
Interval	intv	Oölicast, oölicastic	ooc
Intraformational	intfm	Oölite, oölitic	ool
Intrusion, intrusive	intr	Oömold, oömoldic	oom
Invertebrate	invrtb	Opaque	op
Iron	Fe	Orange	orng
Ironstone	Fe-st	Organic	org
Irregular	ireg	Orthoclase	orth
Irridescent	irid	Ostracode	Ost
Jasper, jasperoid	jasp	Oxidized	ox
Jointed	jtd	Part, partly	pt
Joints	jts	Parting	ptg
Kaolin	kao	Pearl, pearly	prly
Laminated	lam	Pebble	pbl
Large, larger	lrg	Pebbly	pbly
Lavender	lav	Pelecypod	Plcy
Leached	lchd	Pellet	pel
Ledge	ldg	Permeability	perm
Lentil, lenticular	len	Petroleum, petroliferous	pet

[1]Plural of noun may be indicated by adding "s" to abbreviation.

TABLE 6 (Cont'd.)

Word	*Suggested Abbreviation*[1]	*Word*	*Suggested Abbreviation*[1]
Phosphate, phosphatic	phos	Small	s
Pink	pk	Smooth	sm
Pin-point	p-p	Soft	sft
Pisolite, pisolitic	piso	Solution	sol
Pitted	pit	Sort	srt
Plagioclase	plag	Sorted	srtd
Plant fossils	pl fos	Sorting	srtg
Plastic	plas	Speck, speckled	spec
Platy	plty	Sphalerite	sphal
Polish, polished	pol	Spherules	sph
Poor, poorly	p	Spicule, spicular	spic
Porcelaneous	porc	Splintery	splty
Porosity, porous	por	Sponge	Spg
Possible, possibility	pos	Spore	Spr
Predominate, predominantly	pred	Spot, spotted, spotty	sp
Preserved, preservation	pres	Stain, stained, staining	stn
Primary	prim	Stippled	stip
Prism, prismatic	pris	Stone	st
Probable, probably	prob	Strata, stratified, stratification	strat
Prominent, prominently	prom	Streak	str
Pseudo-	psdo	Striated	stri
Purple	purp	Stringer	strg
Pyrite, pyritized	pyr	Stromatoporoid	Strom
Pyrobitumen	pyrbit	Structure	struc
Pyroclastic	pyrclas	Stylolite	styl
Quartz	qtz	Subangular	sbang
Quartzite	qtzt	Subhedral	sbhed
Quartzitic	qtzc	Subrounded	sbrd
Quartzose	qtzs	Sucrose	suc
Radiate, radiating	rad	Sulphur	S
Range, ranging	rng	Surface	surf
Rare	rr	Tabular	tab
Regular	reg	Texture	tex
Remains, remnant	rmn	Thick	thk
Replaced, replacing, replacement	repl	Thin	thn
Residue, residual	resd	Throughout	thru
Resinous	rsns	Tight, tightly	tt
Rhomb, rhombic	rhmb	Trace	tr
Rock	rk	Translucent	trnsl
Round, rounded	rd	Transparent	trnsp
Rubbly	rbly	Trilobite	Trilo
Sample	spl	Tripoli, tripolitic	trip
Sand	sd	Tubular	tub
Sandstone	ss	Tuffaceous	tuf
Sandy	sdy	Unconformity	unconf
Saturated, saturation	sat	Unconsolidated	uncons
Scales	sc	Upper	up
Scarce	scs	Variable	var
Scattered	scat	Varicolored	vcol
Schist	sch	Variegated	vgt
Scolecodonts	Scol	Varved	vrvd
Secondary	sec	Vein	vn
Sediment, sedimentary	sed	Vertebrate	vrtb
Selenite	sel	Very	v
Shadow	shad	Vesicular	ves
Shale	sh	Vitreous	vit
Shaly	shy	Volcanics	volc
Siderite, sideritic	sid	Vug, vuggy, vugular	vug
Silica, siliceous	sil	Water	wtr
Silky	slky	Wavy	wvy
Silt	slt	Waxy	wxy
Siltstone	sltst	Weather, weathered	wthr, wthrd
Silty	slty	Well	w
Size	sz	White	wh
Slabby	slab	With	/
Slickensided	sks	Yellow	yel
Slight, slightly	sl	Zone	zn

[1]Plural of noun may be indicated by adding "s" to abbreviation.

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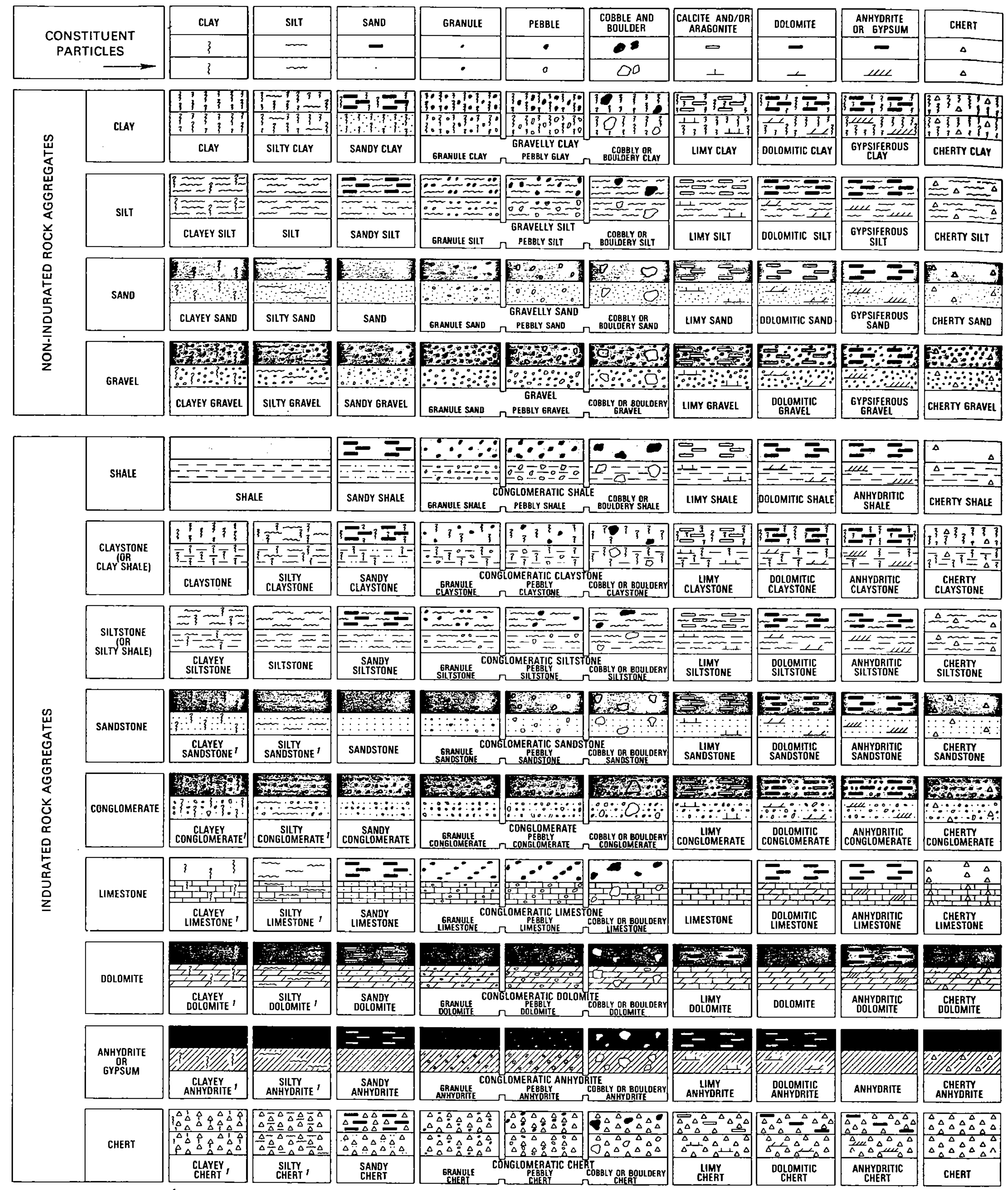
A. SYMBOLS FOR COMMON SEDIMENTARY ROCKS AND THEIR CONSTITUENT PARTICLES



[1] Although bedding usually cannot be determined in well cuttings, the adjective "shaly" and the shale symbol may be substituted to indicate undifferentiated clay and silt in these rocks.

B. MISCELLANEOUS SYMBOLS

ACCESSORIES AND SPECIAL ROCK TYPES

Glauconite	green [2]
Pyrite (or sulfides in general)	[2]
Hematite (or oxides in general)	[2]
Phosphate	P [2] / P
Feldspar	red
Mica	
Volcanic ash or bentonite	
Salt	purple / #
Coal	
Acidic igneous rocks	
Basic igneous rocks	+ + +
Metamorphic rocks	

STRUCTURE

Oolites	
Oolmolds	
Stylolites	[2]
Slickensides	// [2]
Cone-in-cone	[2]

FOSSILS [2]

Mega-fossils	
Micro-fossils	
Plant fossils	Z
Brachiopods	
Pelecypods	
Bryozoa	Y
Crinoids	
Cephalopods	
Gastropods	
Trilobites	
Corals	
Sponges	
Spines	
Foraminifera	
Fusulinids	
Fish	
Fish plates	
Conodonts	
Ostracods	

MISCELLANEOUS DATA [2]

No samples	NS
Core	CR
Oil stain, or production	●
Slight oil stain, or show	
Gas	!
Gas show	S
Fluorescence	F
Slight Fluorescence	SF
Water	W
Oil and water	OW
Salt water	SW
Fresh water	FW

[2] Symbols to be placed outside lithologic column.

Plate 1. — Suggested symbols for composite interpretive logs:

(A) Symbols for common sedimentary rocks and their constituent particles. Symbols for colored strip logs are shown above symbols for black and white publications.

(B) Miscellaneous symbols for both colored strip logs and black and white publications.