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CLASSIFICATION OF ROCKS

by

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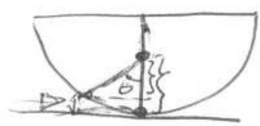

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PREFACE

The purpose of this Quarterly is to present, in compact form, the generally accepted conventions for naming rocks on the basis of mineralogy and texture. Nomenclature based on chemical composition or on genesis is not considered. An ideal classification of rocks should include petrography, genesis, and chemical composition, and should group together genetically related rocks. This is an ideal which, as yet, has not been achieved, and it appears that it will not be achieved to everyone's satisfaction. For the sake of intelligible communication then, our only alternative is to drop the genetic implications of nomenclature and adopt a purely petrographic basis. In this way, a rock may at least have an identity while we debate its petrologic significance. This Quarterly is not, in any way, intended as a substitute for the thorough treatment of classification given in standard text books.

The conventions and terms presented here are those recommended by the majority of authorities as determined from geological literature, dictionaries, and personal communications. Many of these terms do not have unanimous support, by any means, but only those supported by a clear majority of American, British, and European authorities (weighted in that order) are included. As such, this publication does not present new classifications or new proposals, but merely existing nomenclature. The only exception is the term "lithic sandstone" which appears on the sedimentary rock chart.

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Rock nomenclature, especially for the sediments, is in dire need of standardization. Geologists owe it to themselves and to workers in other sciences to use standard nomenclature. It is hoped that this Quarterly will exert influence in that direction.

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January 1955

CONTENTS

LIST OF ILLUSTRATIONS

FIGURES

PLATES

INTRODUCTION

Rocks are classified chemically, petrographically, or genetically, depending on the purpose of the classification. Each basis has its own merits, but for general use in naming and describing rocks, the petrographic basis has certain obvious advantages which account for its nearly universal adoption. Even so, the petrographic basis applies only after a primary division based on genesis has been made. (See "Primary Division," p. 1.) In support of this procedure, the principle followed herein, after the primary genetic division has been made is to *name rocks on the basis of visible features, not on the basis of inference.* Rock classification should be independent of the method of examination. More precise identification can be accomplished with a microscope than with a hand lens, but this fact does not justify separate classification schemes. A rock is a rock and should have an identifying name irrespective of the method of study. Simplified charts designed for megascopic or field classification of rocks do more harm than good if names based on them must be changed after microscopic examination. Furthermore, they deceive students into believing that naming rocks correctly is relatively simple. It is far better to use complete charts (like those included in this Quarterly) at all times and to name rocks as precisely as examination methods allow. Complete charts reveal at a glance whether a rock may be named precisely. If not, a purely descriptive name should be applied until a more detailed examination is made. Simple descriptive names are informative, easily derived and do not necessarily imply mineral composition.

Suggestions to aid megascopic identification of important minerals are given in this text, but techniques for microscopic identification are amply treated in standard texts and are not discussed here.

The included charts and conventions are for naming rocks, not for describing them, although a rock name is simply an abridged description. The degree of detail included in the rock name depends entirely on the requirements of the situation. For example, in one situation "gabbro" or "limestone" may be sufficient, whereas, in another, "coarse-grained uralitized biotite leucogabbro" or "light gray silty dolomitic limestone" may be necessary. Long, cumbersome names should be avoided whenever possible.

The igneous rock chart is, with minor exceptions, a standard chart based on mineralogy and texture and is familiar to all geologists. However, the sedimentary and metamorphic rock charts which are also based on mineralogy and texture,[1] differ from conventional charts. The difference

[1] Texture, structure, and fabric are used by different writers in different, and even in opposite senses. For the most part, in this Quarterly, these terms are used according to Webster's New International Dictionary (Merriam, 2d Ed. 1949). In places, however, the term "texture" is used to include structure. Geologists need a single term for all these noncompositional features of rocks. The term "fabric" as conventionally defined includes nearly all noncompositional features, and some geologists have extended it to include all.

exists only in the form of the chart; the rock names have conventional definitions. It can not be overemphasized that rock charts impose an artificial systematization on rocks. The lines on the charts are not honored by nature, and all gradations of composition and texture are possible.

PRIMARY DIVISION

Rocks are classically divided genetically into igneous, sedimentary, and metamorphic. The advantages of this primary division far exceed disadvantages of the necessary inferences and of the occasional ambiguities. Actually, this three-fold division is not without its problems. Many rocks such as vein rocks, metasomatites, and migmatites are not readily ascribed to any one of these divisions. Also, on the basis of a hand specimen without knowledge of its field relationships, it is often difficult and sometimes impossible to make the primary division. It is not the purpose of this Quarterly to discuss these problems in detail, but only to point out that they exist and that they may be highly controversial.

The following outline should help the beginning student in making this division. It is necessarily oversimplified and there are many exceptions because it is not possible to prepare an outline that will unerringly determine the origin of every rock specimen.

I. Phaneritic[2] crystalline texture (phanerocrystalline).
- A. Hardness of the major constituents over 5½.
  - 1. Nondirectional structure.
    - a. Presence of tremolite, wollastonite, cordierite, vesuvianite, or chondrodite.................. *metamorphic*
    - b. Absence of minerals listed in "a".................. *igneous*
    - c. Presence of feldspathoids.................. *igneous*
    - d. Chiefly hornblende.................. *metamorphic* or *igneous*
  - 2. Directional structure (except flow structure in igneous rocks).................. *metamorphic*
- B. Hardness of the major constituents under 5½.
  - 1. Nondirectional structure.
    - a. High luster, normally coarse grained.
      - 1. Carbonate minerals.................. *metamorphic* (See limestone p. 22)
      - 2. Noncarbonate minerals.................. *sedimentary*
      - 3. Serpentine (see note 1).
    - b. Dull luster, normally fine grained.................. *sedimentary* (See limestone p. 22)
  - 2. Directional structure.................. *metamorphic*

II. Clastic texture.................. *sedimentary* (see note 2)

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[2] Phaneritic and aphanitic are defined on page 3. Although these terms are usually restricted to igneous rocks, it would probably be well, in the absence of suitable equivalent terms, to extend their use to sedimentary and metamorphic rocks. No ambiguity can arise if they are used prudently.

III. Aphanitic texture

A. Hardness of the major constituents over $5\frac{1}{2}$.

1. Microcrystalline texture.......................... *igneous* or *sedimentary*
2. Microclastic texture .... *sedimentary*
3. Amorphous or cryptocrystalline texture.
   a. Chiefly silica .... *sedimentary*
   b. Chiefly glass .... *igneous*
   c. Indeterminate mixture (see note 3).

B. Hardness of the major constituents under $5\frac{1}{2}$.

1. Slaty structure .... *metamorphic*
2. Other structures .... *sedimentary*
3. Serpentine (see note 1).

Notes

1. Serpentine is a product of hydrothermal alteration of ferromagnesian minerals and may form large rock masses. It may be regarded as igneous or metamorphic and consequently appears on both charts.
2. Some altered phaneritic igneous rocks resemble feldspathic sandstone. Even in the field, the distinction may be difficult. For example, alteration products of basic volcanic rocks are megascopically nearly indistinguishable from graywacke, with which they are commonly associated. Distinction is virtually impossible if the graywacke has a high proportion of volcanic debris.
3. The hard aphanitic rocks are the most difficult to distinguish. Many siliceous, aphanitic sedimentary rocks closely resemble igneous rocks. A silicified tuffaceous mudstone is indistinguishable in hand specimens from certain volcanic rocks. Megascopically, black siliceous limestone is not unlike basic volcanic rocks.

SECTION I

IGNEOUS ROCKS

TEXTURE

Texture is the most conspicuous feature of most igneous rocks, and because it forms one of the bases on which igneous rocks are classified, it is necessary to have definitions of various textures clearly in mind. Following are some textural terms used in classifying and in describing igneous rocks.

I. Degree of crystallinity

A. Holocrystalline — essentially all crystalline.

B. Hypocrystalline (hyalocrystalline or merocrystalline) — in part composed of glass.

C. Holohyaline (glassy) — essentially all glass.

II. Grain size

A. Phaneritic — composed of grains individually visible to the unaided eye. (Plates 1-9.)

1. Coarse grained — composed of grains more than 5 mm. in diameter.
2. Medium grained — composed of grains 1-5 mm. in diameter
3. Fine grained — composed of grains less than 1 mm. in diameter.

B. Aphanitic — composed of grains not individually visible to the unaided eye. (Plates 10-15.)

1. Microcrystalline — composed of grains individually visible with a microscope. (Plates 51-53.)
2. Cryptocrystalline — composed of grains not individually visible with a microscope, but essentially crystalline.
3. Glassy — composed essentially of glass. (Plate 15.)

III. Grain relationships

(If the following features are apparent only with a microscope, the terms should be prefixed by the word "micro," for example, "microgranular.")

A. Granular — composed of nearly equidimensional grains. (Plates 1, 2, 4, 6, 7, and 9.)

B. Equigranular — composed of grains of nearly uniform size. (Plates 1, 2, 3, 4, and 6.)

C. Granitic — hypidiomorphic-granular (see below). (Plates 2 and 48.)

D. Porphyritic — composed of grains of one or more sizes in a groundmass of uniformly finer grain. (Plates 10-13, 51 and 52.)

E. Diabasic — composed of anhedral pyroxene (or amphibole), between unoriented laths of plagioclase. (Plates 3 and 50.)

F. Ophitic — composed of plagioclase laths enclosed in plates of pyroxene.

G. Pegmatitic — composed of grains exhibiting a wide range of size but in general conspicuously larger than those of the parent rock. (See standard text books for complete definition.) (Plate 9.)

H. Aplitic — allotrimorphic-granular, sugary; generally fine grained. (Plate 47.)

IV. Degree of crystal face development on grains.[3]

A. Terms applying to individual grains.

1. Euhedral (idiomorphic, automorphic) — completely or almost completely bounded by crystal faces. (Plates 49 and 52.)
2. Subhedral — partly bounded by crystal faces. (Plates 5 and 12.)
3. Anhedral (xenomorphic) — completely unbounded by crystal faces. (Plates 46 and 47.)

B. Terms applying to igneous rock texture.

1. Panidiomorphic — composed essentially of euhedral grains. (Plate 49.)
2. Hypidiomorphic (hypautomorphic) — composed of a mixture of anhedral and subhedral and/or euhedral grains. (Plates 2 and 48.)
3. Allotriomorphic — composed essentially of anhedral grains. (Plates 1, 46, and 47.)

V. Some common volcanic rock textures.

A. Vesicular—having spherical, ovoid or tubular openings (vesicles). (Plate 13.)

B. Amygdaloidal — having amygdules (vesicle fillings composed of secondary minerals).

C. Pumiceous — highly vesicular, finely cellular; vesicles generally tubular. (Common in siliceous volcanic rocks.)

D. Scoriaceous — highly vesicular, coarsely cellular; vesicles generally spherical. (Common in basic volcanic rocks.)

E. Spherulitic — having spherical bodies of crystalline material (spherulites). (Plate 15.)

[3] Terminology for degree of crystal face development on grains is not specifically divided into terms which apply to grains and those which apply to rock texture. For example, "idiomorphic" generally applies to grains, whereas, "hypidiomorphic" which should have equivalent application, generally applies to texture. The definitions as given are in accord with general usage.

MINERALOGY

The minerals comprising igneous rocks may be grouped as follows:

I. Primary minerals — minerals crystallizing directly from magma.

A. Essential minerals — minerals which determine the root name.

B. Characterizing accessory minerals — minerals which modify the root name.

C. Minor accessory minerals — minerals which do not affect the name.

II. Secondary minerals — minerals formed from the alteration of primary minerals or deposited after solidification of the igneous body.

ESSENTIAL MINERALS

Inasmuch as identifying feldspar is the key to classifying igneous rocks, it is important to know how to distinguish potash feldspar from plagioclase. The most reliable criterion is the presence in plagioclase of uninterrupted polysynthetic twinning (Plates 48 and 52). Orthoclase may exhibit simple twinning, and perthite may exhibit small patches with twinning striations. Sanidine, a high-temperature form of potash feldspar found in siliceous volcanic rocks, is recognized by its vitreous (quartz-like) luster, occurrence in volcanic rock, and common tabular habit parallel to (010). Some plagioclase twinning is extremely close spaced, and considerable patience and practice are required to establish its presence. It must be remembered that striations of common plagioclase twinning appear only on (001) and (100), and that the conspicuous grains are those showing the (001) and (010) cleavages. In general then, only half the conspicuous grains exhibit striations. Alteration may destroy striations more or less completely, but the green greasy saussurite formed from calcic plagioclase (see "Secondary Minerals," page 6) is more readily recognized than twinning. Weathering of plagioclase and potash feldspar may yield indistinguishable white earthy products. However, if plagioclase is present, careful search will usually reveal small remnants exhibiting polysynthetic twinning.

Mineral associations and rock color give additional, though less reliable, clues to feldspar composition. For example, potash feldspar and sodic plagioclase are not common in rocks containing pyroxene or olivine, and calcic plagioclase is not common in rocks containing abundant quartz. Light-colored rocks normally contain potash feldspar and/or sodic plagioclase, whereas dark rocks normally contain calcic plagioclase. As a general rule, feldspar grains of the same composition look alike in a given rock (Plate 7). Therefore, it is unnecessary to examine each grain for striations. After a few grains of each type have been examined, if more than one type occurs, the relative proportions can be estimated. This general rule must be used cautiously because in some rocks the difference in appearance between potash feldspar and plagioclase is very slight.

Nepheline is nearly indistinguishable megascopically from quartz.

The association of nepheline with cancrinite (yellow) or sodalite (blue) is the most reliable criterion. In addition nepheline normally contains inclusions, has a greasier luster, and is softer and more susceptible to alteration and weathering than quartz. Usually chemical or microscopic tests are necessary to distinguish them.

ACCESSORY MINERALS

The most common accessory minerals are listed on the igneous rock chart. Small grains of olivine in many rocks can be detected by their yellowish-green color, glassy luster, and iridescence. Small compact books of biotite can be distinguished from black lustrous hornblende by the brown fringes on the biotite where the sheets are slightly separated. The sodic amphiboles, riebeckite, arfvedsonite, and barkevikite have a tendency to more pronounced acicular or bladed habit than ordinary hornblende, but distinction by this criterion is not always reliable.

SECONDARY MINERALS

The most common secondary minerals are formed by the following processes:

Kaolinization (argillization) — alteration of feldspars to kaolinite or related clay minerals. Recognized by white or light gray color, earthy texture and odor, and absence of cleavage.

Saussuritization — alteration of calcic plagioclase to saussurite, a mixture chiefly of albite and epidote minerals. Recognized by greasy luster, green color, and absence of cleavage and twinning.

Chloritization — alteration of ferromagnesian minerals to chlorite.

Uralitization — replacement of pyroxene by amphibole (uralite).

Serpentinization — alteration of ferromagnesian minerals, especially olivine, to serpentine.

Silification — a secondary process by which a rock is impregnated with or replaced by silica.

Propylitization — alteration of ferromagnesian minerals to chlorite, calcite, serpentine, and iron ore; and alteration of plagioclase to albite and epidote in forming a characteristic green rock, propylite. Especially common to andesite.

NOMENCLATURE

GENERAL CONVENTIONS

The complete name of an igneous rock should include, in order: color, texture, alteration if any, accessory minerals, and root name. Root names are listed in the compartments on the chart. Typical names are "pink porphyritic medium-grained biotite granite"; "gray schistose fine-grained epidotized hornblende granodiorite"; and "green amygdaloidal biotite andesite porphyry." A complete name as outlined is not always necessary and should be abridged to fit the use. The best abridgement is the root name prefixed by the most conspicuous feature of the rock (or the feature that sets it off from similar rocks in the area) for example, "pink granite," "epidotized granodiorite," and "amygdaloidal andesite porphyry." Determination of the root name is simple and straightforward, although considerable care must be exercised in distinguishing the feldspars. To the root name is prefixed the name of the most abundant accessory mineral, providing it is conspicuous megascopically or constitutes over 10 percent of the rock. Common sense must often dictate the proper usage; for example, minerals genetically or economically important should certainly be mentioned regardless of abundance. As a rule, only one accessory mineral is included in the name. If two accessory minerals are included, the less abundant one should precede the more abundant one. However, this convention is not established, and some authorities reverse the above order.

An average color index for each rock type is recorded on the igneous rock chart. This index, which is the dark-mineral percentage, applies only to the phaneritic rocks. Actually, color index for each type ranges more or less widely. A rock having a much smaller or much larger color index than that given on the chart may be designated by using the prefixes "leuco" (light) and "mela" (dark). For example, a gabbro which has only 15 percent dark minerals should be called "leucogabbro," whereas a diorite with over 40 percent dark minerals should be called "meladiorite." Several authors have proposed specific limits for leucocratic and melanocratic rocks but there is no unanimity. In practice, the general rule given above, is followed somewhat loosely, but experience is requisite for its use. That is, the student must be familiar enough with rocks to recognize an unusually light-colored or dark-colored one. In general, if the color index deviates by more than 10 or 15 percent from that given on the chart, the appropriate prefix may be used. Figure 1 may be used as a guide in estimating color index. (See also Plates 1-7.)

Color of aphanitic rocks may be expressed by the use of the rock names "felsite" and "trap" for light-colored and dark-colored rocks respectively. These terms have the advantage of expressing both color and texture and may be extended to aphanoporphyritic rocks (porphyritic with aphanitic groundmass — also aphanophyric or porphyroaphanitic) to designate the color of the groundmass. For example, plagioclase porphyry can be named "plagioclase trap porphyry" or "plagioclase felsite porphyry" to indicate a dark-colored or light-colored groundmass respectively (Plates 10-13). For essentially nonporphyritic microcrystalline rocks, the name may be purely descriptive, as "red felsite" or "gray felsite" for light-colored rocks and "trap" for dark-colored ones.

It should be remembered that the chart is designed for both mega-

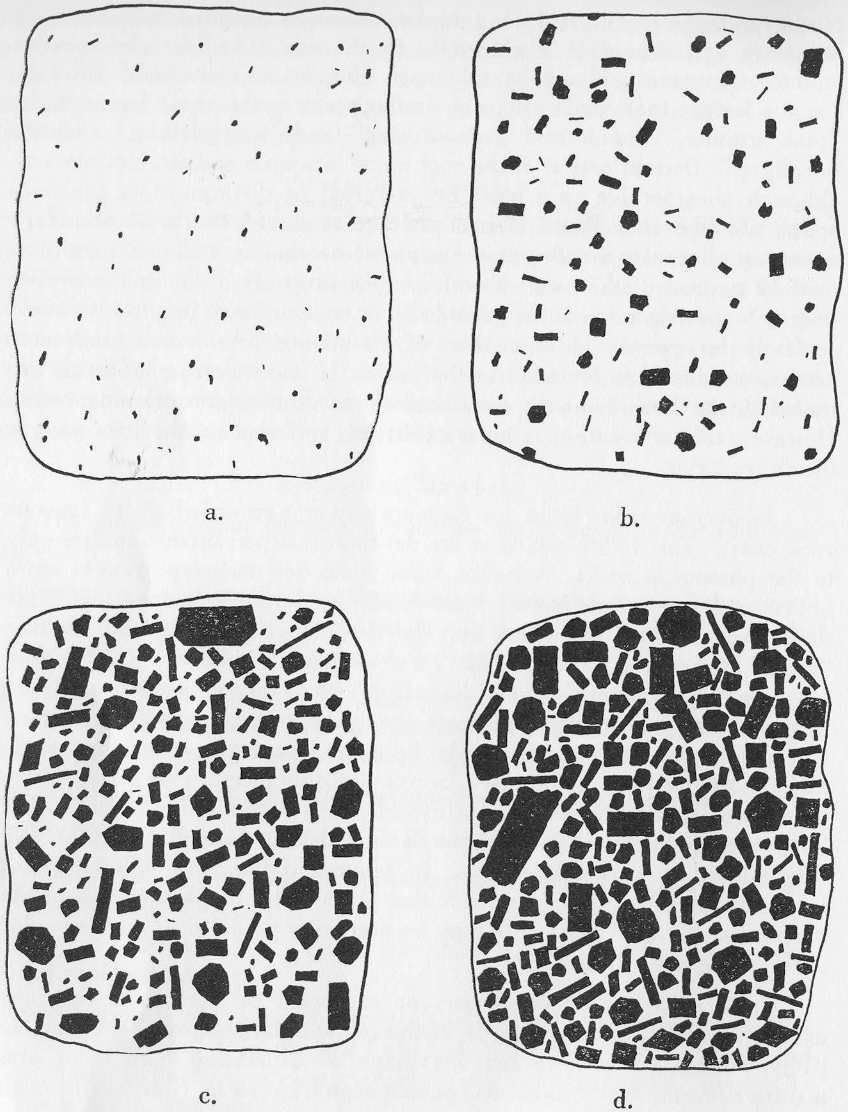

FIGURE 1. Percent dark minerals in a rock specimen.

a. 1% b. 10%
c. 40% d. 70%

scopic and microscopic use and that some of the rocks listed can not be megascopically identified. Names of most of these rocks, however, appear on the chart only as special varieties of main compartment names. Exceptions are phonolite, nepheline latite, tephrite and theralite which will probably not be megascopically recognized if the feldspathoid is nepheline.

PORPHYRITIC ROCKS

There are some special conventions for naming porphyritic rocks. In the granite-rhyolite series, there are the following possibilities: granite, porphyritic granite, granite porphyry, rhyolite porphyry, porphyritic rhyolite, and rhyolite. The conventions governing the use of these names are outlined on the following chart. Although the names granite and rhyolite are used, the chart may be applied to any series of rocks by substituting the proper phaneritic and aphanitic names.

Groundmass Texture	*Percent Phenocrysts*			
	under 12	*12-50*	*50-75*	*over 75*
Phaneritic	Granite or Porphyritic granite	Granite porphyry	Granite porphyry	Granite
Aphanitic	Rhyolite or Porphyritic rhyolite	Rhyolite porphyry	Granite porphyry	Granite

Some geologists object to the application of the name "granite porphyry" to a rock with an aphanitic groundmass, regardless of the proportion of phenocrysts. However, if a rock has more than 50 percent phaneritic constituents, it is only petrographically logical that it should have a phaneritic designation. Furthermore, aphanoporphyritic rocks are not uncommon in the chilled margins of some intrusive bodies. In most rocks, if the proportion of phenocrysts exceeds 75 percent, the porphyritic aspect is lost; the appearance is equigranular, and the name "granite" should be applied. Some geologists have attempted to inject a genetic criterion for naming porphyries by applying the name "rhyolite porphyry" to intrusive rhyolite, and "porphyritic rhyolite" to extrusive rhyolite. This practice has led to the absurdity of naming intrusive nonporphyritic rhyolite "rhyolite porphyry."

It is good practice to name porphyritic rocks by their phenocrysts and color if normal rock composition is not represented by the phenocrysts. For example, a rock containing phenocrysts only of quartz in an aphanitic groundmass is certainly "rhyolite porphyry," but the name "gray quartz porphyry" conveys more precise information. Similarly "plagioclase porphyry" and "feldspar porphyry" are accurate names and do not imply exact feldspar composition.

Pyroclastic Rocks

The three major divisions of rocks are not sharply distinct but merge into one another. The igneous and sedimentary merge in the pyroclastic rocks as the name implies. They may be regarded as igneous in that they are "fire-born"; they may be regarded as sedimentary in that they are accumulations of material deposited from air or water. In many rock charts, pyroclastics are included with the igneous rocks. However, it seems more logical to divide them at the point of ability of the fragments to weld themselves together. If they are hot and tend to weld together (fuse) and form a compact rock, they should be regarded as igneous and termed "welded tuff." If they are cool and do not tend to weld together so that fragmental or clastic texture results, they should be regarded as sedimentary. Many "rhyolites" are actually welded tuffs made compact and dense by the fusing of hot pyroclastic material. In any case, the use of the root name "tuff" serves to designate these rocks. (Plates 14 and 30).

Diorite Versus Gabbro

Mineralogically, the distinction between the rocks in the diorite and gabbro columns is based on the composition of the plagioclase. If it is more sodic than An_{50}, the rock should be named diorite or andesite. If it is more calcic than An_{50}, the rock should be named gabbro or basalt. On this basis it is not possible to have "oligoclase basalt" (mugearite) or "labradorite diorite," names which usually are based on chemical analysis. Inasmuch as it is not possible to determine the composition of plagioclase megascopically, the distinction between these rocks usually must be made microscopically. However, there are some indirect megascopic methods for ascertaining whether the plagioclase is sodic or calcic. It should be emphasized that these methods are not infallible and that it is wise to use some noncommittal expression like "dark phaneritic rock," "mafic igneous rock," or "plagioclase porphyry" if there is doubt about the composition of the plagioclase. In general, sodic plagioclase alters to white or gray earthy material, whereas calcic plagioclase alters to gray or green greasy material (saussurite). Normally sodic plagioclase does not occur with olivine, is rare in rocks with color indices exceeding 50, but is commonly associated with biotite and hornblende in phaneritic rocks. Calcic plagioclase normally does not occur with muscovite, but is commonly associated with pyroxene (or uralite) and although it may occur in rocks with color indices less than 50, it is almost certain that if the index is greater than 50, the plagioclase is calcic. It should be kept in mind that pyroxene andesite and quartz gabbro are very common rocks.

ORIGIN

Although the igneous rock chart is based on mineralogy and texture it is also genetic, in a general way, because texture is determined principally by cooling history. Slow cooling and low viscosity promote coarse grain. Because large or deep-seated masses cool more slowly than others, grain size is roughly proportional to depth of origin and/or size of the cooling mass. This general relationship is modified by viscosity. Highly fluid solutions in the late stages of magmatism may develop coarse-grained dikes and other small bodies. The fact that siliceous melts are more viscous than basic melts is apparently the reason that rhyolites are generally finer grained than basalts. Possible genetic environments are given at the left of each horizontal column of the chart.

ESSENTIAL MINERALS		POTASH FELDSPAR >⅔ TOTAL FELDSPAR			POTASH FELDSPAR ⅓–⅔ TOTAL FELDSPAR			PLAGIOCLASE FELDSPAR >⅔ TOTAL FELDS			
		QUARTZ >10%	QUARTZ <10% FELDSPATHOID <10%	FELDSPATHOID >10%	QUARTZ >10%	QUARTZ <10% FELDSPATHOID <10%	FELDSPATHOID >10%	POTASH FELDSPAR >10% TOTAL FELDSPAR	POTASH FELDSPAR <10% TOTAI		
									SODIC PLAGIOCLASE		CA
								QUARTZ >10%	QUARTZ >10%	QUARTZ <10% FELDSPATHOID <10%	QUARTZ <10 FELDSPATHO
CHARACTERIZING ACCESSORY MINERALS		CHIEFLY: HORNBLENDE, BIOTITE, PYROXENE, MUSCOVITE ALSO: SODIC AMPHIBOLES, AEGIRINE, CANCRINITE, SODALITE, TOURMALINE			CHIEFLY: HORNBLENDE, BIOTITE, PYROXENE ALSO: SODIC AMPHIBOLES, AEGIRINE			CHIEFLY: HORNBLENDE, BIOTITE, PYROXENE (IN ANDESITE) ALSO: PYROXENE FELDSPATHOID SODIC AMPHIBOLES			CHIEFLY: PYROXENI ALSO: HORNBLENDI AEGIRINE, S(
COLOR INDEX		10	15	20	20	25	30	20	20	25	50
AVERAGE CHEMICAL COMPOSITION (DALY)	SiO_2	71.5	60.4	56.0	66.8	57.0	54.1	65.3	61.6	58.2	48.6
	Al_2O_3	14.0	17.0	19.2	15.8	17.1	21.0	16.1	16.2	17.0	16.8
	Fe_2O_3	1.5	2.7	2.9	2.3	3.4	1.8	2.1	2.5	3.2	4.8
	FeO	1.4	2.9	1.6	1.3	3.6	3.3	2.3	3.8	3.7	6.0
	MgO	0.6	1.8	0.6	1.0	2.3	1.1	1.7	2.8	3.5	5.1
	CaO	1.6	3.7	2.0	2.8	5.4	3.2	3.9	5.4	6.3	8.9
	Na_2O	3.4	4.2	8.5	3.7	4.7	6.2	3.8	3.4	3.5	3.7
	K_2O	4.3	5.1	5.3	4.2	3.7	5.9	2.7	2.1	2.1	1.9
PHANERITIC	**EQUIGRANULAR** Batholiths, lopoliths, stocks, large laccoliths, thick dikes, and sills.	**GRANITE** ALASKITE—few dark minerals GRAPHIC GRANITE—graphic texture ALKALI GRANITE—abundant albite and sodic amphibole or pyroxene CHARNOCKITE—with orthopyroxene LUXULLIANITE—tourmalinized	**SYENITE** QUARTZ SYENITE—a little quartz ALKALI SYENITE—no plagioclase except albite PULASKITE—a little nepheline NORDMARKITE—a little quartz LARVIKITE—with "blue" feldspar SHONKINITE—abundant FeMg minerals	**NEPHELINE SYENITE** LEUCITE SYENITE—pseudoleucite only feldspathoid SODALITE SYENITE—sodalite only feldspathoid FOYAITE—abundant feldspar MALIGNITE—abundant FeMg minerals DITROITE—with nepheline and sodalite	**QUARTZ MONZONITE** (ADAMELLITE)	**MONZONITE**	**NEPHELINE MONZONITE**	**GRANODIORITE**	**QUARTZ DIORITE** (TONALITE)	**DIORITE**	**GABBRO** GABBRO—with clinopyroxene NORITE—with orthopyroxene OLIVINE GABBRO-with olivine TROCTOLITE—olivine and plagioclase only ANORTHOSITE—plagioclase only QUARTZ GABBRO-with quartz
PORPHYRITIC	**PHANERITIC GROUNDMASS** Laccoliths, dikes, sills, plugs, small stocks, margins of larger masses.	**GRANITE PORPHYRY**	**SYENITE PORPHYRY**	**NEPHELINE SYENITE PORPHYRY**	**QUARTZ MONZONITE PORPHYRY**	**MONZONITE PORPHYRY**	**NEPHELINE MONZONITE PORPHYRY**	**GRANODIORITE PORPHYRY**	**QUARTZ DIORITE PORPHYRY**	**DIORITE PORPHYRY**	**GABBRO PORPHYRY**
	APHANITIC GROUNDMASS Dikes, sills, laccoliths, surface flows, margins of larger masses, welded tuffs.	**RHYOLITE PORPHYRY**	**TRACHYTE PORPHYRY**	**PHONOLITE PORPHYRY**	**QUARTZ LATITE PORPHYRY**	**LATITE PORPHYRY**	**NEPHELINE LATITE PORPHYRY**	**DACITE PORPHYRY**		**ANDESITE PORPHYRY**	**BASALT PORPHYRY**
APHANITIC	**MICROCRYSTALLINE** Dikes, sills, surface flows, margins of larger masses, welded tuffs.	**RHYOLITE**	**TRACHYTE**	**PHONOLITE** LEUCITE PHONOLITE (Leucite trachyte)—leucite only feldspathoid TINGUAITE—abundant aegirine WYOMINGITE—leucite and phlogopite	**QUARTZ LATITE** (DELLENITE)	**LATITE** (TRACHY-ANDESITE)	**NEPHELINE LATITE**	**DACITE**		**ANDESITE**	**BASALT** OLIVINE BASALT-with olivine ANALCITE BASALT—with analcite QUARTZ BASALT-with quartz OCEANITE—with abundant olivine
	GLASSY Surface flows, margins of dikes and sills, welded tuffs.	**OBSIDIAN**—black **PITCHSTONE**—resinous **VITROPHYRE**—porphyritic **PERLITE**—concentric fractures **PUMICE**—finely cellular, light colored **SCORIA**—coarsely cellular, dark colored			Normally it is not possible to determine the composition of these rocks. They are customarily designated by the names at the left of this column. Basic glass is rare so rocks named, except scoria, will normally be silicic. If the approximate composition (by close association) or silica content (by refractive index or analysis), can be determined, the name may be prefixed by the name of the appropriate aphanitic rock, for example, "trachyte obsidian," or "latite vitrophyre." In general, scoria is basic; basic obsidian is called "tachylite", and spherulitic tachylite is "variolite."						

CLASSIFICATION OF IGNEOUS ROCKS

Russell B. Travis

AR		LITTLE OR NO FELDSPAR		SPECIAL TYPES
FELDSPAR CIC PLAGIOCLASE		CHIEFLY PYROXENE AND/OR OLIVINE	CHIEFLY FERRO-MAGNESIAN MINERALS AND FELDSPATHOIDS	
D <10%	FELDSPATHOID >10% PYROXENE >10%			
URALITE, OLIVINE BIOTITE, QUARTZ, ANALCITE, IC AMPHIBOLES		CHIEFLY: SERPENTINE, IRON ORE ALSO: HORNBLENDE, BIOTITE	HORNBLENDE BIOTITE IRON ORE	
	60	95	55	
	47.4 15.4 4.9 5.4 5.0 9.7 3.8 3.5	41.1 4.8 4.0 7.1 32.2 4.4 0.5 1.0	42.0 17.9 5.7 5.7 3.4 10.3 8.0 2.4	
DIABASE (Dolerite of British) Phaneritic diabasic texture, normally medium or fine-grained	**THERALITE** (ESSEXITE, NEPHELINE GABBRO) TESCHENITE—analcite only feldspathoid OLIVINE THERALITE—with olivine	**PERIDOTITE** PERIDOTITE—clinopyroxene and olivine HARZBURGITE—orthopyroxene and olivine PICRITE—pyroxene and olivine with some plagioclase DUNITE—olivine only PYROXENITE—pyroxene only SERPENTINE (SERPENTINITE)—chiefly serpentine	MISSOURITE—pyroxene, olivine, and pseudoleucite IJOLITE—pyroxene and nepheline FERGUSITE—pyroxene and pseudoleucite UNCOMPAHGRITE (MELILITE PYROXENITE)—pyroxene and melilite	**PEGMATITE—** phanerocrystalline, normally silicic, dike rock (or small irregular mass) having a conspicuously coarser texture than parent. **APLITE—** phanerocrystalline rock having sugary (fine-grained allotriomorphic-granular) texture. **LAMPROPHYRE—** dark dike rock with exclusive FeMg phenocrysts and/or euhedral FeMg minerals in groundmass
	THERALITE PORPHYRY	**PERIDOTITE PORPHYRY** KIMBERLITE—peridotite porphyry or breccia		
	TEPHRITE PORPHYRY	**LIMBURGITE PORPHYRY**		
	TEPHRITE LEUCITE TEPHRITE—leucite only feldspathoid BASANITE—with olivine LEUCITE BASANITE—with olivine and leucite	**LIMBURGITE**	NEPHELINITE—pyroxene and nepheline LEUCITITE—pyroxene and leucite MELILITITE—pyroxene and melilite OLIVINE NEPHELINITE (NEPHELINE BASALT)—pyroxene, nepheline, and olivine. ETC.	**TRAP—** dark-colored aphanitic rock. **FELSITE—** light-colored aphanitic rock.

FREQUENCY OF OCCURRENCE:

his size type indicates **COMMON ROCKS.**

is size type indicates **UNCOMMON ROCKS.**

s size type indicates **RARE ROCKS.**

Section II

SEDIMENTARY ROCKS

Modern sedimentary rock nomenclature is based on the proposals of Krynine (1948). The included sedimentary rock chart and most current conventions are modifications of his proposals. Previously, most sedimentary rock charts were not prepared for the purpose of determining names but were merely segregations of sedimentary rocks according to genesis. With development of more precise petrographic nomenclature for sedimentary rocks in the past few years, it seems appropriate to offer students a chart which can be used in the same way that the igneous rock chart is used to determine the name of a specimen. It is impossible to show on a two-component diagram all combinations of the large number of components forming sedimentary rocks. However, by including both texture and major fraction composition on the same axis of reference (horizontal), it is possible to show most combinations representing common sedimentary rocks. As indicated on the chart, some combinations are much more common than others. The names of rocks not included specifically, may be derived by following the instructions at the bottom of the chart, or in this text.

TEXTURE

The chart has three major subdivisions based on grain size. The first step in naming a sedimentary rock is determination of the grain size that defines the subdivision to which the rock belongs, and usually determines the basic or root name. The modal or average grain size determines the grain size adjective. Further subdivision of the chart is based on grain relationships. The following terms are used:

Clastic — fragmental, composed of discrete grains; that is, each grain has its own boundary. (Plates 19, 20, 22, 23, 26, 27, 28, 30, 55, 58, 59, 60, and 61.) Clastic material is allogenic; it has been transported as grains to the site of deposition.

Detrital — composed of products of detrition, mechanically deposited, hence, possessing clastic texture.

Crystalline — composed of interlocking grains; that is, each grain shares its boundary with adjacent grains forming a mosaic. (Plates 24, 25, 29, and 56.) Crystalline material is authigenic; it has been formed in place by chemical deposition.

Amorphous — composed of noncrystalline authigenic material.

Chemical — composed of products formed in place or chemically deposited, hence, possessing crystalline, or amorphous texture.

Oolitic — composed of spheroids less than 2 mm. in diameter. (Plates 26 and 59.)

Pisolitic — composed of spheroids greater than 2 mm. in diameter.

Bioclastic — composed of fragments of fossils. (Plates 27, 28, and 60.)

Fissile — capable of being split, cleavable.

MINERALOGY

Most sediments are composed of mixtures of a detrital fraction and a chemical fraction (Plates 21, 24, and 57). An uncemented sandstone is 100 percent detrital; a pure evaporite is 100 percent chemical. This is the end-member concept introduced by Krynine (1948). Each of these fractions or end members has a characteristic composition. The most abundant or essential constituents of the detrital fraction are quartz, feldspar, clay minerals, micas, and rock fragments (amorphous or polycomponent grains consisting of one or more minerals). Minor or accessory constituents are magnetite, hematite, chromite and other so-called iron ores, amphibole, tourmaline, zircon, apatite, garnet, and micas. In some detrital rocks, the essential constituents are pyroclastic fragments, fossil debris, or calcite.

The common essential minerals of the chemical fraction are calcite, dolomite, chalcedony, opal, siderite, evaporite minerals, and iron oxides. Accessory constituents are quartz, sericite, chlorite, glauconite, feldspar, and phosphate minerals. In addition to the main detrital fraction, many sedimentary rocks, especially conglomerates, have a matrix, a detrital fraction that is interstitial to the main detrital fraction.

PHANERITIC DETRITAL CONSTITUENTS

The essential detrital constituents listed above are not difficult to identify in the coarse-grained sediments but become progressively more difficult to identify with decreasing grain size. Inasmuch as the proportions of these constituents determine the names of the sandstones which are economically and scientifically important rocks, it is desirable to extend precise nomenclature to as fine-grained rocks as possible. Obviously, the boundary between those which can be and those which can not be identified is not sharp and depends to a great extent on the composition of the rock and on the experience of the student.

The following information may aid in distinguishing some detrital constituents:

Feldspars: Alteration of feldspar to white or gray earthy material in many sandstones serves to distinguish it from quartz. The proportion of feldspar in many (but not all) sandstones is related to the proportion of dark minerals or argillaceous material. If dark minerals or argillaceous materials are conspicuous, feldspar probably constitutes over 10 percent of the detrital fraction; and if abundant, feldspar may constitute over 25 percent. Dark minerals and argillaceous material give sandstones a gray color which, therefore, may usually be taken as evidence of the presence of feldspar. Extreme caution must be exercised in depending on this relationship because it is by no means universal.

Rock Fragments: Except for small grains of quartzite, rock fragments are normally not difficult to distinguish from mineral grains in coarse-grained sandstone. Chert, volcanic rocks, shale and fine-grained metamorphic rocks are the most common varieties.

Pyroclastic Debris: Volcanic ejecta are recognized by the presence of glass shards, pumice, or abundant angular volcanic rock fragments.

CHEMICAL AND APHANITIC DETRITAL CONSTITUENTS

Limestone and dolomite can be distinguished with cold dilute hydrochloric acid (calcite effervesces vigorously; dolomite very slowly) or by selective stain tests. Effervescence from scattered small amounts of calcite in dolomite may give the first impression that the specimen is limestone. Silica cement (opal or chalcedony) is readily recognized by its hardness; calcite cement by its softness and crystallinity; clay[4] by its earthy texture and odor. It may be necessary to use hydrochloric acid to distinguish clay and earthy calcite. Calcite and silica in aphanitic sedimentary rocks impart conchoidal fracture. Clay minerals may also impart conchoidal fracture but give the rock a waxy luster. Highly calcareous rocks have a noticeably higher specific gravity than argillaceous rocks. Fissility is, in general, proportional to clay content. Carbonates and silica, as well as abundant silt or sand, cause a blocky structure and hinder pronounced fissility. Bentonite may be detected by its tendency to swell and disaggregate in water.

In sediments, the term "carbonaceous" refers to material composed largely of elemental carbon. It is "dry," normally brittle, and in the form of vegetable matter — twigs, leaves, etc. The term "bituminous," on the other hand, refers to asphaltic material and is normally "oily," without definite form, occurring as a coating on or bond between grains (Plate 20); and it may have a petroliferous odor. Siderite is detected by the abnormally high specific gravity it imparts to the rock. Other sedimentary constituents are readily recognizable. It must be kept in mind that mixtures of all these constituents, especially silica, calcite, and clay, are common.

NOMENCLATURE

Names of sedimentary rocks are more descriptive than names of igneous rocks because there are fewer sedimentary rock root names. Therefore, different rocks must be distinguished by the use of modifiers. Under these circumstances, the distinction between the name of a rock and the

[4] The term "clay" applies to certain minerals, to material composed of clay minerals, and to detrital material less than 1/256 mm. in diameter. Ambiguity can be avoided by applying the terms "pelite" (pelitic) or "lutite" (lutitic) to material of clay size restricting the terms "clay" and "argillaceous" to material composed of clay materials. However, use of "clay" and "argillaceous" in the broad sense is widely established and will not be altered easily.

description of a rock is not sharp. The degree of detail of the name will depend on the requirements of the situation and should be kept to the minimum necessary. A more or less widely adopted convention governs the sequence of the terms used. This convention is outlined at the bottom of the rock chart, and the terms usually employed are discussed in order below.

COLOR

Usually the first-mentioned feature is color, but the nomenclature of color is expressed so differently by different people that care must be taken in choosing the color term. A number of standard color charts are available for reference, and geologists should use them whenever practicable (DeFord, 1944). Otherwise, simple color terms should be used.

STRUCTURE

Most structural features of sedimentary rocks are not evident in hand specimens, and must be observed in the field. Some structures which may be recognized in hand specimens are cross-bedding, lamination. ripple marks, stylolites, and nodules.

GRAIN SIZE

Nomenclature for size grades of sandstone and conglomerate is given on the chart. The quantitative way to determine grade is by mechanical analysis using the median diameter of the material in the range indicated by the root name. That is, in a silty sandstone, only the material in the sand range determines the size grade term. Mechanical analysis is impractical for every sample, so it is necessary to estimate the median grain size. Millimeter cross-section paper or sample sets of different sized grains are very useful in estimating grain size. Grain shape, and angularity may be mentioned here also but are not often included in a rock name. Figure 2 shows the relationship between grain shape and grain angularity.

MINOR CONSTITUENTS

Noticeable proportions of detrital material differing in grain size from the major constituents should be represented in the name by the appropriate qualifier: clayey (argillaceous), silty, sandy (arenaceous), pebbly (up to 15 percent) or conglomeratic (over 15 percent). Noticeable proportions of the chemical fraction are represented by the cement term (See "Root name," p. 18).

Conspicuous mineral composition other than that implied in the root name should be represented. The use of the adjectival form of the mineral name as directed in the chart may occasionally lead to confusion

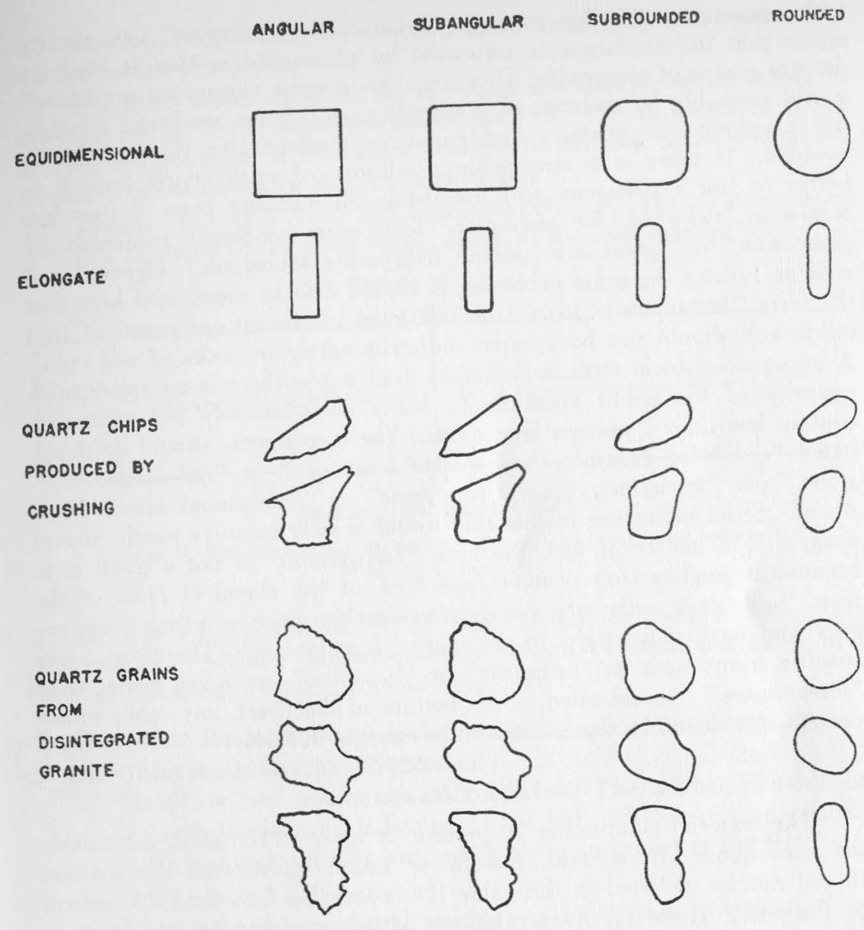

FIGURE 2. Two-dimensional sphericity and roundness of grains.

As seen in two dimensions grains are either *equidimensional or elongate*. Cross-sections of a sphere, the small section of a prism (rod), and the broad section of a disk are all equidimensional. The long sections through rod-, disk-, and blade-shaped grains are elongate. Typical quartz grains, shown in the lower and middle parts of the diagram, tend to be equidimensional rather than markedly elongate.

The four vertical columns represent four classes of roundness, which can be described qualitatively as follows: *Angular:* all corners sharp, having radius of curvature equal to zero; surface not abraded. *Subangular:* corners not sharp but having very small radius of curvature; most of surface not abraded. *Subrounded:* corners very noticeably rounded but surface not completely abraded. *Rounded:* entire surface abraded; radius of curvature of sharpest edges is about equal to radius of maximum inscribed circle.

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with cement terms. For example, "glauconitic sandstone" can signify either that the sandstone is cemented by glauconite or that it contains detrital grains of glauconite. However, "glauconitic calcareous sandstone" would probably be understood to signify a calcareous sandstone containing glauconite as grains. Ambiguous expressions like this should be avoided. If there is a reasonable possibility of misinterpretation, it is better to use expressions with unmistakable meaning even if they are somewhat awkward, for example: "feldspathic sandstone cemented by glauconite," or "glauconite-bearing feldspathic sandstone." Gypsum and siderite involve the same problem. It should also be mentioned here that the term "ferruginous" should be restricted to cement composed of iron oxide and should not be applied indiscriminately to rocks of red color. A minor constituent term must not be used unless there is an appreciable quantity of the minor constituent. Many conspicuously red sediments contain less than 1 percent iron oxide. These sediments should be designated "red," for example, "red quartz sandstone" or "red clastic limestone," not "ferruginous quartz sandstone" or "ferruginous clastic limestone." Strict adherence to this rule would greatly improve much current usage. As a matter of fact, the term "ferruginous" is not a good term because it implies iron content regardless of the chemical form of the iron. Some dark sediments contain considerably more iron than some red ones and have more right to the name "ferruginous." Therefore, more specific terms such as "hematitic" or "limonitic" are much better than "ferruginous." As indicated at the bottom of the chart, any other minor constituents should be represented in the name at this point.

ROOT NAME

The material comprising 50 percent or more of the rock, determines the root name. In general, cement or minor constituent composition should not be included in the name if it comprises less than 10 percent of the rock. However, if constituents in less amount are important in some respect, economically, genetically, or paleontologically, they should be represented. Bituminous shale may have much less than 10 percent bitumen, but a geologist who failed to mention it would certainly be making a serious mistake. One method of including constituents under 10 percent is to use "bearing" as a suffix in the constituent name as suggested by Krynine (1948), for example, "hematite-bearing feldspathic sandstone." A rock which is 50 percent chemical calcite and 50 percent detrital quartz may be called "sandy limestone" or "calcareous quartz sandstone" with equal justification. These conventions (50 and 10 percent) are graphically illustrated in Figure 3.

This diagram applies to any combination of sedimentary constituents by substituting the proper names for limestone and quartz sandstone, for example, "sandy shale" and "argillaceous sandstone," or "siliceous limestone" and "calcareous chert."

The following directions may aid determination of root name from the sedimentary rock chart.

The three major divisions on the chart are subdivided according to the composition of the *major fraction* of the rock. The horizontal divisions are for compositions of the *minor fraction* of the rock, chiefly chemical constituents but including also clay and carbon.

1. Estimate grain size range and average grain size. These values determine to which of the three major divisions the rock belongs.[5]

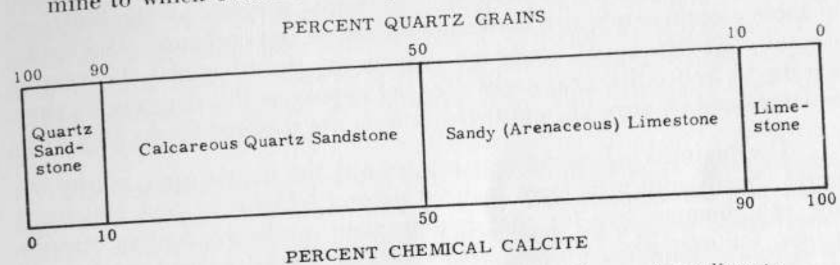

FIGURE 3. Ten-percent and 50-percent conventions for naming sediments of mixed composition.

2. Estimate whether the detrital or chemical fraction predominates. This determines whether the name is in a "clastic" vertical column or in a "miscellaneous" vertical column (See chart).

3. Determine the proportions and composition of the two fractions.
   A. Grain size is less than 1/256 mm.
      There are two columns in this division. The left-hand column is for compositions as indicated at the left. The right-hand column is for mixtures of clay and materials as indicated at the left.
   B. Grain size is 1/256 to 2 mm.
      This is the siltstone[6] and sandstone size division. Although "siltstone" does not appear among the compartment names on the chart, it should be substituted for "sandstone" for rocks of appropriate grain size. The two left-hand columns of this division are miscellaneous columns and include several textures, whereas the remaining vertical columns are for rocks with predominantly clastic texture; that is, for rocks with more than 50 percent detrital fraction. Major fraction composition is given at the top of each vertical column and minor fraction composition at the left of the chart.
   C. Grain size for more than 25 percent of the rock is over 2 mm.
      See "Conglomerate" below.

[5] As an exception to the general 50 percent convention, and although not an established rule, many geologists apply "conglomerate" to any rock having more than 25 percent gravel. A few require only 10 percent. The difference between silt and clay size may be taken as the difference between phaneritic and aphanitic constituents. Even though it is not precisely true, it is a useful approximation for megascopic work.

[6] If a siltstone possesses fissility (normally due to a high proportion of clay and fine-grained silt) it is usually called "shale" (or "silty shale") even though it may have over 50 percent silt.

The composition percentages which determine the name of a sandstone apply only to the detrital fraction, not to the entire rock. For example, a rock consisting of 30 percent chemical calcite, 8 percent feldspar, and 62 percent quartz is "calcareous feldspathic sandstone" because feldspar comprises 8/70 or 11 + percent of the detrital fraction. The principal constituents of the detrital fraction are quartz, feldspar, rock fragments, and clay. Inasmuch as clay enters sandstone names as a compositional modifier or "cement" term, only three constituents affect the root name. It is possible, therefore, to show on a triangular diagram all combinations of these constituents which determine sandstone nomenclature. The fundamental classification of sandstone is given by the triangular diagram in Figure 4. Notice that graywacke does not appear on this diagram because, as mentioned on page 22, additional criteria are required for its definition.

The majority of sandstones fall toward the quartz apex of the triangle. Sandstones with more than 50 percent feldspar or rock fragments are not common but for that reason alone probably deserve specific names, for example, "feldspar sandstone" or "rock-fragment sandstone." However, there is no present convention for this usage. For compositions near the center of the triangle, adjectival expressions such as "lithic arkose" or "feldspathic lithic sandstone" are usefully proper. Any other constituent comprising over 50 percent of a sandstone should be specifically

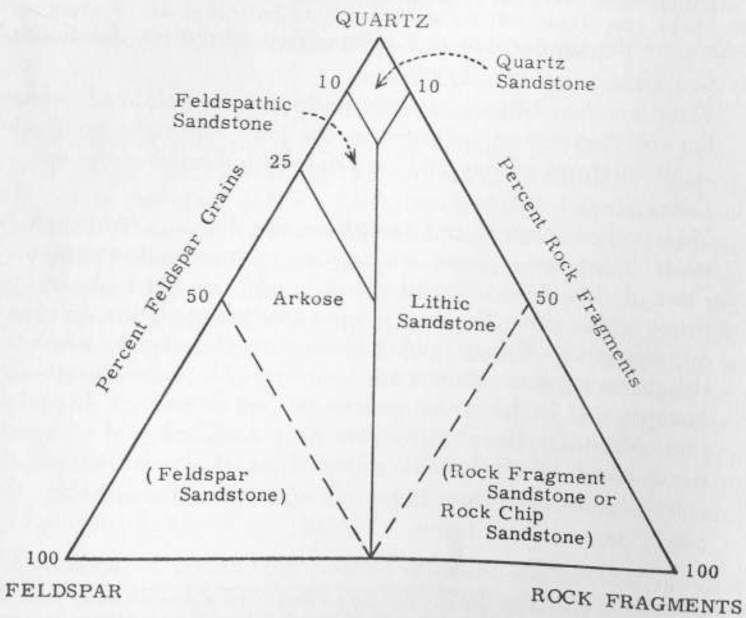

FIGURE 4. Sandstone classification based on proportion of sand-size detrital constituents.

represented in the name, for example, "olivine sandstone" or "gypsum sandstone." However, "clastic limestone" or "calcarenite" is preferable to "calcite sandstone."

If the rock fragments of a lithic sandstone are predominantly of one species, they should be mentioned in the name, for example, "chert lithic sandstone" or "volcanic lithic sandstone." Some authors prefer to include chert and quartzite fragments with quartz in classifying sandstones. There is good genetic justification for this procedure, and inasmuch as these constituents are difficult to distinguish megascopically it is a practical concept. However, it is probably more advisable to keep nomenclature on a strictly petrographic basis and to regard chert and quartzite as rock fragments.

For constituents comprising less than 50 percent of the rock, an appropriate compositional modifier is used. For example, the root name "oolite" should be used if oolites comprise over 50 percent of the rock, but if less, the term "oolitic" should be used as a non-mineral compositional modifier. There are many genetic names on the chart which should be used if the origin of the rock is known. When in doubt, descriptive nomenclature is preferred. Gilbert (Williams, Turner and Gilbert, 1953) has proposed the terms "wacke" and "arenite" for sandstones with more than 10 percent and less than 10 percent argillaceous matrix respectively. These terms are exceedingly useful because they are purely petrographic, readily applicable, and representative of genetic history. It is hoped that geologists will adopt these terms.

SPECIAL SEDIMENTARY ROCKS

QUARTZITE

As mentioned on page 2, certain siliceous rocks are difficult to identify as igneous, sedimentary, or metamorphic. Sedimentary and metamorphic processes merge in forming quartzites so that it is difficult to distinguish them petrographically as well as genetically. For the sake of petrographic classification, the distinction between orthoquartzite (sedimentary) and metaquartzite (metamorphic) should be based first on the presence of metamorphic minerals and second, if no metamorphic minerals are present, on texture. If clastic texture is still recognizable, the rock should be called "orthoquartzite," "sedimentary quartzite," or "siliceous quartz sandstone" (Plate 21). If the texture is crystalline, that is, if the original clastic texture has been obliterated by recrystallization of the quartz grains, it should be called "metaquartzite" (Plate 31). If in doubt, the non-committal term "quartzite" can be used. A sandstone intermediate between friable quartz sandstone and orthoquartzite may be designated "quartzitic sandstone."

LIMESTONE

The distinction between limestone and marble is both petrographically and genetically difficult, but is usually based on the presence of metamorphic minerals or on texture (Plates 24, 25, 32, and 34). If the rock is coarsely crystalline with a high luster, it is probably marble. Otherwise, it is probably limestone. Without metamorphic minerals or knowledge of associated rocks, this distinction may not be possible; in which case, the term "crystalline limestone" is useful. Grain size of limestones should always be given. Inasmuch as no established convention exists for indicating grain size, it is best to give the average grain size in millimeters. The Wentworth scale for sand would probably be the most practical to use, especially because so many limestones are detrital rather than chemical and are, therefore, actually calcite sandstones (clastic limestones or calcarenites). It would apply, of course, only to calcarenites.

Carbonate rocks composed of various proportions of calcite and dolomite are appropriately named "dolomitic limestone" or "calcitic (calcareous) dolomite." Relatively pure aphanitic limestone with smooth texture is called "lithographic limestone" by many geologists (Plate 25). Some geologists have adopted a modification of Grabau's classification for naming carbonate rocks. In this system, the suffixes "rudite," "arenite," and "lutite" denote grain size equivalent to gravel, sand, or clay respectively. Composition is denoted by "calc" or "calci-" for calcite, and "dolo" or "dolom-" for dolomite. Other carbonate minerals may likewise be represented. Thus a "sandy calcarenite" is a sandy limestone having a grain size in the sandstone range. This term is already rather commonly used. An "argillaceous calcilutite" is an argillaceous limestone having a grain size within the clay range. A "dolocalcirudite" is a dolomitic limestone of gravel range grain size. These terms are intended to and should apply only to detrital limestones, leaving the problem of nomenclature for grain size of crystalline limestones as before. However, distinction between clastic and crystalline texture in clay-size limestones is virtually impossible so that the suffix "lutite" can hardly be restricted to limestones of detrital origin. Use of this system should be encouraged because it is completely petrographic. The few names on the chart for the carbonate rocks belie their abundance and diversity and point up the current inadequacy of our nomenclature. The student must be as explicit as possible in naming these rocks, including grain size, minor constituents, and any other conspicuous features.

GRAYWACKE

A strict definition of graywacke has not yet found universal acceptance. One reason is that most authorities require more than compositional criteria for its definition. These additional requirements are firm induration, lack of porosity, little or no chemical cement, and angular grains.

In this Quarterly, the term "graywacke" is used in accordance with these requirements (Plate 23). Although there is less agreement on the definition of graywacke than there is on definitions of other sedimentary rocks, a majority of authorities define it as used herein. Percentages of feldspar and rock chips are not listed on the sedimentary rock chart because no limits have been set. Probably most graywacke has feldspar and rock chips both in excess of 10 percent. Actually there is considerable compositional variation in graywacke. For example, in some coarse-grained varieties there is practically no matrix. Sharply angular grains of quartz, feldspar, and rock fragments are tightly appressed, forming an interlocking texture rivaling normal igneous rocks in toughness. In the finer-grained rocks, however, the matrix may compose fully half the rock. One of the most notable features of graywacke is its similarity to igneous rock in toughness and outcrop form. In part, this similarity is due to extreme angularity of grain and to the bonding strength of the matrix probably produced by incipient metamorphism which many "true" graywackes have undergone.

The reason for these special additional criteria is that graywacke is a petrographically distinct rock and is extremely abundant in the sharply folded geosynclinal belts found especially along the continental margins. If the term "graywacke" is defined on the basis of composition alone, no special name exists for these abundant and distinctive rocks. There is a tendency by some to use this term for any dark feldspathic or lithic sandstone, a tendency which should be curbed if the name "graywacke" is to maintain its significance.

There are other sandstones which are like graywacke except for one or two features. For example, they may have less than 10 percent feldspar, may have more chemical cement than matrix, or may not be exceedingly coherent. These rocks, which are more like graywacke than the other defined sandstones but which lack one or two features characteristic of graywacke, may be called "subgraywacke." The term "subgraywacke" is not used with a precise definition, and although it is a useful term because it helps to restrict graywacke, it should probably be dropped.

Most graywacke compositions are represented in the upper central part of the triangular diagram (Fig. 4). Therefore, any graywacke may be named according to the convention represented by the triangle. The column for graywacke on the sedimentary rock chart could be, and perhaps should be, omitted. In fact, the writer recommends use of the triangular diagram names, reserving graywacke for those rocks which unquestionably qualify. It is unfortunate that some authors have redefined "graywacke" as a compositional subdivision of sandstones representing deposition in a certain type of tectonic basin. The "graywacke" of some of these authors is simply argillaceous lithic arkose or feldspathic lithic sandstone, and much confusion would be avoided if it were so named. The column for graywacke has been retained because it is one of the four basic subdivisions of sandstone in modern literature.

CONGLOMERATE

The coarse-grained detrital sediments are divided into two groups on the basis of composition. Conglomerates or breccias composed essentially of one component or two related components, normally chert, quartz, quartzite, or very hard porphyries of various kinds, are homogeneous or unicomponent conglomerates or breccias (Plates 16 and 18). They are named according to the main rock constituents, for example, "quartz pebble conglomerate," or "chert-quartzite cobble conglomerate." Most intraformational conglomerates are homogenous (unicomponent), usually consisting of shale or limestone, and homogeneous breccias are very common. Mixed conglomerates and breccias are polycomponent; they have a varied composition of several rock types (Plate 17). Because it is awkward to name all the constituents, the term "mixed," "polycomponent," or "heterogeneous" is included in the name, for example "gray mixed pebble conglomerate;" or if one component is noticeably more abundant than the rest it may be included as a prefix to "mixed" as "granite mixed pebble conglomerate." As contrasted to the convention for sandstone, the cement term for conglomerates precedes rock composition and size terms, as "calcareous quartz pebble conglomerate," but follows other compositional modifiers as "fossiliferous calcareous quartz pebble conglomerate" or "tuffaceous siliceous mixed boulder conglomerate." The terms "arkose conglomerate" and "graywacke conglomerate" proposed by some authors to signify compositions approximating those of arkose and graywacke are ambiguous because they literally indicate conglomerates composed of arkose and graywacke pebbles.

ORIGIN

Because mineralogy and texture reflect environment of deposition, the sedimentary rock chart is to a certain degree genetic. Proportion of feldspar is the key to tectonic environment. Abundant feldspar results from rapid deposition brought about by tectonism. Paucity or absence of feldspar indicates stable tectonic conditions under which the sediment was worked and reworked until the unstable constituents, feldspar and ferromagnesian minerals, were destroyed. This explains the frequent correlation between feldspar and dark minerals mentioned on page 14. A summary of typical sediments originating in certain depositional environments modified from Krumbein and Sloss (1951) is as follows:

I. Stable shelf

Quartz sandstone, clay shale, and "pure" limestone.

II. Unstable shelf

Feldspathic sandstone (some arkose), silty shale, argillaceous limestone.

III. Basin

Lithic feldspathic sandstones (and siltstones) with chemical cement or lithic sandstones low in feldspar moderately well-sorted and rounded. Subgraywacke common. Black shale, evaporites, impure limestone, and dolomite.

IV. Geosyncline

Argillaceous lithic sandstone and lithic arkose, poorly sorted and angular. Graywacke common, especially in pre-Tertiary sediments. Micaceous siliceous shale, chert, impure siliceous limestone.

TEXTURE →	GRAIN SIZE <1/256 mm.		GRAIN SIZE 1/256-2 mm.					
	CRYSTALLINE, CLASTIC OR AMORPHOUS		CRYSTALLINE, CLASTIC, BIOCLASTIC, OOLITIC, ETC.		CLASTIC UNCONSOLIDATED - silt, sand SIZE GRADES (mm.) 1/256 - 1/16, silt; 1/16 - 1/8 very fine sand; 1/8 - 1/4, fine sand; 1/4 - 1/2, medium sand; 1/2 - 1, coarse sand; 1-2, very coarse sand			CONSOLI
COMPOSITION OF MAJOR FRACTION →	Composition as Indicated in left column (prefix appropriate names for mixtures)	Clay Minerals or Clay-Size Material	Composition as Indicated in left column (prefix appropriate names for mixtures)	Chiefly Calcite or Dolomite	Chiefly Quartz			Quartz and >25% Felds
COMPOSITION OF MINOR FRACTION					>90% Quartz	Feldspar 10-25%	Rock Chips >10%	
<10% Minor Fraction				**LIMESTONE** **DOLOMITE** **ETC.** All varieties in the Calcite-Dolomite horizontal column are possible here.	**QUARTZ SANDSTONE** (Quartzose sandstone)	**FELDSPATHIC SANDSTONE**	**LITHIC SANDSTONE**	**ARKOSE** (Arkosic sandstone) Normally pink, red or li
Clay Minerals or Clay-Size Materials	**CLAYSTONE**—massive, blocky structure. **MUDSTONE**—indurated mud. Includes claystone and siltstone. **SHALE**—finely fissile. May include much silt. **CLAY SHALE** (Argillaceous shale)—chiefly clay minerals. **ARGILLITE**—highly indurated. Incipiently recrystallized. **BENTONITE**—swells and disaggregates in water.			**ARGILLACEOUS LIMESTONE** **ETC.** All varieties in the Calcite-Dolomite horizontal column are possible here.	**ARGILLACEOUS QUARTZ SANDSTONE**	**ARGILLACEOUS FELDSPATHIC SANDSTONE** **LOESS**—fine sand or silt. Massive, porous, coherent	**ARGILLACEOUS LITHIC SANDSTONE**	**ARGILLACEOUS ARI**
SILICA Opal Chalcedony Quartz	**CHERT**—chalcedony or opal. Bedded, nodular, massive. **DIATOMITE** (Diatomaceous earth)—diatom tests. **RADIOLARITE** (Tripoli, in part)—radiolarian tests. **SILICEOUS SINTER** (Geyserite) — porous geyser deposit. **PORCELLANITE**—argillaceous or silty chert.	**SILICEOUS SHALE** " **CLAYSTONE** " **MUDSTONE** **ETC.**	**SILICEOUS OOLITE**—>50% oolitic **OOLITIC CHERT**—<50% oolitic **DIATOMITE**—diatom tests **RADIOLARITE**—radiolarian tests	**SILICEOUS LIMESTONE**—disseminated silica **CHERTY LIMESTONE**—containing chert nodules **ETC.** All varieties in the Calcite-Dolomite horizontal column are possible here.	**ORTHOQUARTZITE** (Sedimentary quartzite) (Siliceous quartz sandstone)	**FELDSPATHIC ORTHOQUARTZITE** (Siliceous feldspathic sandstone)	**LITHIC ORTHOQUARTZITE** (Siliceous lithic sandstone)	**SILICEOUS ARKOSE** (Quartzitic arkose
CALCITE OR DOLOMITE	**LIMESTONE**—chiefly calcite, massive. **DOLOMITE** (Dolostone)—chiefly dolomite, massive. **CHALK**—chalky texture. **TUFA**—very porous, friable. **TRAVERTINE**—banded, coherent, denser than tufa. **CALICHE**—lime-rich deposit formed near surface.	**CALCAREOUS SHALE** (Limy shale) etc. **MARLSTONE** 25-75% carbonate	**LIMESTONE** — chiefly calcite, crystalline **DOLOMITE** (Dolostone) — chiefly dolomite, crystalline **CLASTIC LIMESTONE** (Calcarenite or calcite sandstone) — clastic **CALCAREOUS OOLITE** — > 50% oolitic **OOLITIC LIMESTONE** — < 50% oolitic **COQUINA** — shells, little cement **ORGANIC LIMESTONE** — Richly fossiliferous		**CALCAREOUS QUARTZ SANDSTONE**	**CALCAREOUS FELDSPATHIC SANDSTONE**	**CALCAREOUS LITHIC SANDSTONE**	**CALCAREOUS ARKO**
IRON MINERALS Chiefly: Limonite Siderite Goethite Chamosite Hematite	**HEMATITE ROCK**—massive hematite. **LIMONITE ROCK**—massive limonite. **BOG IRON ORE**—earthy, impure, limonite. **IRONSTONE** (Clay ironstone) — coherent mixture of iron, silica, clay, and carbonate. **SIDERITE** (Iron carbonate)—massive siderite.	**LIMONITIC or HEMATITIC** (Ferruginous) **SHALE** **ETC.**	**HEMATITE OOLITE**—>50% oolitic **LIMONITE OOLITE**—>50% oolitic **OOLITIC IRON ORE**—<50% oolitic **SIDERITE** (Iron carbonate)—chiefly siderite, crystalline	**LIMONITIC or HEMATITIC (Ferruginous) LIMESTONE** **ETC.** All varieties in the Calcite-Dolomite horizontal column are possible here.	**LIMONITIC or HEMATITIC (Ferruginous) QUARTZ SANDSTONE**	**LIMONITIC or HEMATITIC (Ferruginous) FELDSPATHIC SANDSTONE**	**LIMONITIC or HEMATITIC (Ferruginous) LITHIC SANDSTONE**	**LIMONITIC or HEMAT (Ferruginous) ARKOS**
CARBON Humus-Yields carbonaceous derivatives Sapropel-Yields bituminous derivatives	**COAL** **BITUMINOUS**—Hackly fracture. **ANTHRACITE**—conchoidal fracture. **ASPHALT**—asphaltic. **GILSONITE**—black, high luster, amorphous.	**RBONACEOUS ALE, ETC.**—arbonized mains. **UMINOUS ALE** (Oil shale) **TC.**—sapropelic	**PEAT**—dark semi-carbonized plant remains **LIGNITE**—brown-black well-carbonized plant remains	**CARBONACEOUS LIMESTONE** **BITUMINOUS LIMESTONE** **ETC.** All varieties in the Calcite-Dolomite horizontal column are possible here.	**CARBONACEOUS QUARTZ SANDSTONE** **BITUMINOUS QUARTZ SANDSTONE**	**CARBONACEOUS FELDSPATHIC SANDSTONE** **BITUMINOUS FELSPATHIC SANDSTONE**	**CARBONACEOUS LITHIC SANDSTONE** **BITUMINOUS LITHIC SANDSTONE**	**CARBONACEOUS ARK** **BITUMINOUS ARKOSE**
MISCELLANEOUS Phosphate (Collophane) Evaporites Halite and Sylvite Anhydrite Gypsum	**PHOSPHORITE**—phosphate rock. **ROCK SALT**—massive halite or sylvite. **ROCK ANHYDRITE**—massive anhydrite. **ROCK GYPSUM**—massive gypsum.	**PHOSPHATIC SHALE, ETC.**	**PHOSPHATIC OOLITE**—>50% oolitic **ROCK SALT**—crystalline **ROCK ANHYDRITE**—crystalline **ROCK GYPSUM**—crystalline **GYPSUM SAND**—clastic	**PHOSPHATIC LIMESTONE** **ETC.** All varieties in the Calcite-Dolomite horizontal column are possible here.	**PHOSPHATIC QUARTZ SANDSTONE** **ETC.**	**PHOSPHATIC FELDSPATHIC SANDSTONE** **ETC.**	**PHOSPHATIC LITHIC SANDSTONE** **ETC.**	**PHOSPHATIC ARKOSE** **ETC.**

The names in the above chart are root names and should be preceded by appropriate terms for any significant feature of the rock. The proper order is color, structure, grain size (sandstones only), minor constituents, cement, and root name. Structure includes, for example, "thin-bedded," "massive," "cross-bedded," "thinly laminated," etc. The size grade for conglomerates should immediately precede "conglomerate." Some common nonmineral minor constituent terms are "tuffaceous," "cherty," "fossiliferous," "crinoidal," "coralline," "clayey (argillaceous)," "silty," "shaly," "sandy (arenaceous)," and "conglomeratic." Minor mineralogy should follow the nonmineral composition and should be restricted to one conspicuous mineral not implied in the root name. It should be applied in adjective form as "micaceous," "chloritic," "glauconitic," and "pyritic." The most common cement terms are given in the chart with the root names. Some typical rock names are "black thin-bedded micaceous shale," "gray massive, medium-grained glauconitic quartz sandstone," "tan siliceous quartz pebble conglomerate," and "white vuggy foraminiferal limestone."

CLASSIFICATION OF SEDIMENTARY ROCKS

By Russell B. Travis

TED - siltstone, sandstone			**GRAIN SIZE >2 mm.**	
			CLASTIC **UNCONSOLIDATED** - gravel (rounded), rubble (angular) **CONSOLIDATED** - conglomerate (rounded), breccia (angular) **SIZE GRADES** (mm.) - 2-4, granules; 4-64, pebbles; 64-256 cobbles; >256 boulders	
r	**Quartz, Feldspar, Rock Chips, Pelitic Matrix, Angular grains, Tough.**	**Volcanic Ejecta**	**CHIEFLY ONE CONSTITUENT** Especially quartz, chert, or quartzite. Also shale or limestone. Homogeneous conglomerates and breccias.	**SEVERAL CONSTITUENTS** Usually including unstable constituents. Mixed conglomerates and breccias.
nt gray	**GRAYWACKE**—normally greenish gray **SUBGRAYWACKE**—low in feldspar, rock chips, or less angular grains. Tendency to chemical cement	**ASH**—unconsolidated fragments under 4 mm. **TUFF**—consolidated ash **VOLCANIC BRECCIA**—angular fragments over 4 mm. **AGGLOMERATE**—large proportion (>25%) of bombs	Name consists of chief constituent and size grade, for example: QUARTZ PEBBLE CONGLOMERATE CHERT COBBLE CONGLOMERATE LIMESTONE PEBBLE BRECCIA ETC.	Name consists of "mixed" or "polycomponent" and size grade, for example: MIXED PEBBLE CONGLOMERATE or MIXED COBBLE CONGLOMERATE Name may include composition as GRAYWACKE-ANDESITE-CHERT PEBBLE CONGLOMERATE
OSE	**ARGILLACEOUS GRAYWACKE** **ARGILLACEOUS SUBGRAYWACKE**	These rocks are classified on the proportions of vitric, crystal (mineral), or lithic material they contain, for example: "vitric lithic ash," or "crystal vitric tuff." If the mineralogy of the crystal or lithic fragments can be determined, the name of the appropriate volcanic rock can be prefixed as, "rhyolite vitric crystal tuff," or simply, "rhyolite tuff."	**ARGILLACEOUS** (rock, grade) **CONGLOMERATE**—uncommon with stable constituent	**ARGILLACEOUS MIXED** (grade) **CONGLOMERATE** **GLACIAL TILL**—chaotic mixture of clay, sand and gravel **TILLITE**—indurated till **FANGLOMERATE**—alluvial fan material
	SILICEOUS SUBGRAYWACKE		**SILICEOUS** (rock, grade) **CONGLOMERATE** (Orthoquartzitic [rock, grade] conglomerate)	**SILICEOUS MIXED** (grade) **CONGLOMERATE**
E	**CALCAREOUS SUBGRAYWACKE**		**CALCAREOUS** (rock, grade) **CONGLOMERATE**	**CALCAREOUS MIXED** (grade) **CONGLOMERATE**
IIC	**LIMONITIC or HEMATITIC (Ferruginous) GRAYWACKE** **LIMONITIC or HEMATITIC (Ferruginous) SUBGRAYWACKE**		**LIMONITIC or HEMATITIC (Ferruginous)** (rock, grade) **CONGLOMERATE**	**LIMONITIC or HEMATITIC (Ferruginous) MIXED** (grade) **CONGLOMERATE**
SE	**CARBONACEOUS GRAYWACKE ETC.** **CARBONACEOUS SUBGRAYWACKE ETC.**		**CARBONACEOUS** (rock, grade) **CONGLOMERATE** **BITUMINOUS** (rock, grade) **CONGLOMERATE**	**CARBONACEOUS MIXED** (grade) **CONGLOMERATE** **BITUMINOUS MIXED** (grade) **CONGLOMERATE**
	PHOSPHATIC SUBGRAYWACKE ETC.		**PHOSPHATIC** (rock, grade) **CONGLOMERATE**	**PHOSPHATIC MIXED** (grade) **CONGLOMERATE**

aywacke currently has two meanings. To some, it denotes a ldspar-quartz sandstone with more than 20 (or 15) percent pe- ic matrix. To many others, it has retained its original meaning; at is a very hard, firm sandstone without porosity or chemical nent. In addition, these "true" graywackes typically have ex- emely angular grains, a pelitic matrix, and a dark color.

FREQUENCY OF OCCURRENCE:

This size type indicates **COMMON ROCKS.**

This size type indicates **UNCOMMON ROCKS.**

This size type indicates **RARE ROCKS.**

Section III

METAMORPHIC ROCKS

Inasmuch as names of most metamorphic rocks are simply structure terms prefixed by constituent mineral names, the need for a metamorphic rock chart may be questioned. It has been included for two reasons: (1) the chart helps the student systematize the subject in his thinking and is thus an aid to learning; (2) it lists combinations of minerals and fabrics that are common and accessory minerals that are normally included in a name.

TEXTURE AND STRUCTURE

Generally, the most conspicuous feature of metamorphic rocks is structure. Following are some common terms which apply to metamorphic rocks.

blastic — a suffix to textural or structural terms indicating metamorphic origin. (Plates 40, 41, 42, and 66.)

blasto — a prefix to textural or structural terms indicating relic fabric in a metamorphic rock.

lineation — parallel directional structure expressed in one direction only.

foliation (schistosity) — parallel directional structure expressed in two directions imparting a tendency to split into layers. (Plates 38-45.)

granulose (granoblastic) texture — granular texture with nondirectional structure. (Plates 31-34.)

hornfelsic structure — nondirectional structure. (Plates 31-35.)

cataclastic structure — structure developed by crushing and granulation. (Plates 36 and 37.)

mylonitic structure—foliated, fine-grained cataclastic structure. (Plate 36.)

slaty structure — foliation in aphanitic metamorphic rocks which permits splitting into thin sheets. (Plate 38.)

schistose structure — foliation due to parallel orientation of phaneritic flaky, lamellar or occasionally rod-shaped minerals. (Plates 40-42.)

phyllitic structure — foliation intermediate between slaty and schistose, that is, aphanitic but exhibiting a sheen due to oriented micaceous minerals. (Plate 39.)

gneissose (gneissic) structure — foliation due to alternation of granulose and schistose bands. (Plates 43-45.)

migmatitic — a term based on genesis denoting mixed igneous and metamorphic origin. Bands, veins, and pods of granitic rock in an essentially metamorphic host. (Plate 44.)

flaser structure — cataclastic structure in which lensoid remnants of original rock are set in a mylonitic groundmass. (Plate 37.)

augen structure — lensoid grains in finer grained groundmass which may or may not be cataclastic. (Plate 45.)

MINERALOGY

Minerals comprising metamorphic rocks are divided into groups I and II below. Those in I are rock-forming or essential minerals which are also common in igneous or sedimentary rocks. Those in II are characterizing accessory minerals which may not occur in abundance, except locally, but are characteristically metamorphic.

I *Essential Minerals*		II *Characterizing Accessory Minerals*	
Quartz	Sericite	Tremolite	Andalusite
Potash feldspar	Biotite	Wollastonite	(Chiastolite)
Plagioclase	Chlorite	Vesuvianite	Sillimanite
Calcite	Serpentine	Chondrodite	Kyanite
Dolomite	Hornblende	Epidote	Staurolite
Muscovite	Pyroxene	Spinel	Graphite
		Grossularite	Actinolite
		Chloritoid	Glaucophane
			Anthophyllite
			Cordierite

The methods of distinction of the essential and many of the accessory minerals are simple or have been already treated in preceding pages. For distinguishing some of the other accessories, a few notes may help. The first seven minerals in II are common products of contact metamorphism (with or without metasomatism) of carbonate rocks, and their association with marble and with each other aid in their recognition. Wollastonite is distinguished from tremolite by its cleavage at nearly 90°. Epidote and vesuvianite may be distinguished by the characteristic color of epidote or by the tetragonal form of vesuvianite. Otherwise, they may not be distinguished megascopically. The chiastolite variety of andalusite occurs exclusively as porphyroblasts in slates and schists and is characterized by nearly square prismatic crystals marked at the ends by diagonal lines of carbonaceous inclusions forming a black cross. Staurolite also occurs in porphyroblasts, but commonly as orthorhombic penetration twins. Kyanite is readily recognized by its blue color and anisotropic hardness. Sillimanite is recognized by its fine grain, fibrous texture, silky luster, and occurrence in compact schists. Cordierite is difficult to recognize even microscopically, but because it is important genetically every effort should be made to establish its presence or absence. In some rocks it forms conspicuous "knots" (Plate 42), but in others it occurs inconspicuously among the other constituents.

NOMENCLATURE

Most metamorphic rock names are derived by prefixing the names of the most abundant minerals to a structural term, for example "quartz-mica schist" or "wollastonite hornfels." If one of the characterizing accessory minerals is present even though not abundant, its name is included also, for example "sillimanite-quartz-mica schist" or "garnet-wollastonite hornfels." In aphanitic porphyroblastic rocks, only the mineral forming the porphyroblasts may be prefixed to a structural term, for example "chiastolite slate." If no minerals are recognizable, color may be the only prefix to the root name (structural term), for example "gray phyllite" or "green slate." The names of some metamorphic rocks with nondirectional structure do not include a structural term, "marble," "metaquartzite," and "skarn" for example. However, appropriate qualifiers are prefixed to these names in the same way they are to structural terms as outlined above. Rocks with nondirectional structure which do not have special names take "hornfels" as the root name, preceded by essential mineral names, for example "glaucophane-albite hornfels" or "tremolite hornfels." Aphanitic rocks with nondirectional structure, if known to be metamorphic, may be called "hornfels" without any qualifier other than color. The term "rock" is useful to denote rocks whose genesis is uncertain. For example, a rock consisting essentially of hornblende may be igneous or metamorphic, and naming it "hornblende rock" avoids commitment pending further study. Essential mineralogy of gneisses and migmatites may be expressed by use of the appropriate igneous rock name as indicated on the chart.

Rocks of known parentage or which contain new minerals but retain the original structure, are named by prefixing "meta" to the original rock name, for example "metadiabase," "metaporphyry," and "metaconglomerate." Rocks which are somewhat foliate, but which have been little recrystallized, are not truly metamorphic and retain the original names. However, the term "schistose" may be prefixed as a structural term, for example "gray schistose feldspathic sandstone" or "pink schistose biotite rhyolite." The use of "schistose" in this way is noted here because there is complete gradation between nonmetamorphic schistose rocks and schists.

Metamorphic processes merge into igneous processes at two points; very low-grade metamorphism and very high-grade metamorphism. It is difficult to ascribe one origin or the other to borderline rocks. At the low-grade end are serpentine and talc. These minerals (and rocks) originate from hydrothermal alteration of ferromagnesian minerals by late magmatic fluids or by fluids of extraneous origin. Alteration by late magmatic fluids is commonly called "autometamorphism," but is actually part of the igneous process. Much, but not all, pegmatitization, saussuritization, as well as uralitization are autometamorphic processes. The problems involved in classifying these various processes are those involved in metasomatism in general. Some metasomatic processes are ascribed to metamorphism, others to magmatism, but there is no unanimity among geologists on the division. Perhaps magmatic metasomatism should involve syngenetic fluids and metamorphic metasomatism epigenetic fluids, but the problem is too complex to be treated here. Serpentine is the most abundant rock in this dual igneous-metamorphic category and is included in both the igneous and metamorphic rock charts. Talc rocks are less abundant.

At the high-grade end are rocks formed in the zone of remelting and are mixtures of truly igneous and truly metamorphic rocks. These are, in part, migmatites. Many of these rocks can be recognized as mixtures — but others are indistinguishable from metamorphic gneisses. Inasmuch as the name "migmatite" has genetic implication whereas "gneiss" is simply a structural term, the root name "migmatite" should be restricted to rocks whose mixed genesis is apparent.

ORIGIN

Kind and Grade of Metamorphism

A great deal about the origin of metamorphic rocks may be inferred from mineralogy and structure on the basis of a few simple rules. The chief agents of metamorphism are heat and directed stress. Hydrostatic stress is much less effective and chemical solutions, although they may produce spectacular mineral assemblages and economically very important rocks, are only locally important. There are two aspects of metamorphism which serve to classify it: kind and grade (degree). Kind of metamorphism is determined by directed stress; and grade, by heat. The two basic changes taking place in a rock undergoing metamorphism are mechanical structural changes due to directed stress, and mineralogical recrystallization and reconstitution due principally to heat. Therefore, structure reveals the kind of metamorphism; and mineralogy, the grade. The following correlations may be used as a rather general guide to interpreting structure and mineralogy, but there are many exceptions:

I. Nondirectional structure — contact (thermal) metamorphism
   - A. Little recrystallization — low grade
   - B. Formation of hydrous metamorphic minerals — moderate grade
   - C. Formation of anhydrous metamorphic minerals — high grade (may also be high grade regional metamorphism)

II. Directional structure — regional (dynamothermal) metamorphism
   - A. Granulation, no recrystallization — very low grade regional or mechanical metamorphism
   - B. Slaty or phyllitic structure — low grade
   - C. Presence of andalusite or cordierite — polymetamorphism; commonly contact or regional

   - D. Schistose or gneissose structure — low grade to high grade
     1. Green mica and green amphiboles — low grade
     2. Biotite and black amphiboles — medium grade
     3. Anhydrous minerals — high grade
   - E. Migmatitic structure — plutonic or ultrametamorphism; extreme regional

Facies classification is the modern genetic classification of metamorphic rocks and is based on mineralogy and, to some extent, on structure. Each facies consists of all rocks, regardless of bulk composition, developed under a certain set of metamorphic conditions. Each is recognized by certain critical mineral assemblages. Use of this system to obtain a more detailed genetic classification than has already been given requires microscopic examination and much more elaboration than is pertinent to the purpose of this Quarterly.

Parent Rock

As a general rule, the bulk composition of a metamorphic rock is the same as that of the parent. On the basis of bulk composition and relic fabric, the nature of the parent rock may be inferred. For example, metamorphic rocks rich in silica must have come from parents rich in silica; rocks rich in ferromagnesian minerals, from parents rich in ferromagnesian minerals, etc. The mineralogy may be different but excluding the metasomatic processes mentioned above, the chemical composition normally undergoes little change, so that chlorite schist, amphibolite, or pyroxene hornfels may be derived from gabbro, diabase, or basalt, depending on the kind and grade of metamorphism.

REFERENCES

(Limited to treatments of petrography in English)

DeFord, R. K., 1944, Rock colors: Am. Assoc. Petroleum Geologists Bull., vol. 28, pp. 128-137.

Grout, F. F., 1932, Petrography and petrology: McGraw-Hill Book Company, Inc., New York.

Harker, Alfred, 1939, Metamorphism: Methuen and Co., Ltd., 2d ed. rev., London.

Holmes, Arthur, 1928, The nomenclature of petrology: Thomas Murby and Co., London.

Johannsen, Albert, 1932-1939, A descriptive petrography of the igneous rocks: University of Chicago Press, Chicago, vols. 1-4.

Krumbein, W. C., and Sloss, L. L., 1951, Stratigraphy and sedimentation: W. H. Freeman and Co., San Francisco.

Krynine, P. D., 1948, The megascopic study and field classification of sedimentary rocks: Jour. Geology, vol. 56, pp. 130-165.

Milner, H. B., 1940, Sedimentary petrography: Thomas Murby and Co., 3d ed., London.

Pettijohn, F. J., 1949, Sedimentary rocks: Harper and Bros., New York.

Pirsson, L. V., 3d ed. revised by Knopf, Adolph, 1947, Rocks and rock minerals: John Wiley and Sons, Inc., New York.

Rice, C. M., 1940, Dictionary of geological terms: Edwards Brothers, Inc., Ann Arbor, Michigan.

Shand, S. J., 1947, Eruptive rocks: John Wiley and Sons, Inc., 3d ed., New York.

Turner, F. J., 1948, Mineralogical and structural evolution of the metamorphic rocks: Geol. Soc. America Memoir 30.

Tyrrell, G. W., 1927, The principles of petrology: E. P. Dutton and Co., Inc., New York.

Wahlstrom, E. E., 1947, Igneous minerals and rocks: John Wiley and Sons, Inc., New York.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954, Petrography: W. H. Freeman and Co., San Francisco.

COLOR	CHIEF MINERALS	CHARACTERIZING ACCESSORY MINERALS	NONDIRECTIONAL STRUCTURE Massive or Granulose — Contact Metamorphism*			DIRECTIC	
			Fine Grained (Aphanitic)	Medium or Coarse Grained (Phaneritic)	Mechanical Metamorphism — Cataclastic	Slaty	
LIGHT	QUARTZ FELDSPAR CALCITE DOLOMITE TALC MUSCOVITE SERICITE	Muscovite Sericite Sillimanite Kyanite Cordierite Tremolite Wollastonite Albite Andalusite Garnet Phlogopite Diopside Enstatite Staurolite Glaucophane Anthophyllite Pyrophyllite Chloritoid Actinolite Tourmaline Epidote Chiastolite Olivine Serpentine Chlorite Biotite Graphite Chondrodite Scapolite	METAQUARTZITE MARBLE BRUCITE MARBLE SOAPSTONE—chiefly talc HORNFELS—any metamorphic rock with nondirectional structure	METAQUARTZITE MARBLE BRUCITE MARBLE TREMOLITE MARBLE WOLLASTONITE MARBLE TREMOLITE HORNFELS WOLLASTONITE HORNFELS CALC-SILICATE HORNFELS—chiefly calc-silicate minerals	These rocks are formed by crushing and shearing with only minor recrystallization. If there are no conspicuous directional features, the rock is called "crush breccia" if coarse grained, and "cataclasite" if fine grained. Most of them, however, are foliate. MYLONITE—finely ground, foliate FLASER GRANITE, FLASER DIORITE, FLASER CONGLOMERATE, ETC.—flaser structure AUGEN GNEISS—augen structure ULTRAMYLONITE—partially fused mylonite Rocks with only minor deformation may be called "schistose," for example "schistose sandstone," "schistose rhyolite," etc., but these are not properly metamorphic rocks.		PH PHY
INTERMEDIATE (Includes Red or Brown)	ABOUT EQUAL PROPORTIONS OF LIGHT-COLORED AND DARK-COLORED MINERALS		METAQUARTZITE MARBLE SKARN—pyroxene-garnet-carbonate hornfels SOAPSTONE—chiefly talc HORNFELS—any metamorphic rock with nondirectional structure SERPENTINE*	METAQUARTZITE MARBLE DIOPSIDE MARBLE CHONDRODITE MARBLE ANDALUSITE HORNFELS SKARN—pyroxene-garnet-carbonate hornfels GARNET HORNFELS KYANITE HORNFELS ANTHOPHYLLITE HORNFELS CALC-SILICATE HORNFELS SERPENTINE* CORDIERITE-ANTHOPHYLLITE HORNFELS		Most slates are dark colored	
DARK (Includes Green)	QUARTZ CALCITE DOLOMITE FELDSPAR CHLORITE HORNBLENDE SERPENTINE BIOTITE PYROXENE ACTINOLITE EPIDOTE OLIVINE MAGNETITE		METAQUARTZITE MARBLE SKARN—pyroxene-garnet-carbonate hornfels GRAPHITE MARBLE CHLORITE MARBLE SERPENTINE MARBLE (Ophicalcite) HORNFELS—any metamorphic rock with nondirectional structure SERPENTINE*	METAQUARTZITE MARBLE GRAPHITE MARBLE CHLORITE MARBLE OLIVINE MARBLE SKARN—pyroxene-garnet-carbonate hornfels ACTINOLITE MARBLE ACTINOLITE-EPIDOTE HORNFELS ACTINOLITE HORNFELS PYROXENE HORNFELS EPIDOTE HORNFELS TOURMALINE HORNFELS ANDALUSITE-BIOTITE HORNFELS SERPENTINE* ECLOGITE—pyrope-omphacite hornfels MAGNETITE ROCK CORDIERITE HORNFELS AMPHIBOLITE—chiefly hornblende and or plagioclase		SILTY SLATE GREEN SLATE BLACK SLATE SPOTTED SLATE ANDALUSITE SPOTTED SLATE CHIASTOLITE SPOTTED SLATE BIOTITE SPOTTED SLATE CARBONACEOUS SLATE CALCAREOUS SLATE	

As can be noted from the chart, naming a metamorphic rock consists chiefly of prefixing the structural term with mineral names or an appropriate rock name. The rock name indicates either the original rock, if recognizable, or the new mineral composition. The prefix "meta," as "metagabbro," "metasandstone," "metatuff," etc., is applied to rocks that have undergone considerable recrystallization but have largely retained their original fabric. Most of the minerals listed as accessories are genetically important and if present should be included in the rock name regardless of their quantity.

* **SERPENTINE** is a product of hydrothermal alteration which some (ties consider to be an igneous process and others a metamorphic proc this reason, serpentine appears both on this chart and on the igneo chart.

By Russell B. Travis

NAL STRUCTURE (Lineate or Foliate)

Regional Metamorphism			Plutonic Metamorphism
Phyllitic	**Schistose**	**Gneissose**	**Migmatitic**
LLITE is intermediate ween slate and schist. differs from slate in t crystallization of aceous minerals im- ts a sheen to the rock; differs from schist in t grains are too small megascopic identifi- ion. **.ONITE**—a phyllite owing its grain to mylonitization	**QUARTZ-MICA SCHIST** **TALC SCHIST** **SILLIMANITE SCHIST** **ALBITE-MICA SCHIST** **QUARTZ-SERICITE SCHIST** **KYANITE SCHIST** **CALCITE SCHIST** (Schistose marble)	**RHYOLITE GNEISS** **QUARTZ PORPHYRY GNEISS** **QUARTZITE GNEISS** **SILLIMANITE GNEISS** **GRANULITE**—banding due to elongated quartz or feldspar grains	These rocks have a gneissose, streaked, or irregular structure produced by intimate mixing of metamorphic and magmatic materials. When they can be recognized as "mixed rock," they are called migmatite or migmatite gneiss. They may originate by injection (injection migmatite, injection gneiss, or lit-par-lit gneiss), or by differential fusion. Many so-called migmatites probably originate by partial granitization or by metamorphic differentiation. But at great depth these processes apparently do not differ substantially from the igneous processes forming migmatite, so the products are usually indistinguishable. Migmatites are named by prefixing the rock name of the granitic material to the appropriate root as "granite migmatite," "monzonite injection migmatite," etc.
	MICA SCHIST **CHIASTOLITE SCHIST** **ANDALUSITE SCHIST** **STAUROLITE SCHIST** **KYANITE SCHIST** **PYROPHYLLITE SCHIST** **GARNET-MICA SCHIST** **SERPENTINE*** **TOURMALINE-MICA SCHIST** **ANTHOPHYLLITE SCHIST** **STAUROLITE-KYANITE SCHIST** **SILLIMANITE-GARNET SCHIST** **GRAPHITE SCHIST** **CALCITE SCHIST** (Schistose marble) **SCHISTOSE QUARTZITE**	**GRANITE GNEISS** **SYENITE GNEISS** **MONZONITE GNEISS** **GRANODIORITE GNEISS** **ANORTHOSITE GNEISS** **TRACHYTE GNEISS** **CONGLOMERATE GNEISS** **ARKOSE GNEISS** **SANDSTONE GNEISS** **AUGEN GNEISS**—augen structure **BIOTITE GNEISS** **STAUROLITE GNEISS** **PLAGIOCLASE GNEISS** **GARNET GNEISS** **MUSCOVITE-BIOTITE-QUARTZ GNEISS** **KYANITE GNEISS** **GRANULITE**—banding due to elongated quartz or feldspar grains	
	GREENSCHIST **CHLORITE SCHIST** **CHLORITOID SCHIST** **GLAUCOPHANE SCHIST** **AMPHIBOLITE** (HORNBLENDE SCHIST) **ACTINOLITE SCHIST** **GRAPHITE SCHIST** **PYROXENE SCHIST** **EPIDOTE-CHLORITE SCHIST** **HORNBLENDE- BIOTITE SCHIST** **BIOTITE-CHLORITE SCHIST** **SERPENTINE*** **TOURMALINE SCHIST** **EPIDOTE AMPHIBOLITE** **GARNET-PYROXENE AMPHIBOLITE** **GARNET-CHLORITE SCHIST**	**QUARTZ DIORITE GNEISS** **DIORITE GNEISS** **GABBRO GNEISS** **PERIDOTITE GNEISS** **DIABASE GNEISS** **PYROXENE GNEISS** **GRAYWACKE GNEISS** **EPIDOTE GNEISS** **GARNET-BIOTITE GNEISS** **SKARN GNEISS** **AMPHIBOLITE GNEISS**	

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FREQUENCY OF OCCURRENCE:

This size type indicates **COMMON ROCKS.**

This size type indicates **UNCOMMON ROCKS.**

This size type indicates **RARE ROCKS.**

PLATE 2. Medium-grained biotite-hornblende diorite exhibiting hypiodiomorphic-granular texture. Color index about 40. (x2)

PLATE 3. Quartz diabase exhibiting diabasic texture. For magnified thin section see Plate 50. Color index about 60. (x1½)

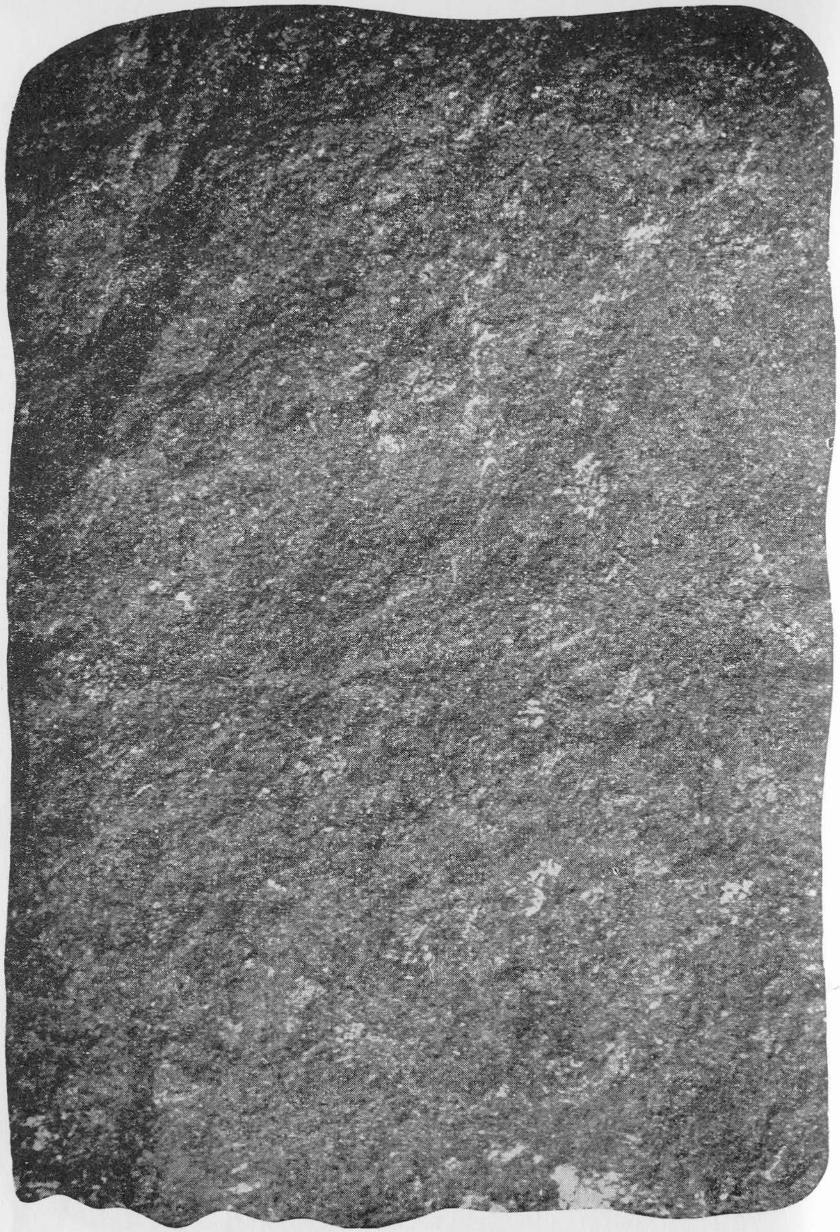

PLATE 4. Moderately coarse-grained peridotite with allotriomorphic-granular texture (not readily apparent). The glistening grains are brown biotite. Color index 100. (x1½)

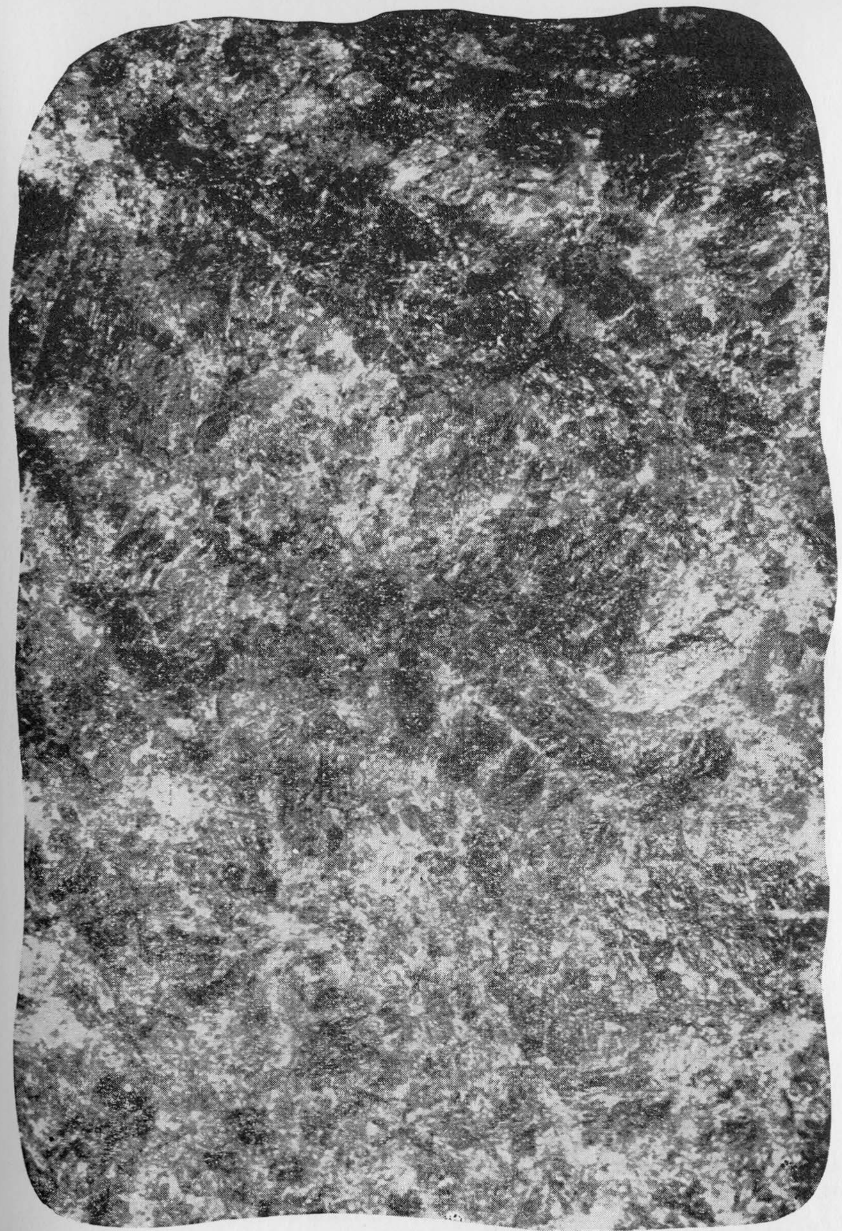

PLATE 5. Coarse-grained anorthosite exhibiting cataclastic texture. Large dark laths of plagioclase in lighter colored groundmass of crushed plagioclase. Color index 0. (x1½)

PLATE 6. Coarse-grained pyroxenite exhibiting hypidiomorphic-granular texture. Composed almost entirely of subhedral pyroxene. Color index 100. (x1½)

PLATE 7. Medium-grained hornblende-biotite quartz monzonite porphyry. Large pale-colored grains of orthoclase set in a groundmass of quartz, plagioclase, biotite and hornblende. Color index about 10. (x1½)

PLATE 8. Graphic granite exhibiting graphic texture. Glassy hieroglyphs of quartz in perthite. (x1)

PLATE 9. Granite pegmatite. Large grains of quartz, perthite, and biotite. (x½)

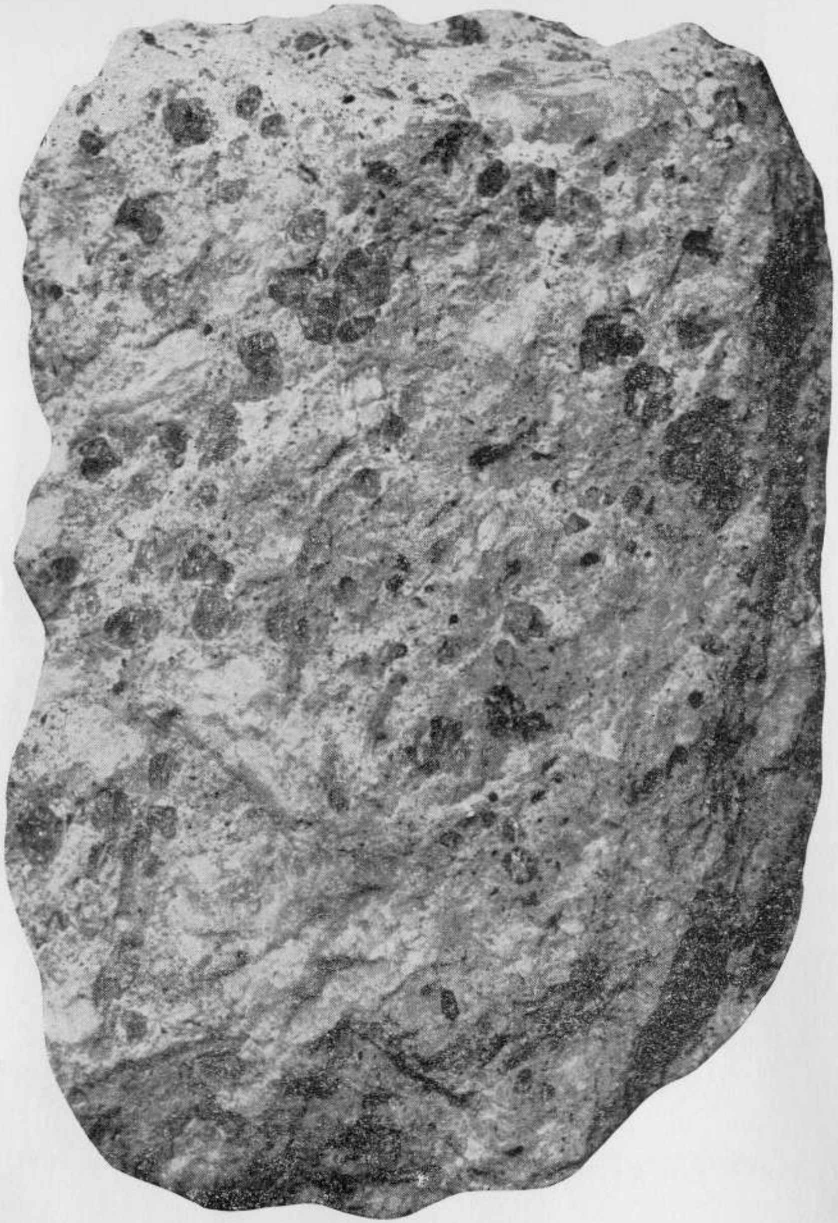

PLATE 10. Rhyolite porphyry. Abundant gray, glassy phenocrysts of quartz, large pale phenocrysts of sanidine and sparse phenocrysts of biotite in light-colored aphanitic groundmass. For magnified thin section see Plate 51. (x3)

PLATE 11. Dacite porphyry. Round phenocrysts of quartz and white lath-shaped phenocrysts of plagioclase in gray aphanitic groundmass. (x3)

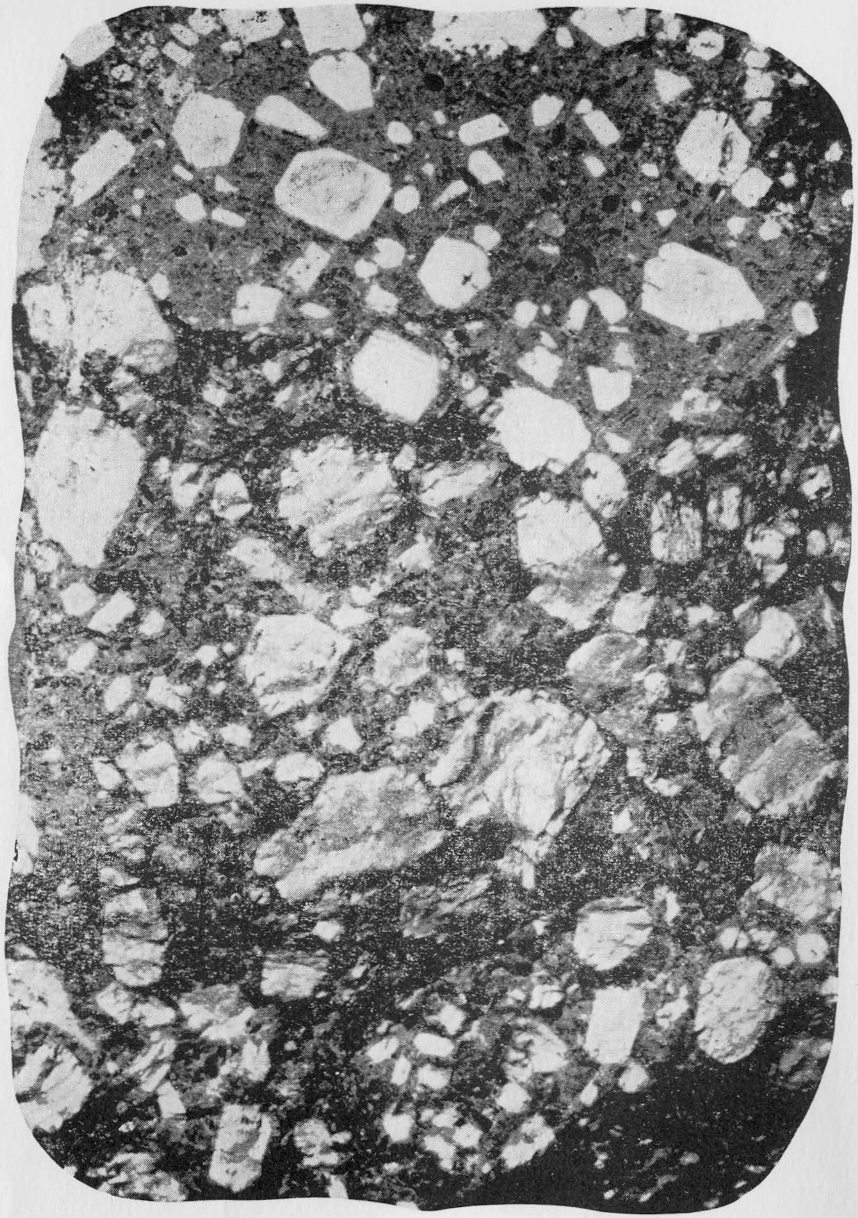

PLATE 12. Dacite porphyry with abundant, large, zoned phenocrysts of plagioclase and less conspicuous phenocrysts of quartz in green aphanitic groundmass. For magnified thin section see Plate 52. (x2)

PLATE 13. Vesicular olivine trap porphyry (olivine basalt porphyry). Glassy phenocrysts are olivine. (x1)

PLATE 14. Banded welded tuff with black phenocrysts of biotite and pale, inconspicuous phenocrysts of quartz and sanidine. Pyroclastic texture is apparent only under the microscope. For magnified thin section see Plate 54. (x3)

PLATE 15. Spherulitic obsidian. Spherulites composed of narrow laths of potash feldspar in radial arrangement. (x1½)

PLATE 16. Chert pebble conglomerate. A homogeneous conglomerate composed of pebbles of chert in a sand matrix. (x¾) (Photo by L. W. LeRoy)

PLATE 17. Mixed pebble conglomerate. A polycomponent conglomerate composed of pebbles of chert, quartzite, sandstone, and aphanitic igneous rock in a sand matrix. (x½)

PLATE 18. Limestone breccia. A homogeneous breccia composed of pebble size fragments of limestone in a black siliceous matrix. (x½)

PLATE 19. Fine-grained quartz sandstone. For magnified thin section see Plate 55. (x3)

PLATE 20. Fine-grained bituminous quartz sandstone. (x1)

PLATE 21. Medium-grained orthoquartzite. Although the interstices of this specimen have been filled completely with authigenic quartz, the clastic texture is still vaguely visible. (x1)

PLATE 22. Red medium-grained arkose with large muscovite flakes (glistening grains). For magnified thin section see Plate 58. (x3)

PLATE 23. Medium-grained graywacke. This specimen is dark olive green and as tough as fresh igneous rock. Megascopically visible are feldspar, rock fragments, minor quartz and a chloritic rock paste matrix. (x3)

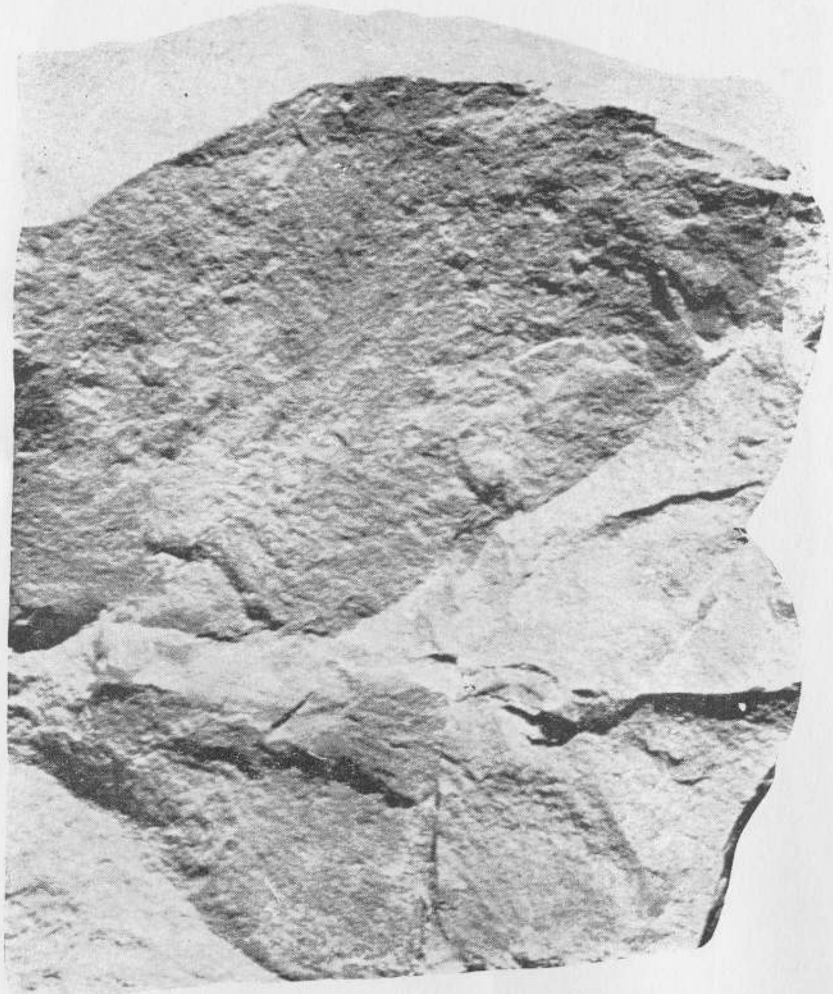

PLATE 24. Argillaceous limestone. Note rough aphanitic texture, giving hackly fracture. (x2)

PLATE 25. Lithographic limestone. Note smooth aphanitic texture, giving conchoidal fracture. (x2)

PLATE 26. Calcareous oolite. For magnified thin section see Plate 59. (x2)

PLATE 27. Brachiopod limestone (organic limestone). (x1½)
(Photo by L. W. LeRoy)

PLATE 28. Coquina. (x1½)

PLATE 29. Crinkly laminated rock gypsum. (x1½)