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THE NOMENCLATURE OF IGNEOUS AND METAMORPHIC ROCKS

by

W.R. Morgan

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THE NOMENCLATURE OF IGNEOUS AND METAMORPHIC ROCKS

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PROLOGUE

"Few people seem to realize that classification stands towards science in the same relation as book-keeping towards business. What would happen to a bank if the staff kept their books as we keep ours? Mr. X.has drawn out a considerable quantity of gold. The amount deposited by Mr. Y.is approximately the same as that credited to Mr. Z., according to the senior partner, but the junior partner thinks it is less. The account of Mr. P.typically shows no credit whatever, but it may record a small deposit or an appreciable overdraft.

"Childish, is it? Fantastic, is it? Yet it strikes me as being remarkably like the condition of petrography at the present day!"

(Quoted from S.J. Shand (1927, p. 449)).

SUMMARY

The classification of the igneous rocks presented here has been adapted from that of Nockolds (1954), because his nomenclature is simple, non-genetic, and based on mineralogical composition. In the classification, the primary division depends on whether or not essential (i.e., more than 10% of the total rock) quartz or feldspathoid is present, or if neither is present in essential quantity. Further subdivision is based on ratio of alkali feldspar to lime-bearing plagioclase, anorthite content of plagioclase, feldspathoids forming more or less than 90% of the leucocratic minerals, ferro-magnesian minerals forming more or less than 90% of the rock, types of ferro-magnesian minerals, colour index, and grain-size. Rock names are to be qualified by their "characterizing accessory minerals"* e.g., in biotite granite, biotite is the characterizing accessory mineral. Some more commonly used igneous textural terms are discussed.

The account of the nomenclature of metamorphic rocks is divided into four parts dealing with Contact, Dynamic, Regional, and General metamorphic rock names. In general, rock names consist of two parts; one part denotes texture, metamorphic grade, or composition - e.g., schist, granulite, or marble, respectively. The other consists of qualifying mineral names listed in order of increasing abundance - e.g., quartz - muscovite - biotite schist. The concluding section in metamorphic rocks describes some textural terms.

Appendix I contains averages of chemical analyses of igneous rocks, and is reproduced from Nockolds(1954).

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* Usage of Williams, Turner and Gilbert (1954).

GENERAL INTRODUCTION

This report has been prepared in order to obtain uniformity within the Bureau of Mineral Resources on the nomenclature of igneous and metamorphic rocks. This is especially needed now because a data processing system has been designed (Walpole, Haldane, Mather, and Morgan, 1964) to provide storage and computer facilities for the results of descriptive and analytical examination of specimens. The system is designed to use the nomenclature presented in this report. In the text, names that are used in the punched card system are given in capital letters - e.g., MONZONITE. Other names mentioned are in lower case, and are underlined - e.g., eucrite.

The report contains a fairly simple classification of the igneous rocks which is based on that of Nockolds (1954). Some notes on metamorphic rock names are also presented - this information is culled from a variety of sources. In addition, some notes on igneous and metamorphic textural terms are given.

It must be emphasized that the classification and notes given are meant only as a guide to the petrography of the igneous and metamorphic rocks. For more detailed textural and mineralogical descriptions, readers are referred to the text books such as Hatch, Wells, & Wells (1960), Williams, Turner, & Gilbert (1954), Moorhouse (1959), Harker (1950, 1954), Heinrich (1956), and Johannsen (1939) and other references quoted in the text.

The writer is grateful to Dr. A.J.R. White and Dr. G.A. Joplin, of the Australian National University, and to Doctors W. Oldershaw, R.R.E. Jacobson, R.R. Harding, D. Gellatly, D.H. Blake, and Messrs. W.B. Dallwitz, R. Bryan, and J.M. Rhodes, of the Bureau of Mineral Resources, for discussion, criticism, and comments on this work. Dr. Joplin is at present writing a text book on Australian petrography, and uses the Nockolds classification as the basis of the nomenclature of igneous rocks.

The nomenclature and classification of sedimentary rocks is contained in a report by Guppy (1964).

NOMENCLATURE OF IGNEOUS ROCKS

INTRODUCTION

The nomenclature described here forms the basis of the list of rock names that is used in the data processing system (Walpole, et al., 1964). It is a somewhat modified version of the classification used by Nockolds (1954) when he presented his averages of chemical analyses of various igneous rock types (see Appendix I). Although Nockolds' paper dealt mainly with the analyses, his classification is based on mineralogical composition. Its use by the Bureau will have several advantages. First, it is mineralogical rather than chemical - most rocks examined by Bureau geologists are petrographically described, but not commonly chemically analysed. Secondly, the rock names are backed up by Nockolds' average chemical analyses. The third advantage is that the classification is descriptive rather than genetic; a descriptive classification is most suitable for Bureau use because of the general nature of most geological surveys undertaken by the Bureau.

PRINCIPLES OF THE CLASSIFICATION

As stated above, the classification is mineralogical rather than chemical; however the mineralogy of an igneous rock is, very commonly, a reflection of its chemistry. For example, in peralkaline granites, the sum of the molecular proportions of the alkalis exceeds that of alumina; hence sodic ferromagnesian minerals will be present. In calc-alkaline granites, the molecular proportion of alumina exceeds that of the alkalis, so that non-sodic ferro-magnesian minerals are present.

Probably the most important principle of a classification is silica content. In relation to mineralogy this determines whether quartz, or feldspathoid, or neither, is present in a rock in essential quantities. Nockolds (op.cit.) uses the quantity 10% of the total rock in defining whether or not either of these components is present in essential quantities. Thus, igneous rocks are divided into three main groups, depending on whether:-

1. quartz exceeds 10% of the total rock.
2. quartz or feldspathoid forms less than 10% of the total rock.
3. feldspathoid exceeds 10% of the rock.

Thereafter, igneous rocks are further subdivided according to the following characters:

a. Alkali feldspar forming more than 60%, 60 to 40%, 40 to 10%, or less than 10% of the <u>total feldspar</u>. Alkali feldspar is a term that embraces albite, perthite, anorthoclase, sanidine, orthoclase, and microcline. The term "lime-bearing plagioclase", where used in this report, comprises the series oligoclase to anorthite.

b. The average anorthite content of the plagioclase more or less than 50 molecular percent. This, of course, is one method of distinguishing between, for example, basalt and andesite, or gabbro and diorite. However, in calc-alkaline andesites the anorthite content of the plagioclase composition may exceed 50 mol. percent, especially in phenocrysts; hence, this criterion should be used in conjunction with others, such as colour index, and the amount and refractive index of glass.

c. The quantity of feldspathoid - more or less than 90% of the total leucocratic minerals. This serves to distinguish between certain ultra-alkaline basic rocks, such as nephelinite, and alkaline basic rocks, such as tephrite.

d. The quantity of ferro-magnesian minerals - more or less than 90% of the total rock. This is used to distinguish the ultrabasic rocks, such as peridotite, and melanocratic rocks, such as mela-gabbro.

e. The types of ferro-magnesian minerals present. This criterion is used, first, in classifying ultramafic and some basic rocks. Secondly, it is used to distinguish between peralkaline and calc-alkaline acid and intermediate rocks.

f. Colour index. Writers differ on limits within this criterion. Nockolds (1954) does not mention any; Johannsen (1939) uses the figures 5, 50, and 95 - the figure 50 is unrealistic for distinguishing between, for example, andesite (less than 50) and basalt (greater than 50), because most basalts have colour indices of between 35 and 50. Shand (1950) used the figures 30,60, and 90. Ellis (1948) suggested 10, 40, and 70.1

The limits adopted here are those of Shand (1950) - i.e., 30, 60, and 90. 30 is a useful figure for distinguishing between, for example, andesite and basalt; rocks with colour indices of over 90 are, of course, ultrabasic. Rocks with colour indices of between 60 and 90 will have their names prefixed with "mela -". The prefix "leuco-" should be restricted to acid and intermediate rocks containing less than 5% dark minerals, and to basic rocks with colour indices of less than 30.

g. Grain-size. This criterion is commonly used in conjunction with mode of occurrence. Hatch, Wells, and Wells (1961) would prefer geologists to allot names by grain-size, and ignore mode of occurrence. This is probably the most logical approach, and will be used here. The limits of grain-size are:-

fine-grained : less than 1 mm.
medium-grained : 1 to 5 mm.
coarse-grained : more than 5 mm.

Thus , for example, a basic rock that has a grain-size of less than 1 mm. would be termed basalt, even if it occurs as an intrusion; care must be taken in petrographic descriptions to state whether or not such a rock is intrusive or extrusive, or if the mode of occurrence is not known.

Some difficulty arises in judging grainsize in porphyritic rocks. In the scheme adopted here, if a sample contains coarse crystals enclosed in a groundmass that forms more than 10% of the rock, the sample is to be regarded as porphyritic, and the grainsize classification is judged from the groundmass.

GENERAL REMARKS

It will be noted that the classification adopted in this report, and shown in Plate I, is simple if it is compared with that of Johannsen (1939) or even with those given in some other reference books. Table A is from Nockolds (1954) and is reproduced for comparison with Plate I. The intention is to provide a name for a defined combination of essential minerals considered in conjunction with grain-size. Varietal names for rocks showing differences in texture and in characterizing accessory minerals have been avoided as far as possible.

Essential* minerals in a rock are those that are used to define a rock name - in other words, they are essential for the definition. Thus, in a granite, more than 10% of the total rock is quartz, and more than 60% of the total feldspar is alkali feldspar. If more than 60% of the feldspar is lime-bearing plagioclase, then the rock is granodiorite.

Characterizing accessory* minerals are those present in sufficient quantity to warrant inclusion in the rock name, but which are not essential to the definition of the name. Thus, "hornblende" in hornblende diorite is a characterizing accessory. In this classification, rock names are to be qualified by any characterizing accessories present - e.g., augite,norite, muscovite-biotite granite, olivine basalt, etc.

Minor accessory* minerals are those that are present in very small quantities - e.g., zircon in

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* These terms are used in the same way as is given in Williams, Turner, & Gilbert, 1954, p. 32.

Table A. Classification of Igneous Rocks - Nockolds, 1954.

Other Essential Minerals	Essential Alkali Feldspar (Potash Feldspar or Albite, or both)	ESSENTIAL POTASH AND LIME-BEARING PLAGIOCLASE				No Essential Feldspar
		Potash feldspar 60% of total feldspar	Potash feldspar 60% -40% of total feldspar	Potash Feldspar 40% -10% of total feldspar	Potash Feldspar 10% of total feldspar	
Quartz greater than 10% of rock.	Alkali Granite (alkali rhyolite) Peralkaline Granite (peralkaline rhyolite)	Calc-alkali granite (calc-alkali rhyolite)	Adamellite (dollerite)	Granodiorite (rhyodacite)	Tonalite (dacite)	
No essential quartz or feldspathoid (i.e., less than 10%).	Alkali Syenite (alkali trachyte) Peralkaline Syenite (peralkaline trachyte).	Calc-alkali syenite (calc-alkali trachyte)	Monzonite (latite)	Mangerite (doreite)	Diorite (andesite) Gabbro (basalt)	Perknite Peridotite
Feldspathoid greater than 10% of rock	Nepheline Syenite (phonolite)		Nepheline Monzonite (nepheline latite)	Essexite (nepheline ordandrite) Glenmuirite (analcite ordandrite)	Theralite (nepheline Teschenite (analcite tephrite)	Ultra-Alkaline Rocks (nephelinite, etc.).

granite, apatite in dolerite, etc. These are not used to qualify rock names except in very special circumstances, such as in very detailed petrographic work on rocks of the same general type.

Where less than 10% of the total rock consists of quartz or feldspathoid, the fact that one or the other of these occur is recorded by including the relevant mineral name as a qualifier in the rock name - e.g., nepheline syenite, quartz dolerite. It is important that this should be done, because the combined rock and mineral name will tell us whether or not the rock is oversaturated or undersaturated with respect to silica; this can be important in petrogenetic studies. Note that nepheline syenite in this classification means that only accessory quantities of nepheline are present in the rock. The term foyaite indicates a syenitic rock containing essential feldspathoid (such as nepheline).

However, all names given to rocks containing essential feldspathoid have to be qualified by the type or types of feldspathoid they contain, e.g., nepheline tephrite, leucite tephrite etc. (This rule applies to all such rocks).

The characterizing accessory minerals (including quartz and feldspathoid) are to be written in order of increasing abundance in front of the rock name. This rule follows the practice of Hatch, Wells, and Wells (1960), Harker (1954) Johannsen (1939), and Williams, Turner and Gilbert (1954). Thus, a hornblende-biotite diorite contains more biotite than hornblende; biotite-hornblende diorite contains less biotite than hornblende.

DETAILS OF CLASSIFICATION

Acid Rocks

In all acid rocks, quartz forms more than 10% of the total rock. Their plagioclase generally contains less than 50% of the anorthite molecule, although there may be exceptions to this rule, particularly in phenocrysts in some hornblende or augite tonalites. The acid rocks are sub-divided by the ratios of alkali feldspar to lime-bearing plagioclase. Alkali feldspar is a commonly-used term that includes albite, perthite, anorthoclase, sanidine, orthoclase, and microcline.

Granite and Related Rocks.

Granite, microgranite, and rhyolite are rocks that contain essential (more than 10%) quartz, and in which alkali feldspar forms more than 60% of the total feldspar.

In CALC-ALKALINE GRANITE, potash feldspar forms more than 60% of the total feldspar; the remaining feldspar is a lime-bearing plagioclase, usually oligoclase. The ferro-magnesian minerals present are commonly biotite, muscovite, and hornblende; pyroxene is much less common. Some granites contain fayalitic olivine (e.g. Morgan, 1963). The medium-grained and fine-grained equivalents of the calc-alkaline granites are CALC-ALKALINE MICROGRANITES and RHYOLITES.

ALKALINE GRANITE, MICROGRANITE and RHYOLITE contain alkali feldspar, and non-sodic ferro-magnesian minerals. The alkali feldspar can be any combination of potash feldspar and albite, or either of them singly. No lime-bearing plagioclase is present.

PERALKALINE GRANITE, MICROGRANITE, and RHYOLITE are similar to the alkaline variety, except that the ferro-magnesian minerals are sodic - e.g., aegerine, aegerine-augite, riebeckite, arfvedsonite, etc. Fayalite occurs in some peralkaline granites (e.g., Jacobson, MacLeod, and Black, 1958). The peralkaline rhyolites have received other names - e.g., pantellerite (e.g., Zies, 1960; Carmichael, 1962), comendite; for the sake of simplicity, such names are ignored in this classification.

Adamellite and Related Rocks.

In ADAMELLITE potash feldspar forms between 60% and 40% of the total feldspar, and essential quartz is present. MICROADAMELLITE (medium-grained) and DELLENITE (fine-grained) are mineralogically similar. Plagioclase is most commonly calcic oligoclase; the ferro-magnesian minerals are biotite, muscovite, hornblende, and, less commonly, pyroxene. Fayalite has also been observed in adamellitic rocks (Wheeler, 1955; Oyawoye, 1961).

Granodiorite and Related Rocks.

In GRANODIORITE, potash feldspar forms from 40% to 10% of the total feldspar and plagioclase is most commonly calcic oligoclase to andesine, and essential quartz is present. The ferro-magnesian minerals are biotite and hornblende, less commonly muscovite or pyroxene, and, rarely fayalite. MICROGRANODIORITE and RHYODACITE are the medium-grained and fine-grained equivalents.

Tonalite and Related Rocks.

The potash feldspar in TONALITE forms less than 10% of the total feldspar, and the plagioclase is usually andesine, although phenocrysts can be more calcic. Quartz makes up more than 10% of the total rock. The ferro-magnesian minerals are hornblende, biotite, and pyroxene, and, less commonly, muscovite. MICROTONALITE and DACITE are the medium-grained and fine-grained equivalents. TRONDHJEMITE is a leucocratic form of tonalite; its plagioclase is more sodic, about oligoclase in composition.

Acid Volcanic Glasses

In addition to the rocks dealt with above are several volcanic rock types that are or were composed of glass. Their composition may be that of rhyolite, dellenite, rhyodacite, or dacite, but can be found only by chemical analysis. OBSIDIAN is an acid glass with only a small amount of water in it; in hand specimen it is vitreous and dark brown to black, whereas PITCHSTONE is a water-rich glass that has a dull, resinous lustre in hand specimen. FELSITE (Hatch, Wells, & Wells, 1961 ., p.229) is an exceedingly fine-grained rock composed of anisotropic material that has resulted from devitrification of acid volcanic glass. PUMICE is a sponge-like rock formed from frothy, acid lava.

Granophyre

GRANOPHYRES are porphyritic rocks of granitic or adamellitic composition in which the phenocrysts are enclosed in a fine- or medium-grained groundmass. The groundmass is composed of micrographically intergrown quartz and alkali feldspar. Biotite, muscovite, amphibole, and, more rarely, pyroxene and fayalite (e.g., McDougall, 1962), may be present in granophyre.

Intermediate Rocks

The intermediate rocks contain less than 10% of quartz or feldspathoid; plagioclase usually has a composition of less than An_{50} (although there are exceptions to this rule), and colour indices are generally less than 30. Like the acid rocks, they are subdivided by the ratios of alkali feldspar to lime-bearing plagioclase.

The intermediate rocks may contain either quartz or feldspathoid in accessory amounts; if either of them is present, then the rock names are qualified accordingly - e.g., quartz diorite, nepheline trachyte, etc.

Syenites and Related Rock.

Syenite, microsyenite, and trachyte are rocks in which alkali feldspar forms more than 60% of the total feldspar.

In CALC-ALKALINE SYENITES, potash feldspar forms more than 60% of the total feldspar; the remaining feldspar is a lime-bearing plagioclase. The ferro-magnesian minerals are non-sodic species. The medium-grained variety is CALC-ALKALINE MICROSYENITE, and the fine-grained, CALC-ALKALINE TRACHYTE.

ALKALINE SYENITE, MICROSYENITE, and TRACHYTE. The feldspar is alkaline (i.e., albite, perthite, or potash feldspar) no lime-bearing plagioclase is present, and the ferro-magnesian minerals are non-sodic.

PERALKALINE SYENITE, MICROSYENITE, and TRACHYTE are similar to the alkaline variety, except that the ferro-magnesian minerals are sodic.

PERTHOSITES (e.g., Morel, 1961) and ALBITES are LEUCOSYENITES composed almost entirely of perthite and albite respectively.

Monzonite and Related Rocks.

In MONZONITE, between 60% and 40% of the feldspar is lime-bearing plagioclase, the remainder is potash feldspar. The ferro-magnesian minerals are hornblende, biotite, and, less commonly, pyroxene. MICROMONZONITE is the medium-grained variety. The fine-grained variety is LATITE; Dr. G.A. Joplin (pers. comm.) states that the term shoshonite has priority over latite, although the latter is in common use for lavas of this sort nowadays. LEUCOMONZONITE has a colour index of less than 5.

Mangerite and Related Rocks.

MANGERITE is a name used by Nockolds (1954) to describe plutonic intermediate rocks in which potash feldspar forms between 40% and 10% of the total feldspar, the remaining feldspar being lime-bearing plagioclase. According to Nockolds (1954) there are three types of mangerite. One is calc-alkaline, and contains non-sodic ferro-magnesian minerals. The other two are alkaline, the Aker type containing sodic ferro-magnesian minerals, and the Hurum type containing titaniferous ferro-magnesians. Johannsen (op.cit., Vol.III, p. 63) regards mangerite as a form of syenite.

For medium-grained rocks of this type, the name MICROMANGERITE will be used. Nockolds (1954) uses the term DOREITE* for the fine-grained equivalent of mangerite. The name is after the type locality at Mt. Dore, le Saucy, Auvergne, France. Doreites are represented in the alkali basalt series by MUGEARITE ("oligoclase - andesite") - McDonald (1960). A recent description of an occurrence of mugearite is given by G.P.L. Walker (1960).

Diorite and Related Rocks.

Potash feldspar forms less than 10% of the total feldspar in DIORITE; ferro-magnesian minerals are hornblende, pyroxene, and biotite. Leucocratic dioritic rocks are called OLIGOCLASITE (formed of oligoclase) and ANDESINITE (formed of andesine). The medium-grained equivalent of diorite is MICRODIORITE; the term porphyrite is in fairly common use for porphyritic micro-diorite, but is not used in this classification. ANDESITE is the fine-grained equivalent of diorite. Andesites are represented in the alkali basalt differentiation series by HAWAIITE ("andesine-andesite") - MacDonald (1960).

Petrographers commonly have difficulty in distinguishing between andesite and basalt, especially if there is an appreciable amount of glass present, or if the plagioclase has an anorthite content greater than 50 mol. percent. Several criteria have to be used, such as the composition of the feldspar, the colour index, the refractive index of the residual glass, the amount of residual glass, and texture. On occasions, nothing short of a chemical analysis will help. In this context, the following general rule will be helpful in naming these rocks: if a rock contains plagioclase with an anorthite content greater than 50 mol. percent but has a colour index of less than 30, it will be termed ANDESITIC BASALT; if, on the other hand, it contains plagioclase whose anorthite content is less than 50 mol. percent, but with a colour index greater than 30, it will be termed BASALTIC ANDESITE.

The term HYALOANDESITE was suggested by Rittman (1960) as a provisional name for rocks that in thin section, have andesitic minerals, but no quartz, enclosed in an abundant glassy matrix, the glass having a low refractive index.

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* A specimen of doreite from the type locality is in the Bureau collection (R.15223); it was presented by Dr. A.J.R. White, of the Australian National University.

These rocks if chemically analysed, would be found to have a dacitic or rhyodacitic composition, and would be named accordingly. Some good examples have been described recently by the writer (Morgan, 1963b). It is suggested that the term hyaloandesite be used for rocks of this kind that have not been chemically analysed.

Basic Rocks with Accessory Quartz or Feldspathoid

In these rocks, quartz and feldspathoid form less than 10% of the total rock. Their colour index is usually greater than 30, and plagioclase (in the plagioclase-bearing rocks) has an anorthite content of greater than 50 mol. percent.

Figure A in Plate I shows the varietal names of basic igneous rocks (including, for the sake of convenience, some feldspathoidal basic and ultrabasic rocks), and the mineralogical relationship between them. This diagram is adapted from that of Yoder and Tilley (1962); their original diagram was meant to illustrate the normative mineral content of basic rocks, as calculated from chemical analyses. The diagram, as used here, indicates, in a general way, the rock names derived from the modal composition of basic rocks. The diagram is an exploded tetrahedron in which the four corners represent modal clinopyroxene, olivine, nepheline and quartz. The significance of the terms alkali and tholeiite is explained on page 12 .

Gabbro and Related Rocks.

Three main terms are in general use to describe the coarse-grained varieties - gabbro, norite, and troctolite. In all these, alkali feldspar makes up less than 10% of the total feldspar. The anorthite content of plagioclase is generally greater than50mol. percent, and the colour index, in most cases, is greater than 30. The varietal names depend upon the dominant ferro-magnesian mineral that accompanies plagioclase, and are defined as follows:-

GABBRO: contains plagioclase, and more clinopyroxene than either orthopyroxene or olivine.

NORITE: contains plagioclase, and more orthopyroxene than either clinopyroxene or olivine.

TROCTOLITE: contains plagioclase, and more olivine than either clinopyroxene or orthopyroxene.

Commonly, these rock types contain, in addition to their essential ferro-magnesians, other ferric minerals. In such cases, the rock name is to be suitably qualified - e.g., augite norite, hypersthene troctolite, olivine-hypersthene gabbro. Some gabbro contain only hornblende as their ferro-magnesian mineral - these are to be referred to as HORNBLENDE GABBRO.

The medium-grained equivalents of the gabbroic rocks are DOLERITE, MICRONORITE, and MICROTROCTOLITE. The names for the fine-grained rocks are BASALT, HYPERSTHENE BASALT, and PICRITE BASALT.

There are certain other terms sometimes used by petrographers to describe gabbroic rocks, but their use is not to be recommended, because of possible confusion. For example, allivalite is a form of troctolite containing bytownite in place of labradorite; eucrite is a noritic rock that has a variety of definitions; the essence of these, it appears, is that it should contain bytownite or anorthite, in place of labradorite. Le Bas (1959) sensibly suggested that the name should be discarded.

Names of gabbroic rocks with low colour indices (i.e., less than 30) should be prefixed "leuco-". Where colour indices are lower than 10, they should be termed ANORTHOSITE. On Plate I, anorthosite is placed with the dioritic intermediate rocks oligoclasite and andesinite; this is unavoidable because of the structure of the diagram.

FERRO-GABBRO and FERRO-DOLERITE are terms applied to iron-rich basic rocks. These names should be applied only if a chemical analysis is available, or if petrographic examination shows that they contain an iron-rich pyroxene and a higher percentage of iron oxide minerals than is normally present in undifferentiated basic rocks. The term FERRO-DIORITE has been applied by Wager and Vincent (1962) to an iron-rich dioritic rock that is thought to be/differentiate related to the basaltic Non-Porphyritic Central Magma type of Mull. In this rock, the anorthite content of the plagioclase is less than 50 mol. percent, whereas in ferro-dolerite, it is greater than 50%.

Some tholeiitic intrusive rocks have a typical doleritic texture, and contain pyroxene (which may be partly or completely uralitized or chloritized) together with fairly sodic plagioclase - andesine or oligoclase - instead of labradorite. The writer has examined several rocks of this sort from the Milne Bay area of Papua (Morgan, 1960(b)). These rocks should be termed DOLERITIC DIORITE.

The pegmatitic varieties of basic rocks are described in the chapter on pegmatites and aplites (p. 20).

Alkali, Tholeiitic, and Calc-alkali Basic Rocks.

In the preceding section, the basic rocks have been treated in a purely descriptive way. However, the terms alkali, tholeiitic, and calc-alkali, in relation to basic rocks, are in fairly common use nowadays, so that it is necessary to digress, in this section, in order to describe briefly their significance.

Yoder and Tilley (1962) divide the basic rocks into two main groups - alkali and tholeiitic (Figure A, Plate I). The significance of this division is partly petrographic, but is, more importantly, petrogenetic, because during differentiation, the alkali basalts mostly give rise to undersaturated rock types, such as phenolite, whereas the tholeiites give rise to oversaturated rocks such as granophyre. A third group of basic rocks (Kuno, 1959) is the calc-alkali type. The main characteristics of these three groups are described in the following paragraphs.

Tholeiitic basalt, dolerite and gabbro contain essential augite or sub-calcic augite, plagioclase (with a composition of about Au50), and iron oxides. Olivine is commonly absent; however, in some of such rocks it may be present in subordinate amounts or, in olivine tholeiite, abundant. Pigeonite or hypersthene, or both, are commonly present. In the coarser-grained dolerites, augite crystals commonly contain exsolution lamellae of orthopyroxene, and hypersthene crystals, exsolution lamellae of clinopyroxene (Hess, 1941, and 1960). Characteristically, an interstitial acid glass, commonly coloured, is developed in the more fractionated types. This interstitial residuum may be represented by quartzofeldspathic intergrowths. Normative olivine and hypersthene (in olivine tholeiites), or quartz and hypersthene (in quartz tholeiites) are present. The differentiates ideally associated with tholeiitic dolerites (or basalts) are ferrodolerite, doleritic diorite (andesite), granophyre, and dolerite pegmatite (rhyolite). Fayalite is a characteristic mineral in the more acid differentiates (Wager and Deer, 1939; McDougall, 1962). Comprehensive petrographic descriptions of tholeiitic dolerites are given by Elliott (1956), Holmes & Harwood (1929), Walker (1930), and McDougall (1962).

The alkali basalts and dolerites contain essential diopsidic or titaniferous augite, plagioclase (about An_{50}), together with olivine, which occurs as phenocrysts and in the groundmass. Nepheline may be present in small quantities; more commonly, however, zeolitic material such as analcite occurs interstitially. The alkali basalts, according to Yoder and Tilley (1962) , are almost universally holocrystalline. In the alkali basalts, the sum of the alkalies (Na_2O and K_2O) generally, but not always exceeds 3%. Yoder and Tilley (1962) state that these rocks contain normative nepheline, but no hypersthene. However, Poldervaart (1964) considers as alkali some basalts that contain small amounts of normative hypersthene, but which have all the petrographic characteristics of alkali basalts. The differentiates associated with alkali basalts include basanite, tephrite, hawaiite, mugearite, trachyte, and phonolite; however, oversaturated rocks such as peralkaline quartz trachyte and peralkaline rhyolite are also associated with them in some places (e.g. Edwards, 1938; Mohr, 1963). Quite commonly, ultra-alkaline rocks such as nephelinite and analcitite may be present (e.g., Stark & Hay, 1963; Morgan, 1959, and 1965).

The basic rocks associated with the calc-alkaline series are not considered by Yoder and Tilley (1962) as a third group; they believe that these rocks can be derived from either alkali or tholeiitic parents. Kuno (1959) states that their main characteristic is that hypersthene occurs in the groundmass, instead of pigeonite (as in the tholeiites). These basalts and gabbros are associated with the calc-alkaline series of andesite-dacite-rhyolite (or diorite - granodiorite-granite). The tholeiitic and alkali rock series are thought to form by crystallization differentiation; the calc-alkaline rock series probably forms from hybridization of variable quantities of basic and acid magma. Examples of calc-alkaline rocks described in the literature are given by Drewes, et al (1961), Oliver (1961), Thayer (1937), Larsen (1948).

In the classification adopted here, the terms alkali, tholeiite, and calc-alkali, in relation to basic rocks, are avoided. The writer believes it to be more accurate (and honest), when naming rocks from petrography alone, to use a descriptive nomenclature rather than genetic. Thus, the name "analcite-olivine basalt" is to be preferred to "alkali basalt."

Other Feldspathoid-Free Basic Rocks.

In KENTALLENITE, between 10% and 60% of the total feldspar consists of potash feldspar; the remainder consists of basic plagioclase. The colour index is greater than 30. The medium-grained variety is MICROKENTALLENITE, and the fine-grained, TRACHYBASALT.

SHONKINITES are roughly syenitic (i.e., more than 60% of the total feldspar is an alkali-type) but they have colour indices greater than 30. The medium-grained equivalent is termed MICROSHONKINITE. There is no specific term for the fine-grained types, probably because they occur very rarely, if ever, in nature; however, MELATRACHYTE is suggested.

Basic Acid Intermediate Rocks with Essential Feldspathoid

The rocks in this group contain more than 10% feldspathoid. Further subdivision depends upon the ratios of alkali feldspar to plagioclase, the composition of the plagioclase, the colour index, and the grainsize. The rock names are qualified by the type of feldspathoid they contain - e.g., nepheline theralite, nepheline-analcite theralite, etc.

Theralite and Related Rocks.

These are gabbroic rocks that contain essential feldspathoid. It is important to note here that the names make them distinct from those gabbroic rocks that contain only accessory feldspathoid. Nepheline gabbro, for example, contains accessory nepheline; nepheline theralite contains essential nepheline.

THERALITE, in addition to the essential feldspathoid, contains plagioclase whose anorthite content is greater than 50%, and has a colour index greater than 30. Up to 40% of its total feldspar consists of alkali feldspar. It should, however, be noted here that Nockolds, in his classification, (1954, and Fig. 1;p b), restricted the name theralite to rocks containing less than 10% alkali feldspar, and used the name essexite for rocks with between 40% and 10% alkali feldspar. However, examination of reference books on petrography indicates that, generally, essexites are peculiar forms of gabbro and (sometimes) kentallite that may or may not contain accessory feldspathoid. Furthermore, the type essexite has been found to be a contact metamorphosed igneous rock (Hatch, Wells, & Wells, 1961). Hence the term theralite, in the classification presented here, is extended to cover Nockolds' definition of essexite.

MICROTHERALITE is a term to be used to describe the medium-grained forms of theralite. The naming of the fine-grained equivalent of theralite is slightly complicated by two varietal names, both of which are in common use nowadays. TEPHRITE is a feldspathoidal basaltic rock containing plagioclase and clinopyroxene as its other essential minerals. BASANITE is similar, but contains essential olivine as well.

TESCHENITE, a name firmly entrenched in the literature, is applied to theralitic rocks in which analcite takes the place of some of the plagioclase (e.g., Tyrrel, 1948; Wilkinson, 1958). The ill-defined term crinanite is used by some writers to describe certain types of teschenite; Wilkinson (1955) suggests that it should be discarded.

Malignite

MALIGNITE is a syenite-like rock that contains essential feldspathoid, and which has a colour index greater than 30. No names have been applied by any writer to medium-grained or fine-grained equivalents of this rock, presumably because they have not been found in nature.

Foyaite and Related Rocks.

In this classification, the writer has broadened the meaning of the term FOYAITE to cover all syenitic rocks containing more than 10% feldspathoid, so as to avoid confusion with syenites containing less than 10% feldspathoid. This is done as a convenience for sorting rock names in the punched card system. It has a colour index of less than 30. MICROFOYAITE (tinguaite)is its medium-grained equivalent, and PHONOLITE, the fine-grained form. The names are qualified according to the type of feldspathoid.

The name foyaite is used in this classification so as to enable petrographers to distinguish and avoid confusion between syenitic rocks containing essential feldspathoid and those with only accessory quantities of feldspathoid - e.g., nepheline foyaite as opposed to nepheline syenite. In its original sense, the name foyaite is used to describe nepheline bearing syenitic rocks containing perthite as the only feldspar (Hatch, Wells, & Wells, op.cit., p. 259). Litchfieldite describes two-feldspar (i.e., potash feldspar and albite) nepheline-bearing rocks. The name mariupolite is used for nepheline syenite rocks containing albite as their only feldspar. It may be necessary in detailed petrographic studies to differentiate between these three main types of feldspathoidal syenitic rocks. Thus, in order to simplify the nomenclature, I suggest the following scheme:-

Hypersolvus foyaite (for foyaite as originally used).
Subsolvus foyaite; in place of litchfieldite.
Soda foyaite; instead of mariupolite.

The terms hypersolvus and subsolvus are used in the same way as by Tuttle and Bowen (1958, p. 129); hypersolvus indicates a perthite-bearing rock, and subsolvus, a two-feldspar rock. The terms are in fairly common use nowadays in relation to granites, syenites and foyaites.

Ultra-Alkaline Rocks

The ultra-alkaline rocks contain less than 10% feldspar, but feldspathoids are an essential constituent. Their characteristics are summarized below, and the descriptions are grouped according to the dominant feldspathoid present in the rocks concerned.

Nepheline-rich Rocks

IJOLITE is an intrusive rock with colour indices ranging from about 30 to 60; it consists essentially of nepheline and sodic clinopyroxene. Rocks with similar mineralogy but with differing colour indices are urtite and melteigite; they are better termed LEUCOIJOLITE and MELAIJOLITE, respectively. JACUPIRANGITE is a nepheline-bearing, alkaline, ultramafic intrusive rock related to the ijolite series.

NEPHELINITE is the fine-grained equivalent of ijolite. Note that in this classification, nephelinite containing olivine is named OLIVINE NEPHELINITE. Some writers (e.g., Heinrich, 1956, p. 87) call such rocks "nepheline basalt" This is illogical because basalt - in all classifications - is a rock containing essential plagioclase and clinopyroxene. Because olivine nephelinite contains little or no plagioclase, it obviously cannot be called basalt.

Leucite-rich Rocks.

Intrusive leucite-rich rocks are very rare because of the instability of leucite at even moderately high pressures. However, they are known, and, unfortunately, have received a variety of names to cover differences in texture and mineralogy. In this classification, the name FERGUSITE (Johannsen, 1939) is used to describe all intrusive rocks containing essential leucite, ferro-magnesian mineral, and little or no feldspar.

LEUCITITES are volcanic rocks consisting essentially of leucite and clinopyroxene. Australian examples of such rocks are described by Prider (1959).

Analcite Rocks

ANALCITITE is a fine-grained rock containing essential analcite and clinopyroxene. Australian lavas of this sort have been described by Wilkinson (1962) and by the writer (Morgan, 1960 (a) and 1965). Note that the rock that Wilkinson in his paper (op.cit.) calls "analcite basalt" would be termed, in this classification, "olivine analcitite".

A rock classified by most writers with the lamprophyres - MONCHIQUITE - is, in fact, a minor intrusive equivalent of analcitite. A rock of this type is described by Carstens (1962).

Melilite-rich Rocks

The MELILITITE are fine-grained rocks composed essentially of melilite and clinopyroxene. ALNOITE is one of several names used to describe mineralogically similar intrusive rocks, and is a member of the Katungite series (Holmes, 1950).

Carbonatites.

CARBONATITES are intrusive or extrusive rocks that consist essentially of carbonate minerals - these are usually calcite (sovite), but dolomite (beforsite), ankerite (ankeritic carbonatite), and, more rarely, siderite (sideritic carbonatite), are known to occur. A review of the carbonatite problem is given by Campbell Smith (1956). Guest (1963) has described a specimen of natro-carbonatite lava from the volcano Oldoingo L'Engai, Tanganyika; this sample was collected soon after extrusion, while the lava was still hot.

Remarks on Ultra-Alkaline Rocks.

The ultra-alkaline volcanic rocks have inspired an awsome nomenclature (e.g., Holmes & Harwood, 1932; Hatch, Wells & Wells, 1961). A much more commonsense approach to the naming of these rocks has been taken by Sahama in a review paper (1962). Thus, ultra-alkaline volcanic rocks are named according to their dominant minerals: e.g., nephelinite, melilitite; gradations between the rock types will be marked by mineralogical qualifiers, e.g., melilite nephelinite, nepheline melilitite.

Lamprophyres

The lamprophyres are a group of petrological curiosities that are usually classified by the type of feldspar (if any) present, and the ferro-magnesian minerals they contain. Table B in Plate I is adapted from the classification used by Williams, Turner, & Gilbert (1954).

The lamprophyres are minor intrusive rocks that are characterized by a porphyritic and panidiomorphic texture; all of them contain euhedral mafic minerals, commonly of two generations. They tend to be basic, volatile-rich rocks, and can be divided into three petrographic categories, according to their mineralogy.

1. The minette-vogesite - soda vogesite group are syenite-like, i.e., their chief feldspar is orthoclase. The chief ferro-magnesian mineral in MINETTE is biotite, in VOGESITE, pyroxene or amphibole, or both and in SODA-VOGESITE, soda-pyroxene or soda-amphibole, or both.

2. The kersantite-spessartite-camptonite group are diorite-like, i.e., their chief feldspar is plagioclase. In KERSANTITE, the chief ferro-magnesian mineral is biotite, in SPESSARTITE, amphibole or pyroxene, or both, and in CAMPTONITE, soda-amphibole or soda-pyroxene, or both.

3. The alnoite-monchiquite group are ultra-alkaline, and have been described in the section on ultra-alkaline rocks.

Spilitic Rocks

The spilitic group (spilite, keratophyre) is the subject of some controversy. Some people regard them simply as igneous rocks; others regard them as normal igneous rocks that have undergone autometasomatism (Nicols, 1958). One writer (Dickinson, 1962) considers on good evidence that a quartz keratophyre in Oregon, U.S.A., has resulted from diagenetic alteration and burial metamorphism of rhyodacitic vitric ash. The problems of the spilites are admirably reviewed by Vallance (1960). The chief petrographic characteristics of the spilitic group are summarized below.

SPILITES are basaltic rocks containing sodic feldspar; their ferro-magnesian minerals are partly or completely chloritized or serpentinized.

KERATOPHYRES are intermediate lavas that have a high percentage of sodic feldspar; this is accompanied by small amounts of coloured minerals now represented by chloritic or serpentinous material (Wells, 1922).

QUARTZ KERATOPHYRE similar to keratophyre, except that essential quartz is present.

Keratophyre and quartz keratophyre should not be confused with alkaline trachytes and rhyolites, which are distinguished from them mainly in containing sodic ferro-magnesian minerals. Descriptions of spilitic rocks are fairly frequent in the literature, e.g., Part (1922), Evans (1945), Thomas & Thomas (1956).

Ultrabasic Rocks

Less than 10% of the total mineral content of these rocks consists of leucocratic minerals. The classification used here is a modified form of that of Johannsen (1939, Vol.IV, p. 402), and is shown in Figure C of Plate I. The classification is extremely simple; it is based on the ratio of olivine to other ferro-magnesian minerals, and on the types of ferro-magnesian minerals, other than olivine, that are present. The definitions of the various rock names are summarized below.

Dunite

Olivine forms more than 90% of the rock. A specimen of type DUNITE from Dun Mountain, New Zealand, is in the Bureau collection (R. 3077).

Olivinite

Olivine forms between 90% and 50% of OLIVINITE. The other minerals are pyroxenes and, in some, amphibole and mica.

Peridotite

Olivine forms between 50% and 10% of the rock. The other minerals are as in olivinite. The name PERIDOTITE is commonly used loosely in order to describe olivinites as well; in this classification, it is restricted to Johannsen's definition.

Pyroxenite.

In PYROXENITE olivine forms less than 10% of the rock, and pyroxene more than 50% of the remainder. ORTHOPYROXENITE is composed mostly of orthopyroxene (i.e. enstatite, hypersthene, bronzite, etc.,), and CLINOPYROXENITE of clinopyroxene (diopside, diallage, etc.).

Perknite

As in pyroxenite, olivine forms less than 10% of PERKNITE ; amphibole or mica, or both together, form more than 50% of the remainder.

Serpentinite

SERPENTINITE is an hydrated alteration product of the ultrabasic rocks described above. It consists of varying proportions of the serpentine minerals chrysotile, antigorite, lizardite, and bastite. In some serpentinites, the alteration has been so complete that no relic texture remains; in others, however, the serpentine minerals are clearly pseudomorphous after olivine and pyroxene. Serpentinite commonly contains relics of unaltered crystals of olivine and pyroxene.

Ultrabasic Rocks Consisting Of Ore Minerals

These rocks contain more than 50% of ore minerals, such as magnetite, chromite, and ilmenite. Their names, following general usage, are MAGNETITITE, CHROMITITE, and ILMENITITE. Other minerals present may be pyroxene and olivine.

Limburgite

LIMBURGITES are dark coloured rocks resembling basalt in appearance, but usually containing no feldspar. They consist, generally, of olivine and augite enclosed in brown glass. An account of rocks of this sort is given by Gass (1958).

Remarks

The names of the olivinites and peridotites are to be qualified by the names of the minerals, other than olivine, that they contain in essential quantities - e.g., enstatite olivinite, diopside - enstatite peridotite, etc. The names of the pyroxenites and perknites are to be qualified by the names of their constituent minerals - e.g., diopside clinopyroxenite. This system of naming the ultramafic rocks is, admittedly somewhat cumbersome; however, I believe that this disadvantage is greatly outweighed by the simplicity of the names if they are compared with the nomenclature used by many writers nowadays - e.g., *harzburgite* (enstatite-olivinite), *websterite* (enstatite - diallage pyroxenite), *saxonite* (roughly synonymous with harzburgite), and so on.

Pegmatites and Aplites

PEGMATITES and APLITES are formed from the residual liquids of intrusive magmas. Some are the direct result of crystallization from a liquid, and others have suffered metasomatic recrystallization during the last stages of igneous activity. Speaking in very general terms, pegmatites are coarse-grained late stage rocks that occur as minor bodies within or close to the intrusions to which they are related. Aplites are fine-grained, late stage rocks that occur under similar circumstances. Pegmatites and aplites are named according to the rock type to which they are petrologically, related - e.g., granite - pegmatite, dolerite - pegmatite, etc.; this usage follows that of Johannsen (1939) Notes on some of the more common types follow.

Granite-pegmatite.

Granite pegmatites are divided into two very general groups: simple and complex granite - pegmatites (Turner & Verhoogen, 1960; Hatch, Wells, and Wells, 1961) .

SIMPLE GRANITE-PEGMATITES generally consist of quartz, alkali feldspar (commonly microcline - perthite), with sodic plagioclase, and minor quantities of mica. Few , if any, accessory minerals are present.

COMPLEX GRANITE-PEGMATITES consist of essential quartz, alkali feldspar (commonly albite), lithium minerals, and minerals containing niobium, tantalum, and other rare elements. A recent account of a complex granite-pegmatite is by Wright (1963); he describes a pollucite-bearing zoned pegmatite at Montgary, Manitoba.

Granite-Aplite

GRANITE-APLITES are fine- or medium-grained leucocratic rocks that have a granular texture, and which consist of essential quartz, alkali feldspar, and, in some, lime-bearing plagioclase.

Pegmatites Associated with Basic Rocks.

DOLERITE-PEGMATITE generally appears to be similar in composition to normal dolerite, except that there are larger amounts of granophyric mesostasis present (McDougall, 1962 Walker 1953). The pyroxenes are feathery and elongated, and are commonly more than 10 mm. long. Plagioclase laths are of similar length. Dolerite-pegmatites usually occur in coarse-grained schlieren and veins in dolerite intrusions.

DOLERITE-APLITE has been described by Tomkeieff (1929) from the Whin Sill, England. It forms fine-grained, spheroidal bodies which grade into the enclosing dolerite; they consist of acid feldspar together with some chlorite and hornblende,

Other Pegmatites.

SYENITE-PEGMATITES are coarse-grained rocks with syenitic mineralogy. FOYAITE-PEGMATITES are feldspathoidal pegmatites. Syenite and foyaite pegmatites are commonly associated with alkali basic rocks (e.g., Walker, 1930), and with syenites.

Pyroclastic Rocks.

The main division of these rocks is by the grainsize, classification of Wentworth and Williams (1932). However, other factors in their nomenclature include lithic character, composition of component fragments, and mode of origin (Hatch, Wells, & Wells, 1960).

Table B.

Grainsize	Unconsolidated Material	Consolidated Material
Greater than 32 mm.	Bomb, block	Agglomerate, Volcanic breccia.
32 to 4 mm.	Lapilli	Lapilli tuff
4 to 0.25 mm.	Ash	Tuff
Less than 0.25 mm.	Fine ash	Fine tuff

After Wentworth & Williams, 1932.

In the nomenclature of pyroclastic rocks to be used here, the actual rock name is given according to the grainsize classification shown in Table B. The names are qualified according to the lithic character, fragment composition and mode of origin.

The <u>lithic character</u> of pyroclastic rocks is described by the three terms vitric, lithic, and crystal (Pirsson, 1915). Thus, a vitric tuff consists of glass fragments; lithic tuff contains mainly rock fragments; crystal tuff is an accumulation of crystals. If the lithic character of the rock is heterogeneous, two or all of the terms can be used together - e.g., crystal and lithic tuff - the qualifying terms are placed in order of increasing abundance. Palagonite tuff is a special type of vitric tuff that consists of fragments of altered basaltic glass (Johannsen, 1939).

The <u>fragment composition</u> in pyroclastic rocks is indicated by such terms as rhyolitic, andesitic, basaltic, etc. The <u>mode of origin</u> of the various types of pyroclastic rocks will be dealt with in the summary descriptions given below.

Coarse-grained Pyroclastic Rocks.

AGGLOMERATE consists of an indurated rock formed of volcanic bombs. VOLCANIC BRECCIA is composed of indurated angular material; the fragments may consist of volcanic rocks or of country rock, or both.

Another form of brecciation occurs when the solidified parts of a lava flow or dome are fragmented because of continued movement of still liquid lava beneath its solidified crust. The interstices between the fragments are filled with lava identical to that forming the fragments. The resulting rock is an AUTOBRECCIATED LAVA - e.g., autobrecciated andesite, autobrecciated rhyolite, etc.

VOLCANIC CONGLOMERATE is a rock formed of pebbles of volcanic material. The term is used by some authors (e.g., Williams, Turner, and Gilbert, 1954, p. 296) to describe a rock formed by purely sedimentary action, e.g., marine erosion, river action, etc., with no reference to vulcanicity. Used in this sense, it is a special type of polymict conglomerate (Pettijohn 1957). However, Cotton (1952), following other authors, restricts the term to conglomeratic deposits that have resulted from the action of lahars, i.e., mud-flows caused by volcanic eruption. "The deposits bear a strong similarity to morainic detritus, but much of the material is considerably water-worn" - Williams (1932). The writer considers that the term volcanic conglomerate should be used in the sense of Cotton (1952) , Williams (1932), and others, i.e., that it is a conglomeratic deposit directly related to volcanic activity.

Lapilli Tuff

LAPILLI TUFF is an indurated rock composed of volcanic material whose grainsizes range from 4 mm. to 32 mm.

Tuff

TUFFS are indurated pyroclastic rocks in which the grainsize is less than 4 mm. They are divided into two main types - ash-fall tuffs and ash-flow tuffs.

ASH-FALL TUFF. According to Ross and Smith (1961), an ash-fall tuff is produced by the deposition of volcanic ash directly from the air after being ejected explosively from a vent. The deposit is generally but not always, stratified, and its components show crude to very complete sorting. One writer (Lauder, 1962) has observed reversed grading in ash-fall tuffs in New Zealand.

ASH-FLOW TUFF (Ross and Smith, 1961). An ash flow consists of a turbulent mixture of gas and pyroclastic materials of high temperature that is ejected explosively from a vent, and which travels swiftly down the slopes of a volcano or over the surrounding country. A NONWELDED TUFF is a deposit from an ash flow in which the welding of grains has not taken place. A WELDED TUFF is ash-flow tuff in which the individual fragments remained plastic enough to become partly or wholly welded. Ignimbrite is a term used by many authors as an alternative to welded ash-flow tuff.

A full discussion of the petrography and theories of petrogenisis of ash-flow tuffs, together with many excellent illustrations, are given by Ross and Smith (1961).

China-stone Tuff

A CHINA-STONE TUFF is a pyroclastic rock composed of ultra-comminuted glass dust. In the past, the term porcellanite has sometimes been used for rocks of this sort; however, the use of the name porcellanite in this sense should be avoided, because certain silicified sedimentary rocks are referred to by this name.

Intrusive Fragmentary Igneous Rocks

EXPLOSION BRECCIA is formed by explosive intrusive activity. It consists of fragments of country rock enclosed in a matrix of similar material. An example of a rock of this type is described from Kentallen, Scotland, by Bowes and Wright (1961). Fine-grained fragmentary rocks resulting from explosive intrusive activity are termed INTRUSIVE TUFF. Some people prefer to call such rocks tuffisite (e.g., Whitten, 1959).

Intrusion Breccia

Although INTRUSION BRECCIAS are not strictly pyroclastic, they are included here for the sake of convenience. They are found quite commonly in near surface intrusions,and rocks usually have a matrix of igneous material, but the fragments are of country rock. Examples are described by Reynolds (1954), French and Pitcher (1959), and Green (1961).

SOME IGNEOUS TEXTURAL TERMS

The terms mentioned here are intended to facilitate reference; ohly those most commonly used are included. Most of the definitions are quoted directly from the reference books cited.

Felted: "A microlitic texture with unoriented lath-like or needle-like crystals" (Johannsen, 1939, Vol.I, p.211).

Hyalopilitic: "A texture consisting of needle-like microlites in a glassy groundmass". (Johannsen, 1939, Vol.I, p. 217, and Fig. 6C, Williams, Turner, & Gilbert, 1954). Pilotaxitic is "the same texture, but without glass" (Johannsen, 1939, p. 217, and Fig. 6B, Williams, Turner, & Gilbert, 1954).

Intergranular: "The angular interstices between the feldspars (in many dolerites and basalts) are occupied by ferro-magnesian granules, usually olivine, pyroxene, or iron ore, of random distribution "Williams, Turner, & Gilbert, 1954, p. 22 and Fig. 5A).

Intersertal is similar to intergranular, but "the interstices may be filled with glass, cryptocrystalline material, or non-granular, deuteric and secondary minerals such as serpentine, nontronite, chlorophaeite, chlorite, calcite, zeolites, and sodalite" (Williams, Turner, & Gilbert, 1954, p. 22 and Fig. 5B).

Micrographic: the fine-grained graphic intergrowth of quartz and alkali feldspar; another, perhaps more expressive but looser, term for the same texture is micropegmatitic.

Ophitic: "laths of plagioclase may lie in a matrix of coarse, subhedral augite or pigeonite, so that in thin section the feldspar laths, whose average length does not exceed that of the diameters of the pyroxene grains appear to be largely or entirely enclosed in pyroxene". (Williams, Turner, & Gilbert, 1954, p.20 and Fig. 3B).

Pilotaxitic - see hyalopilitic.

Spherulitic: "radial aggregates of acicular and fibrous minerals." (Williams, Turner, & Gilbert, 1954, p. 24, and Fig. 39B).

Sub-ophitic: as ophitic, but "if the average length of the plagioclase laths exceeds that of the pyroxene grains, and the latter only partly enclose the former." (Williams, Turner, & Gilbert, 1954, p. 20, and Fig. 3C).

Variolitic: "radial or sheaf-like bodies" of "divergent plagioclase fibres, with or without interstitial glass, or of plagioclase fibres intergrown with granules of pyroxene, olivine, or iron ore". (Williams, Turner, & Gilbert, 1954, p. 24, and Fig. 15C).

Vitroclastic: This term describes the texture of a tuff composed of relatively undeformed volcanic glass shards. The texture is illustrated by Figures 48A and 50B in Williams, Turner, & Gilbert (1954).

NOMENCLATURE OF METAMORPHIC ROCKS

INTRODUCTION

The more common metamorphic rock names have a textural connotation - e.g., hornfels, schist, or gneiss. Some, such as marble and quartzite, give an indication of their composition. Still others refer, in a general way, to the metamorphic grade of the rocks concerned - e.g., amphibolite and granulite. There are, fortunately, far fewer metamorphic rock names than there are igneous. Furthermore, the nomenclature is much more simple.

A metamorphic rock name consists of two parts. One refers to the texture, metamorphic grade, or composition - e.g., schist, granulite, or marble, respectively. The other part consists of mineral names, listed in order of increasing abundance. An example of a metamorphic rock name is "quartz-muscovite-biotite schist". This name tells us three, possibly four, things. First, texture - it is a schist, and therefore probably (but not invariably) resultant from regional metamorphism. Second, broad mineral composition. Third, the relative mineral abundance; because the micas are more abundant than quartz, the rock is pelitic, or at least, semi-pelitic. Fourth, the name gives us some idea of the metamorphic grade - it is at least high in the greenschist facies (this is indicated by "muscovite-biotite"). It is obvious, therefore, that a properly thought out metamorphic rock name is almost as valuable as a brief description.

This account of metamorphic rock nomenclature is divided into four parts that deal with contact, dynamic, regional, and some general names. This is followed by a short section that gives some notes on textural terms relating to metamorphic rocks.

NOMENCLATURE

Contact-Metamorphosed Rocks

HORNFELS is a textural name used for rocks that have undergone contact metamorphism. Mostly the rocks consist of a mosaic of equidimensional grains; in rocks that contain tabular or flaky minerals, the crystals commonly have random crystallographic orientation. However, in some hornfels, minerals may have a preferred orientation that reflects some pre-existing structure such as bedding or cleavage.

SPOTTED SLATE. A contact metamorphosed slate of low metamorphic grade that contains small porphyroblasts or aggregates of cordierite, andalusite, or biotite.

SKARN is a lime-silicate rock formed by contact metamorphism of siliceous and aluminous carbonate rocks, or by contact metasomatism of pure limestone or dolomite. The term tactite (Moorhouse, 1959) refers to contact metasomatized limestone at an igneous contact.

BUCHITE is the name given to material formed by the melting of country rock at an igneous contact, or of the melting of xenoliths enclosed in an igneous rock. The rock consists of glass (or its devitrified equivalent), remnants of the original minerals, and some new minerals, such as spinel, cordierite and tridymite, that have crystallized from the glass. The results of melting of country rocks are most commonly seen at the margins of hypabyssal basic intrusions (e.g., Butler, 1961; Wyllie, 1961). In some places this melted material has been mobilized (Walker, 1958).

Very high-grade contact metamorphosed basic igneous rocks are sometimes called "beerbachite". The term is best abandoned; and rocks of this kind should be called hornfels, and appropriate mineralogical qualifying names should be prefixed.

Dynamically Metamorphosed Rocks.

The controlling physical condition in the formation of dynamically metamorphosed rocks is shearing stress. The resulting fabrics in the rocks are thus essentially due to mechanical rupture (i.e. cataclasis) on faults, thrusts, or slides. Dynamic metamorphism commonly occurs at low temperatures; however, in some places, rupture and shearing have generated sufficiently high temperatures for recrystallization or even local melting to happen.

There is a certain amount of confusion in the literature over the nomenclature of these rocks. The notes given below have been culled from summaries given by Knopf (1931), Waters & Campbell (1935), and Christy (1960), and additions have been made from one or two other sources.

The nomenclature is mainly based on textural features:-

a. The presence or absence of porphyroclasts.

b. The amount of porphyroclastic material present.

c. The presence or absence of a laminar structure in the matrix.

d. Whether or not the material is recrystallized, and if recrystallisation has taken place, whether or not it has affected the porphyroclasts.

e. Whether or not fusion has taken place.

The rock names, in relation to texture, are shown in Table C. The rocks are described in the brief notes given below

Ultramylonite

ULTRAMYLONITE is a very finely crushed rock in which even the porphyroclasts have been destroyed. The rock has no laminar structure, and its appearance is homogeneous, rather like that of chert, felsite, or fine quartzite.

Hartschiefer.

HARTSCHIEFER is similar in general characteristics to ultramylonite, but is has a fine laminar structure (see Fig. 2, p.11, Knopf, 1931).

Mylonite

In these notes, the name MYLONITE is used in the same sense as by Lapworth (1885), who originally defined the rock type. A few porphyroclasts are enclosed in a fine-grained, well-laminated matrix. The rock is composed of broken-down grains showing only minor recrystallization. A photomicrograph of mylonite from Lapworth's original locality can be found in Plate I, FigureI, Teall (1918).

Cataclasite

CATACLASITE is fairly similar to mylonite except that the matrix has no laminar structure.

Phyllonite

PHYLLONITE is a rock of phyllitic appearance that is produced by the mylonitic break-down of a coarser-grained rock. Phyllonites contain elongated lenticles or interrupted bands made up of flattened mineral grains that are of approximately the same size and which have a preferred optical orientation. Adjacent lenticles differ greatly in size, but the individual constituents of each lenticle are equigranular.

Protomylonite

PROTOMYLONITE is a coherent crush breccia made up of megascopically visible patches that are commonly lenticular, and which faintly preserve the primary structures of the original rock. On weathered surfaces, the rock resembles conglomerate or arkose. Protomylonite is a general term to cover such rock types as flaser granite, flaser gabbro, etc. A good example of a protomylonite in the Bureau collection (R.15790) was collected in the Jervois Range area (Northern Territory), and described by the writer (Morgan, 1958) as a "flaser aplogranite". The hand specimen, as well as the thin section, is worthy of examination, because it is very like an arkose in general appearance.

TABLE C: DYNAMICALLY METAMORPHOSED ROCKS

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="4">PORPHYROCLASTS</td></tr>
<tr><td rowspan="2">PORPHYROCLASTS RECRYSTALLIZED</td><td colspan="3">PORPHYROCLASTS NOT RECRYSTALLIZED</td></tr>
<tr><td>PORPHYROCLASTS ABSENT</td><td>FEW PORPHYROCLASTS</td><td>ABUNDANT PORPHYROCLASTS</td></tr>
<tr><td rowspan="5">MATRIX</td><td>Banded lenticular structures. Rock more coarse-grained than those below.</td><td rowspan="3"></td><td colspan="2">PHYLLONITE</td><td rowspan="3">PROTOMYLONITE AND FAULT BRECCIA</td></tr>
<tr><td>LAMINATED</td><td>HARTSCHIEFER</td><td>MYLONITE</td></tr>
<tr><td>NON-LAMINATED</td><td>ULTRAMYLONITE</td><td>CATACLASITE</td></tr>
<tr><td>RECRYSTALLIZED</td><td>BLASTOMYLONITE</td><td colspan="3">MYLONITE-GNEISS</td></tr>
<tr><td>FUSED</td><td colspan="3">HYALOMYLONITE</td><td></td></tr>
</table>

Fault Breccia

FAULT BRECCIA consists of angular fragments in a matrix of finely crushed material.

Mylonite-gneiss

MYLONITE GNEISS is a laminated, mylonitic rock whose matrix is extensively recrystallized, but in which the porphyroclasts have not recrystallized.

Blastomylonite

BLASTOMYLONITE is not easily recognizable as being of cataclastic origin, because the matrix and porphyroclasts have been recrystallized. Excellent photomicrographs of recrystallized mylonitic rocks may be found in Waters and Krauskopf (1941); an account of blastomylonitic rocks formed by transcurrent faulting during high-grade regional metamorphism has been given by Sutton and Watson (1959). It must be stressed that the recrystallization in mylonite - gneiss and blastomylonite took place roughly at the time of the movements responsible for the formation of the rock, i,e., crushing and shearing, together with higher temperatures than in the formation of mylonite. If the recrystallization in the mylonite can be shown by field evidence to be due to contact metamorphism, the rock is a MYLONITE HORNFELS.

Hyalomylonite

Locally in a thrust-or fault-zone, the intense friction could cause very high temperatures, and in places the crushed rocks may fuse, forming a rock glass which, in this account, is called HYALOMYLONITE, a term introduced by Scott & Drever (1954). Names synonymous with this are "flinty crush-rock" and "trapshotten gneiss". A Pre-Cambrian glass formed in a fault is described by Philpots & Miller (1963); these writers, unfortunately, call their rock "pseudo-tachylite". This is incorrect. According to the original description by Shand (1916), pseudo-tachylite is not formed by dynamic metamorphism. It occurs (in the Parijs region of the Orange Free State) as dykes and ramifying veins cutting the granitic country rocks, and seeming to intrude them; the veins are not related to shear-planes. Shand concluded that the pseudo-tachylites had originated by either "sudden rupture of the granite without long-continued friction or shearing", or else by "the outrush of incandescent gases through all the fissures in the granite".

Regionally Metamorphosed Rocks

Slate

SLATE is a low-grade metamorphosed argillite with a cleavage resulting from the preferred orientation of mica, chlorite, etc.. The rock is so fine-grained that the grains cannot be seen with the naked eye.

Phyllite

PHYLLITE is very similar in appearance to slate, but in hand specimen has a silky sheen owing to increased grain-size resulting from recrystallization.

Semischist

SEMISCHIST (Williams, Turner, and Gilbert, 1954) is a siliceous or quartz-feldspathic rock formed by the low-grade metamorphism of arenaceous rocks; it consists of an aggregate of quartz and, commonly, feldspar grains in a recrystallized matrix of oriented flakes of micaceous and chloritic minerals. Some use this name to include phyllonitic rocks; in these notes it is restricted to rocks that have suffered fairly strong recrystallization - that is to say, rocks that have been subjected to higher temperatures during deformation than have phyllonites.

Schist

A SCHIST is a cleaved (i.e., schistose) rock in which the individual grains are visible to the naked eye. The schistocity is caused by the preferred orientation of the flaky or prismatic minerals (i.e., chlorite, mica, or amphibole).

Gneiss

GNEISS is a medium- to coarse-grained, irregularly banded and foliated rock in which the schistocity is often poorly defined because of the common preponderance of quartz and feldspar over micaceous minerals.

Granofels

The term GRANOFELS was suggested by Goldsmith (1959); it is a very useful textural name to cover all metamorphic rocks that have a granular texture, but which do not necessarily belong to the granulite facies of metamorphism.

Granulite

In modern usage, the name GRANULITE is restricted to rocks that commonly have a granular texture, and which, by their mineralogy, belong to the granulite facies of metamorphism.

Amphibolite

AMPHIBOLITE is a term with mineralogical and facies connotations, and is used for rocks that consist of hornblende and plagioclase. Amphibolites can be formed from basic igneous rocks, impure calcareous and dolomitic sediments, or by metasomatic alteration of initially pure limestones (e.g., K.R. Walker, et al, 1959).

Rocks containing actinolite instead of hornblende should not, properly, be called amphibolite, because actinolite is typical of the greenschist, not the amphibolite, facies.

Eclogite

ECLOGITE is a rock generally considered to have formed at high temperatures and extremely high pressure. It consists essentially of magnesian garnet (almandine - pyrope) and omphacite (a sodic, aluminous pyroxene).

Some General Names

Marble

MARBLES are metamorphic rocks composed of calcite or dolomite. They generally have a granular texture, although in some, particularly those which have suffered dynamic metamorphism, have lenticular grains showing preferred orientation. Predazzite is a brucite marble, and ophicalcite is serpentine marble.

Metaquartzite

METAQUARTZITE is a lithological term used to describe quartzites that have been formed by metamorphic processes. The rock consists almost entirely of quartz. Under conditions of contact metamorphism, the rock acquires a granoblastic texture and the quartz grains tend to become intricately intergrown with each other. In regional metamorphism, especially under conditions of strong directed pressure, the quartz occurs in elongated grains commonly strained, and with sutured margins, and often showing a preferred optical orientation.

Charnockite

Following Williams, Turner, & Gilbert (1954), CHARNOCKITES are regarded here as a "product of deep-seated metamorphism of quartzo-feldspathic rocks, many of which were originally igneous". The intermediate to basic rocks commonly associated with charnockites are regarded as granulites.

TEXTURAL TERMS

Blastoporphyritic is a term that describes the texture of metamorphosed porphyritic rocks. In these rocks, the recrystallized groundmass encloses relics of the original phenocrysts. The term should not be confused with "porphyroblastic" (see below).

Crystalloblastic is a term that describes in a very general way the fabrics and textural relations resulting from the growth of crystals during metamorphism.

Decussate refers to the apparent random orientation of flaky and prismatic minerals in many hornfels (Harker, 1950, p. 35).

Gneissic structure "is a foliation characterized by alternating layers or lenticles of different composition". (Moorhouse, 1959, 409). I quote further from Moorhouse: "The term gneissocity increasingly used for this structure is both an offence to the ears and a crime against etymology."

Granoblastic describes the texture of metamorphosed rocks that consist of a mosaic of equidimensional grains.

Idioblastic means that a grain in a metamorphic rock has a good crystal shape.

Lepidoblastic: a texture that is due to the predominance of flaky minerals in a schist. Thus, a mica schist has a lepidoblastic texture, but we generally say that the rocks has a schistosity or foliation.

Mimetic texture is one in which part or all of the previous structure or texture in a rock is fairly well preserved in spite of recrystallization during metamorphism and metasomatism. One commonly finds that pelitic hornfels resulting from the metamorphism of false-cleaved, laminated slate - siltstone rocks have relict textures preserved in this way.

Nematoblastic is a texture that is due to the predominance of prismatic minerals in a schist. Thus, hornblende schists commonly have nematoblastic textures.

Poikiloblastic "texture denotes a porphyroblast containing inclusions of other minerals" (Moorhouse, 1959, p.409)

Porphyroblasts "are large crystals that have grown in a finer-grained rock during metamorphism or metasomatism" (Moorhouse, 1959).

Porphyroclast " is a large grain surviving in an otherwise granulated or mylonitized rock" (Moorhouse, 1959).

Xenoblastic means that a grain in a metamorphic rock has no crystal shape.

APPENDIX I

NOCKOLDS' AVERAGES OF CHEMICAL ANALYSES OF IGNEOUS ROCKS

The tables presented in this appendix are Nockolds' averages of chemical analyses of igneous rocks, and are quoted from his paper (1954). They are given here for the convenience of geologists using the igneous rock classification given in this report, and also to enable geologists to compare analyses they have had done with the average of the particular rock type concerned.

The tables include C.I.P.W. norms. The normative minerals are as follows:

qz - Quartz
or - Orthoclase
ab - Albite
an - Anorthite
lc - Leucite
ne - Nepheline
c - Corundum
ac - Acmite

$CaSiO_3$ - Wollastonite
$MgSiO_3$ - Enstatite
$FeSiO_3$ - Ferrosilite
Ca_2SiO_4 - Calcium metasilicate
Mg_2SiO_4 - Forsterite
Fe_2SiO_4 - Fayalite

mt - Magnetite
il - Ilmenite
ap - Apatite
hm - Hematite
ci - Calcite
fl - fluorite
zr - zircon

Brief notes on some of the rock names used by Nockolds in the tables now follow. "Alkali trachyte lavas corresponding with shonkinite" (Table 3, analysis 4) are termed "mela-trachyte" in this report (Plate I, and p. 14).

Table 9, on Dunites and Peridotites, contains averages of chemical analyses of peridotites (4, 5, I, II, and IIA). Some of these analyses probably include olivinite, as defined in this classification (Plate I, Fig. C, and p. 18). Kimberlite (Table 9, analyses 6, 6A, 7, 7A) is a "mica peridotite".

The "nepheline syenites" shown in Tables 10 and 10A are termed "foyaite" in the classification presented here (Plate I, and p. 15).

Essexite and glenmuirite, in Table II, are rock types that are included with "theralite" and "teschenite" the present classification; the reason for this is given on page Similarly, ordanchite, the fine-grained form of essexite, is included with "tephrite" (pp.14,15) in this classification.

In Table 12, bekinkinite (analysis VIII) is a "barkevikite melteigite" (Plate I and p. 16 in this report; Johannsen, 1939, Vol. IV, p. 332) Tawite (analysis X) is a sodalite ijolite" (Plate I, p. 16 in this report; Johannsen, 1939, Vol. IV, p. 319) Turjaite (analysis XI) is a melilite ijolite. (Plate I, p. 16 of this report; Vol.IV, p. 323 in Johannsen).

Italite, in Table 13, analysis 7, is an extremely "leucocratic leucitite" (Plate I, p. 16 of this report p. 311, Vol.IV of Johannsen). Etindite (analysis 12) is a "leucite nephelinite" (Plate I, p. 16 of this report; Johannsen, 1939 Vol.IV, p. 367).

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TABLE 1.—GRANITES AND RHYOLITES

	CALC-ALKALI GRANITES AND RHYOLITE						ALKALI GRANITES AND RHYOLITE					
	1.	2.	3.	4.	I.	II.	5.	6.	7.	8.	III.	IV.
SiO_2	71·59	73·28	70·56	71·31	72·08	73·66	73·84	74·63	75·01	70·46	73·86	74·57
TiO_2	0·31	0·30	0·40	0·96	0·37	0·22	0·16	0·14	0·17	0·34	0·20	0·17
Al_2O_3	14·69	13·33	14·00	12·67	13·86	13·45	14·29	13·86	13·16	14·37	13·75	12·58
Fe_2O_3	0·56	0·87	0·91	0·91	0·86	1·25	0·34	0·52	0·94	1·09	0·78	1·30
FeO	1·56	1·38	2·41	3·53	1·67	0·75	0·75	0·89	0·88	2·48	1·13	1·02
MnO	0·07	0·05	0·06	0·02	0·06	0·03	0·05	0·04	0·07	0·05	0·05	0·05
MgO	0·54	0·50	0·48	0·37	0·52	0·32	0·21	0·33	0·24	0·22	0·26	0·11
CaO	1·28	1·17	1·63	1·74	1·33	1·13	0·69	0·57	0·56	1·19	0·72	0·61
Na_2O	2·97	2·96	3·56	3·06	3·08	2·99	3·61	3·05	3·48	4·19	3·51	4·13
K_2O	5·48	5·52	5·39	5·04	5·46	5·35	5·21	5·16	5·01	5·18	5·13	4·73
H_2O+	0·69	0·50	0·50	0·33	0·53	0·78	0·60	0·63	0·37	0·37	0·47	0·66
P_2O_5	0·26	0·14	0·10	0·06	0·18	0·07	0·25	0·18	0·11	0·06	0·14	0·07
qz	29·5	31·2	24·5	29·0	29·2	33·2	31·7	35·4	34·1	22·2	32·2	31·1
or	32·8	32·8	31·7	29·5	32·2	31·7	30·6	30·6	29·5	30·6	30·0	27·8
ab	25·2	25·2	29·9	25·7	26·2	25·1	30·4	25·7	29·3	35·6	29·3	35·1
an	4·5	5·0	6·4	6·4	5·6	5·0	1·7	1·9	2·2	5·0	2·8	2·0
C	2·1	0·5	–	–	0·8	0·9	2·1	2·5	1·3	–	1·4	–
$CaSiO_3$	–	–	0·3	0·7	–	–	–	–	–	0·1	–	0·1
$MgSiO_3$	1·3	1·3	1·2	0·9	1·3	0·8	0·5	0·8	0·6	0·5	0·6	0·3
$FeSiO_3$	1·9	1·3	3·0	4·1	1·7	–	0·9	1·1	0·7	3·1	1·1	0·6
ac	–	–	–	–	–	–	–	–	–	–	–	–
mt	0·9	1·2	1·4	1·4	1·4	1·9	0·5	0·7	1·4	1·6	1·2	1·9
il	0·6	0·6	0·8	1·8	0·8	0·5	0·3	0·3	0·3	0·6	0·5	0·3
hm	–	–	–	–	–	–	–	–	–	–	–	–
ap	0·7	0·3	0·3	0·2	0·4	0·2	0·6	0·4	0·3	0·2	0·3	0·2
No. of analyses	(21)	(37)	(6)	(4)	(72)	(22)	(6)	(17)	(12)	(8)	(48)	(21)
	MUSCOVITE-BIOTITE GRANITE	BIOTITE GRANITE	BIOTITE-HORNBLENDE GRANITE	HYPERSTHENE-BEARING GRANITE	AVERAGE CALC-ALKALI GRANITE	AVERAGE CALC-ALKALI RHYOLITE + RHYOLITE-OBSIDIAN	MUSCOVITE GRANITE	MUSCOVITE-BIOTITE ALKALI GRANITE	BIOTITE ALKALI GRANITE	FERROHASTINGSITE GRANITE	AVERAGE ALKALI GRANITE	AVERAGE ALKALI RHYOLITE + RHYOLITE-OBSIDIAN

* Also 0·6 of Na-metasilicate

TABLE 1.—*Continued*

PERALKALINE GRANITES AND RHYOLITE							
9.	10.	11.	12.	13.	V.	VI.	
73·05	71·66	70·68	71·47	67·29	71·08	72·31	SiO_2
0·24	0·36	0·41	0·39	0·68	0·40	0·42	TiO_2
10·62	9·73	10·90	13·91	12·26	11·26	10·88	Al_2O_3
3·04	5·34	6·06	1·91	4·25	4·28	2·92	Fe_2O_3
2·98	2·75	0·90	1·28	3·03	2·19	2·42	FeO
0·21	0·12	0·07	0·12	0·08	0·11	0·14	MnO
0·10	0·32	0·22	0·32	0·33	0·25	0·16	MgO
0·60	0·66	0·92	0·64	1·62	0·84	0·68	CaO
4·23	4·45	5·36	5·63	5·42	4·92	5·17	Na_2O
4·48	4·12	4·13	3·93	4·46	4·21	4·42	K_2O
0·37	0·42	0·29	0·34	0·48	0·39	0·45	H_2O+
0·08	0·07	0·06	0·06	0·10	0·07	0·03	P_2O_5
29·9	30·0	25·5	22·2	17·0	26·2	26·4	qz
26·7	24·5	24·5	23·4	26·7	28·0	26·1	or
29·3	26·7	33·0	47·7	38·2	34·6	31·4	ab
–	–	–	0·8	–	–	–	an
–	–	–	–	–	–	–	C
1·0	1·2	1·6	0·6	3·0	1·4	1·4	$CaSiO_3$
0·3	0·8	0·5	0·3	0·8	0·6	0·4	$MgSiO_3$
4·6	2·9	–	2·9	2·8	1·7	4·0	$FeSiO_3$
5·5	9·7	10·6	–	6·4	6·0	8·3	ac
1·6	2·8	2·1	2·8	3·0	3·2	–	mt
0·5	0·8	0·8	0·8	1·4	0·8	0·8	il
–	–	1·0	–	–	–	–	hm
0·2	0·2	0·2	0·2	0·3	0·2	0·1 *	ap
(10)	(14)	(11)	(9)	(8)	(53)	(39)	No. of analyses
RIEBECKITE (or OSANNITE) GRANITE	RIEBECKITE-AEGIRINE GRANITE	AEGIRINE GRANITE	ARFVEDSONITE-AEGIRINE GRANITE	LANEITE-AEGIRINE GRANITE	AVERAGE PERALKALINE GRANITE	AVERAGE PERALKALINE RHYOLITE + RHYOLITE-OBSIDIAN	

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Table 2.—Adamellites and Dellenite, Granodiorites and Rhyodacite, Tonalites and Dacite

	ADAMELLITES AND DELLENITE						GRANODIORITES AND RHYODACITE					
	1.	2.	3.	4.	I.	II.	5.	6.	7.	8.	III.	IV.
SiO_2	71·86	71·03	65·88	68·91	69·15	70·15	70·47	68·97	65·50	62·64	66·88	66·27
TiO_2	0·30	0·39	0·81	0·76	0·56	0·42	0·30	0·45	0·61	1·32	0·57	0·66
Al_2O_3	14·73	14·31	15·07	13·93	14·63	14·41	15·50	15·47	15·65	15·82	15·66	15·39
Fe_2O_3	0·64	0·95	1·74	1·48	1·22	1·68	0·63	1·12	1·63	1·59	1·33	2·14
FeO	1·61	1·96	2·73	3·20	2·27	1·55	2·12	2·05	2·79	4·31	2·59	2·23
MnO	0·04	0·06	0·08	0·04	0·06	0·06	0·03	0·06	0·09	0·09	0·07	0·07
MgO	0·67	0·75	1·38	1·02	0·99	0·63	0·65	1·15	1·86	2·83	1·57	1·57
CaO	1·51	1·89	3·36	3·06	2·45	2·15	1·91	2·99	4·10	4·72	3·56	3·68
Na_2O	3·18	3·33	3·53	3·00	3·35	3·65	4·12	3·69	3·84	3·37	3·84	4·13
K_2O	4·64	4·66	4·64	4·10	4·58	4·50	3·59	3·16	3·01	2·62	3·07	3·01
H_2O+	0·66	0·50	0·52	0·38	0·54	0·68	0·52	0·70	0·69	0·42	0·65	0·68
P_2O_5	0·16	0·17	0·26	0·12	0·20	0·12	0·16	0·19	0·23	0·27	0·21	0·17
qz	30·7	27·7	18·8	27·0	24·6	26·1	27·1	26·2	20·0	17·7	21·9	20·6
or	27·2	27·8	27·2	24·5	27·2	26·7	21·1	18·9	17·8	15·6	18·3	17·8
ab	27·3	28·3	29·9	25·2	28·3	30·9	34·6	31·4	32·5	28·3	32·5	35·1
an	6·7	8·6	11·7	12·2	11·1	9·5	8·6	14·2	16·4	20·3	16·4	14·5
C	1·9	0·5	—	—	—	—	1·7	0·7	—	—	—	—
$CaSiO_3$	—	—	1·4	0·9	—	0·2	—	—	0·9	0·6	—	1·3
$MgSiO_3$	1·7	1·9	3·4	2·5	2·5	1·6	1·6	2·9	4·6	7·1	3·9	3·9
$FeSiO_3$	2·0	2·2	2·4	3·3	2·2	0·8	2·8	2·2	2·9	4·7	2·9	1·3
mt	0·9	1·4	2·6	2·1	1·9	2·5	0·9	1·6	2·3	2·3	1·9	3·0
il	0·6	0·8	1·5	1·5	1·1	0·8	0·6	0·8	1·2	2·4	1·1	1·4
ap	0·3	0·3	0·6	0·3	0·5	0·3	0·3	0·4	0·6	0·7	0·5	0·3
No. of analyses	(22)	(45)	(41)	(11)	(121)	(58)	(20)	(36)	(65)	(10)	(137)	(115)
	MUSCOVITE-BIOTITE ADAMELLITE	BIOTITE ADAMELLITE	HORNBLENDE-BIOTITE ADAMELLITE	HYPERSTHENE-BEARING ADAMELLITE	AVERAGE ADAMELLITE	AVERAGE DELLENITE + DELLENITE-OBSIDIAN	MUSCOVITE-BIOTITE GRANODIORITE	BIOTITE GRANODIORITE	HORNBLENDE-BIOTITE GRANODIORITE	HYPERSTHENE-BEARING GRANODIORITE	AVERAGE GRANODIORITE	AVERAGE RHYODACITE + RHYODACITE-OBSIDIAN

Table 2.—*Continued*

TONALITES AND DACITE						
9.	10.	11.	12.	V.	VI.	
70·63	69·35	64·41	63·92	66·15	63·58	SiO_2
0·37	0·48	0·62	1·03	0·62	0·64	TiO_2
15·69	14·93	15·95	15·60	15·56	16·67	Al_2O_3
0·86	1·19	1·46	1·70	1·36	2·24	Fe_2O_3
1·40	3·07	3·81	4·61	3·42	3·00	FeO
0·04	0·06	0·10	0·07	0·08	0·11	MnO
0·83	0·94	2·45	2·54	1·94	2·12	MgO
2·82	3·04	5·36	5·23	4·65	5·53	CaO
4·91	4·67	3·39	3·54	3·90	3·98	Na_2O
1·68	1·48	1·45	1·22	1·42	1·40	K_2O
0·62	0·64	0·80	0·33	0·69	0·56	H_2O+
0·15	0·15	0·20	0·21	0·21	0·17	P_2O_5
28·3	27·4	22·7	22·1	24·1	19·6	qz
10·0	8·9	8·3	7·2	8·3	8·3	or
41·4	39·3	28·8	29·9	33·0	34·1	ab
13·1	14·2	23·9	23·1	20·8	23·3	an
1·0	0·4	—	—	—	—	C
—	—	0·6	0·7	0·3	1·3	$CaSiO_3$
2·1	2·3	6·1	6·3	4·9	5·3	$MgSiO_3$
1·1	3·8	4·9	5·4	4·1	2·8	$FeSiO_3$
1·4	1·9	2·1	2·5	2·1	3·3	mt
0·8	0·9	1·2	2·0	1·2	1·2	il
0·3	[illegible]	0·5	0·5	0·5	0·3	ap
(9)	(11)	(22)	(10)	(58)	(50)	No. of analyses
MUSCOVITE-BIOTITE TONALITE	BIOTITE TONALITE	HORNBLENDE-BIOTITE TONALITE	HYPERSTHENE-BEARING TONALITE	AVERAGE TONALITE	AVERAGE DACITE + DACITE-OBSIDIAN	

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Table 3.—Syenites and Trachytes

	CALC-ALKALI SYENITE AND TRACHYTE			ALKALI SYENITES AND TRACHYTES						PERALKALINE SYENITE AND TRACHYTE		
	I.	II.	III.	1.	IV.	V.	2.	3.	4.	5.	VI.	VII.
SiO_2	59·41	52·16	58·31	61·54	61·86	61·95	50·16	49·79	50·26	63·75	61·65	61·65
TiO_2	0·83	1·61	0·66	0·59	0·58	0·73	1·2	0·84	1·22	0·66	0·52	0·52
Al_2O_3	17·12	12·82	18·05	17·45	16·91	18·03	13·20	11·06	13·29	15·32	14·73	17·22
Fe_2O_3	2·19	2·63	2·54	1·82	2·32	2·33	4·24	3·36	3·27	4·11	4·56	3·16
FeO	2·83	6·90	2·02	3·10	2·63	1·51	5·25	5·72	4·63	1·53	3·68	1·81
MnO	0·08	0·19	0·14	0·09	0·11	0·13	0·33	0·13	0·10	0·17	0·20	0·19
MgO	2·02	7·20	2·07	0·74	0·96	0·63	7·15	9·78	7·98	0·36	0·70	0·45
CaO	4·06	8·21	4·25	2·39	2·54	1·89	8·67	9·61	9·30	1·52	1·87	1·58
Na_2O	3·92	2·61	3·85	5·59	5·46	6·55	2·92	2·18	2·19	7·28	6·69	6·92
K_2O	6·53	4·39	7·38	5·97	5·91	5·53	5·37	5·23	5·27	4·62	4·65	5·80
H_2O+	0·63	0·58	0·53	0·59	0·53	0·54	0·75	1·34	1·81	0·53	0·58	0·58
P_2O_5	0·38	0·70	0·20	0·19	0·19	0·18	0·76	0·96	0·68	0·15	0·17	0·12
q	2·0	—	—	0·1	1·7	—	—	—	—	3·3	1·6	—
or	38·4	26·1	43·9	35·6	35·0	32·8	31·7	30·6	31·1	27·2	27·8	34·5
ab	33·0	22·0	28·8	47·2	46·1	54·0	9·4	6·8	10·0	52·9	49·2	50·3
an	10·0	10·0	9·7	4·7	4·2	3·3	7·0	5·3	10·8	—	—	—
ne	—	—	2·0	—	—	0·6	8·2	6·3	4·5	—	—	3·1
ac	—	—	—	—	—	—	—	—	—	7·8	6·5	1·9
$CaSiO_3$	3·0	10·8	4·2	2·7	3·0	2·1	13·1	15·0	12·8	2·7	3·5	3·0
$MgSiO_3$	5·0	6·9	3·2	1·8	2·4	1·6	9·4	10·7	9·6	0·9	1·7	1·1
$FeSiO_3$	2·1	3·2	0·5	3·3	2·1	—	2·5	2·9	1·8	0·8	4·4	0·8
Mg_2SiO_4	—	7·7	1·4	—	—	—	5·9	9·5	7·2	—	—	—
Fe_2SiO_4	—	4·1	0·2	—	—	—	1·8	2·9	1·5	—	—	—
mt	3·3	3·7	3·7	2·5	3·3	3·3	6·0	4·9	4·9	2·1	3·5	3·7
il	1·5	3·0	1·2	1·2	1·2	1·4	2·3	1·5	2·3	1·2	0·9	0·9
ap	1·0	1·7	0·5	0·5	0·5	0·4	1·8	2·3	1·7	0·3	0·4	0·3
No of analyses	(18)	(6)	(24)	(11)	(25)	(15)	(8)	(9)	(6)	(13)	(47)	(12)
	AVERAGE CALC ALKALI SYENITE (LEUCOCRATIC)	AVERAGE CALC-ALKALI SYENITE (MESOTYPE + MELANOCRATIC)	AVERAGE CALC-ALKALI TRACHYTE	FERRO HASTINGSITE SYENITE	AVERAGE ALKALI SYENITE	AVERAGE ALKALI TRACHYTE	AUGITE-BIOTITE SHONKINITE	AUGITE-BIOTITE-OLIVINE SHONKINITE	ALKALI TRACHYTE LAVAS CORRESPONDING WITH SHONKINITE	AEGIRINE SYENITE	AVERAGE PERALKALINE SYENITE	AVERAGE PERALKALINE TRACHYTE

Table 4.—Monzonites and Latite

	1.	2.	3.	4.	I.	II.	5.
SiO_2	58·45	53·39	51·74	54·58	55·36	54·02	57·01
TiO_2	1·40	1·07	1·14	0·84	1·12	1·18	1·67
Al_2O_3	15·65	16·11	14·76	16·83	16·58	17·22	17·88
Fe_2O_3	3·34	2·74	1·86	3·02	2·57	3·83	2·30
FeO	3·99	4·64	6·96	4·71	4·58	3·98	4·18
MnO	0·09	0·11	0·19	0·13	0·13	0·12	0·14
MgO	2·51	4·84	7·33	3·72	3·67	3·87	1·54
CaO	5·55	7·68	8·42	6·62	6·76	6·76	4·39
Na_2O	3·47	3·44	2·68	3·52	3·51	3·32	5·80
K_2O	4·61	4·75	3·93	4·79	4·68	4·43	4·03
H_2O+	0·43	0·73	0·52	0·82	0·60	0·78	0·43
P_2O_5	0·51	0·50	0·47	0·42	0·44	0·49	0·61
q	7·7	—	—	—	—	0·5	—
or	27·2	27·8	23·3	26·4	27·8	26·1	23·9
ab	29·3	24·6	20·4	29·3	29·3	27·8	46·6
an	13·3	14·7	16·4	16·1	15·8	19·2	10·6
ne	—	2·3	1·4	—	—	—	1·4
$CaSiO_3$	4·5	8·5	9·3	5·8	6·3	4·5	3·0
$MgSiO_3$	6·3	5·7	5·7	5·1	8·0	9·7	1·6
$FeSiO_3$	2·4	2·1	3·0	2·9	4·1	2·4	1·3
Mg_2SiO_4	—	4·5	8·8	2·9	0·8	—	1·5
Fe_2SiO_4	—	1·8	5·1	1·6	0·4	—	1·4
mt	4·9	3·9	2·8	4·4	3·7	5·6	3·3
il	2·7	2·1	2·1	1·5	2·1	2·3	3·2
ap	1·2	1·2	1·1	1·0	1·0	1·2	1·5
No. of analyses	(5)	(11)	(6)	(9)	(46)	(42)	(15)
	HORNBLENDE-BIOTITE MONZONITE	AUGITE-BIOTITE MONZONITE	AUGITE-BIOTITE-OLIVINE MONZONITE	PYROXENE-HORNBLENDE-BIOTITE MONZONITE	AVERAGE MONZONITE	AVERAGE LATITE	LARVIKITE

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TABLE 5.—MANGERITES AND DOREITES

	MANGERITES AND DOREITE (CALC-ALKALI)						MANGERITES AND DOREITES (ALKALI)						
	1.	2.	3.	4.	I.	II.	5.	6.	7.	8.	9.	III.	IV.
SiO_2	55·86	55·83	55·06	54·18	54·66	56·00	58·75	46·82	55·12	54·28	48·09	50·00	51·32
TiO_2	1·09	0·83	1·30	1·24	1·09	1·29	1·44	2·70	1·58	1·89	2·87	2·29	2·29
Al_2O_3	17.22	16·51	16·71	17·94	16·98	16·81	17·72	15·64	17·78	16·57	15·91	16·31	16·64
Fe_2O_3	2·92	3·09	3·40	3·09	3·26	3·74	2·79	4·57	3·11	2·95	3·39	3·99	3·24
FeO	5·01	5·88	5·48	4·66	5·38	4·36	4·46	7·10	4·98	6·74	7·40	6·26	6·48
MnO	0·13	0·14	0·12	0·14	0·14	0·13	0·20	0·20	0·14	0·17	0·18	0·20	0·16
MgO	3·42	3·35	4·02	3·48	3·95	3·39	1·96	5·64	2·18	2·45	6·15	4·46	4·80
CaO	6·75	6·44	6·79	7·13	6·99	6·87	5·24	9·77	5·07	5·05	8·80	8·33	7·47
Na_2O	3·57	4·12	3·46	3·95	3·76	3·56	5·20	3·82	5·70	5·68	3·95	4·27	4·78
K_2O	2·82	3·00	2·72	3·24	2·76	2·60	3·13	2·11	2·78	2·76	1·93	2·43	2·33
H_2O+	0·79	0·56	0·51	0·54	0·60	0·92	0·61	0·94	0·58	0·68	0·66	0·83	0·63
P_2O_5	0·42	0·25	0·43	0·41	0·43	0·33	0·50	0·69	0·61	0·78	0·67	0·63	0·66
qz	5·6	1·9	4·7	0·1	2·0	7·2	1·6	—	—	—	—	—	—
or	16·7	17·8	16·1	18·9	16·7	15·6	19·3	12·2	16·7	16·7	11·1	14·4	13·9
ab	29·9	34·6	29·3	33·5	31·9	29·9	44·0	22·0	47·2	47·2	27·2	29·9	35·1
an	22·8	17·8	22·0	21·4	21·1	22·2	15·9	19·5	14·7	11·7	20·0	18·1	17·0
ne	—	—	—	—	—	—	—	5·4	0·6	0·3	3·4	3·4	2·8
$CaSiO_3$	3·2	5·1	3·7	4·8	4·5	4·1	2·9	10·1	3·6	3·2	7·9	8·2	6·2
$MgSiO_3$	8·5	8·4	10·0	8·7	9·9	8·5	4·9	6·8	1·9	1·5	5·2	5·3	3·8
$FeSiO_3$	5·2	7·2	5·3	4·3	5·4	3·0	3·8	2·5	1·6	1·7	2·1	2·4	2·0
Mg_2SiO_4	—	—	—	—	—	—	—	5·0	2·4	3·2	7·1	4·0	4·9
Fe_2SiO_4	—	—	—	—	—	—	—	2·0	2·0	3·9	3·3	1·8	2·9
mt	4·2	4·4	4·9	4·4	4·9	5·3	4·2	6·7	4·4	4·4	4·9	5·8	4·6
il	2·1	1·5	2·4	2·3	2·1	2·4	2·7	5·2	2·9	3·6	5·5	4·4	4·4
ap	1·0	0·7	1·0	1·0	1·0	0·8	1·2	1·7	1·44	1·9	1·6	1·5	1·6
No of analyses	(9)	(10)	(11)	(7)	(56)	(38)	(17)	(36)	(26)	(10)	(40)	(53)	(76)
	HORNBLENDE BIOTITE MANGERITE	PYROXENE - HORNBLENDE - BIOTITE MANGERITE	PYROXENE - BIOTITE MANGERITE	AUGITE - BIOTITE MANGERITE	AVERAGE MANGERITE	AVERAGE DOREITE	ALKALI MANGERITE OF AKER TYPE	ALKALI MANGERITE OF HUHUM TYPE	VOLCANIC EQUIVALENTS & AKER TYPE	MUGEARITE	VOLCANIC EQUIVALENTS & HUHUM TYPE	AVERAGE ALKALI MANGERITE	AVERAGE ALKALI DOREITE

TABLE 6.—DIORITES AND ANDESITES

	1.	2.	3.	I.	II.	III.	IV
SiO_2	52·97	48·55	52·63	51·86	54·20	51·43	47 63
TiO_2	1·60	1·91	1·29	1·50	1·31	2·60	2·84
Al_2O_3	18·19	16·52	15·58	16·40	17·17	13·05	14·57
Fe_2O_3	1·97	3·16	2·27	2·73	3·48	3·36	3 97
FeO	6·29	8·00	6·94	6·97	5·49	9·74	7 83
MnO	0·13	0·22	0·17	0·18	0·15	0·19	0 18
MgO	4·75	6·71	6·88	6·12	4·36	5·28	7 25
CaO	7·61	9·49	8·65	8·40	7·92	8·78	9 48
Na_2O	3·50	3·10	3·16	3·36	3·67	3·18	3·75
K_2O	1·65	0·95	1·42	1·33	1·11	1·04	1·20
H_2O+	1·00	1·11	0·56	0 80	0·86	0·87	0·78
P_2O_5	0·34	0·28	0·45	0·35	0·28	0·48	0·52
qz	2·2	—	0·6	0·3	5·7	3·2	—
or	9·4	5·6	8·3	7·8	6·7	6·1	7·2
ab	29·3	26·2	26·7	28·3	30·9	27·2	27·2
an	29·2	28·4	24·2	25·8	27·2	18·1	19·5
ne	—	—	—	—	—	—	2 3
$CaSiO_3$	2·7	7·1	6·6	5·6	4·2	9·2	10·1
$MgSiO_3$	11·9	9·2	17·2	15·3	10·9	13·2	6·8
$FeSiO_3$	7·5	5·0	9·0	8·5	5·3	11·1	2·5
Mg_2SiO_4	—	5·3	—	—	—	—	8·0
Fe_2SiO_4	—	3·3	—	—	—	—	3·3
mt	3·0	4·6	3·3	3·9	5·1	4·9	5·8
il	3·0	3·6	2·4	2·9	2·4	5·0	5·3
ap	0·8	0·7	1·0	0·8	0·7	1·1	1·2
No. of analyses	(16)	(10)	(11)	(50)	(49)	(26)	(37)
	HORNBLENDE - BIOTITE DIORITE	HORNBLENDE DIORITE + HORNBLENDE-AUGITE DIORITE	PYROXENE-MICA DIORITE	AVERAGE DIORITE	AVERAGE ANDESITE	AVERAGE THOLEIITIC ANDESITE	AVERAGE ALKALI ANDESITE

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TABLE 7.—GABBROS AND RELATED ROCKS, BASALTS

TABLE 7.—*Continued*

	1.	2.	3	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX	X.	XI	XII.
SiO_2	46·01	50·78	46·63	48·36	50·28	43·94	54·54	49·96	43·84	50·83	47·90	45·78	46·77	43·69	51·33
TiO_2	1·55	1·15	0·37	1·32	0·89	2·86	0·52	0·14	0·67	2·03	1·65	2·63	3·00	2·12	1·10
Al_2O_3	17·22	15·68	17·38	16·84	17·07	14·87	25·72	28·94	15·46	14·07	11·84	14·64	14·65	9·06	15·04
Fe_2O_3	2·40	2·26	1·91	2·55	1·30	4·35	0·83	0·80	2·20	2·88	2·32	3·16	3·71	3·46	3·40
FeO	7·68	7·41	8·20	7·92	7·46	7·50	1·46	1·45	9·24	9·00	9·80	8·73	7·94	9·43	5·70
MnO	0·15	0·18	0·14	0·18	0·14	0·15	0·02	0·07	0·15	0·18	0·15	0·20	0·15	0·16	0·16
MgO	7·45	8·35	10·05	8·06	9·27	9·31	0·83	0·84	19·71	6·34	14·07	9·39	6·82	19·68	6·01
CaO	10·80	10·85	11·36	11·07	9·72	12·57	9·62	14·01	8·10	10·42	9·29	10·74	12·42	9·18	10·07
Na_2O	2·28	2·14	2·33	2·26	1·96	2·32	4·66	2·73	1·53	2·23	1·66	2·63	2·59	1·49	2·76
K_2O	0·53	0·56	0·40	0·55	0·63	0·92	1·36	0·42	0·58	0·82	0·54	0·95	1·07	0·69	0·82
H_2O+	1·10	0·48	0·63	0·64	0·47	0·66	0·53	0·55	0·50	0·91	0·59	0·76	0·51	0·74	0·45
P_2O_5	0·33	0·18	0·12	0·24	0·21	0·44	0·11	0·09	0·18	0·23	0·19	0·39	0·37	0·30	0·16
Q	—	0·9	—	—	—	—	1·4	1·7	—	3·5	—	—	—	—	2·2
or	2·8	3·3	2·2	3·3	3·3	5·6	6·7	2·2	3·3	5·0	2·8	6·1	6·7	3·9	5·0
ab	19·4	17·8	17·3	18·9	16·8	12·1	39·3	23·1	11·5	18·9	14·1	18·3	19·4	11·0	23·6
an	35·3	31·7	37·2	34·2	37·8	27·5	45·9	65·3	28·9	25·9	23·4	24·7	25·0	16·1	32·9
ne	—	—	—	—	—	4·0	—	—	—	—	—	2·3	1·4	0·9	—
$CaSiO_3$	6·7	8·8	7·7	8·0	3·7	13·0	0·3	1·5	4·4	10·3	9·1	10·8	14·2	11·5	6·4
$MgSiO_3$	15·4	20·9	7·8	14·0	21·4	9·3	2·1	2·1	3·1	15·8	20·5	7·1	9·4	8·4	15·0
$FeSiO_3$	7·9	10·3	3·9	7·4	10·6	2·5	1·2	1·8	0·9	11·2	7·9	2·9	3·7	2·0	6·1
Mg_2SiO_4	2·2	—	12·0	4·3	1·3	9·8	—	—	32·5	—	10·3	11·5	5·4	28·6	—
Fe_2SiO_4	1·2	—	6·5	2·5	0·6	2·9	—	—	10·2	—	4·4	5·0	2·1	7·1	—
mt	4·2	3·3	2·8	3·7	1·9	6·3	1·2	1·2	3·2	4·2	3·3	4·6	5·3	5·1	4·9
il	2·9	2·1	1·8	2·4	1·7	5·5	0·9	0·3	1·4	3·8	3·2	5·0	5·8	4·0	2·1
ap	0·8	0·4	0·3	0·6	0·5	1·0	0·3	0·2	0·4	0·5	0·4	1·0	0·9	0·6	0·3
No. of analyses	(15)	(38)	(53)	(160)	(39)	(42)	(9)	(8)	(9)	(137)	(28)	(96)	(22)	(31)	(56)
	HORNBLENDE GABBRO	PYROXENE GABBRO	OLIVINE GABBRO	AVERAGE GABBRO	AVERAGE NORITE	AVERAGE ALKALI GABBRO	ANORTHOSITE (in massifs)	ANORTHOSITE (localised)	TROCTOLITE	NORMAL THOLEIITIC BASALT (AND DOLERITE)	THOLEIITIC OLIVINE BASALT	NORMAL ALKALI BASALT (AND DOLERITE)	ALKALI BASALT WITHOUT OLIVINE	OLIVINE-RICH ALKALI BASALT	"CENTRAL BASALT"

TABLE 8.—PERKNITES

	1.	2.	3.	4.	I.	II.	5.	6.	7.	8.	9.
SiO_2	48·86	54·65	51·84	45·02	50·50	41·55	43·72	41·83	49·67	42·00	45·40
TiO_2	0·89	0·17	0·32	1·00	0·53	3·31	2·51	1·54	0·67	2·86	1·83
Al_2O_3	4·53	2·19	4·47	4·38	4·10	7·25	7·54	14·94	7·01	11·39	8·38
Fe_2O_3	1·93	0·90	2·23	4·40	2·44	6·80	5·55	4·09	2·64	5·27	5·05
FeO	4·82	8·63	7·32	8·02	7·37	7·77	5·67	5·28	9·10	10·30	7·72
MnO	0·13	0·15	0·14	0·09	0·13	0·20	0·17	0·18	0·15	0·24	0·20
MgO	15·35	31·08	21·41	19·04	21·71	13·02	14·20	15·13	12·80	12·35	16·83
CaO	21·89	1·60	10·99	16·91	12·00	16·93	15·47	13·81	6·50	11·31	12·02
Na_2O	0·55	0·14	0·56	0·36	0·45	1·38	0·68	0·64	0·70	1·80	1·08
K_2O	0·34	0·08	0·17	0·27	0·21	0·70	2·76	0·35	0·13	0·84	0·39
H_2O+	0·63	0·31	0·49	0·42	0·47	0·50	0·77	0·95	0·42	1·31	0·94
P_2O_5	0·08	0·10	0·06	—	0·09	0·59	0·74	0·06	0·11	0·33	0·16
F	—	—	—	—	—	—	0·38	—	—	—	—
or	—	0·6	1·1	—	1·1	—	2·8	2·2	0·6	5·00	2·2
ab	—	1·0	4·7	—	3·7	—	—	3·7	5·8	8·9	9·4
an	8·9	5·3	9·2	9·5	8·6	11·4	9·2	35·6	15·8	20·6	16·7
lc	1·3	—	—	1·3	—	3·0	10·9	—	—	—	—
ne	2·6	—	—	1·7	—	6·5	3·1	2·0	—	3·4	—
$CaSiO_3$	37·9	0·9	18·8	29·0	21·0	27·4	25·0	13·4	6·5	13·9	17·5
$MgSiO_3$	29·2	70·3	44·9	21·5	40·4	21·8	20·7	10·7	41·8	9·6	20·6
$FeSiO_3$	4·6	13·2	9·4	4·6	8·1	2·4	1·2	1·2	10·3	3·2	3·4
Ca_2SiO_4	2·6	—	—	1·5	—	1·1	—	—	—	—	—
Mg_2SiO_4	6·4	5·2	6·0	18·3	9·7	7·6	10·4	18·9	10·6	14·8	15·1
Fe_2SiO_4	1·2	1·4	1·4	3·7	2·1	0·8	0·8	2·4	2·9	5·5	3·0
mt	2·8	1·4	3·2	6·5	3·5	10·0	7·9	6·0	3·7	7·7	7·4
il	1·7	0·3	0·6	2·0	1·1	6·2	4·7	2·9	1·2	5·5	3·5
ap	0·2	0·2	0·2	—	0·2	1·3	1·7	0·2	0·3	0·8	0·3
fl	—	—	—	—	—	—	0·8	—	—	—	—
No. of analyses	(7)	(9)	(20)	(8)	(46)	(21)	(17)	(9)	(4)	(15)	(5)
	PYROXENITE (WITH AUGITE)	PYROXENITE (WITH RHOMBIC PYROXENE)	PYROXENITE (WITH TWO PYROXENES)	OLIVINE PYROXENITE	<u>AVERAGE PYROXENITE</u>	<u>AVERAGE ALKALI PYROXENITE</u>	BIOTITE PYROXENITE	ARIEGITE	HORNBLENDE HYPERSTHENITE	HORNBLENDITE	OLIVINE HORNBLENDITE

TABLE 9.—DUNITES AND PERIDOTITES

	1.	2.	3	4.	5.	I.	II.	IIA.	6.	6a.	7.	7a.
SiO_2	40·16	35·46	26·17	43·07	42 43	43·54	40·27	41·96	35·02	38·70	36 33	39 45
TiO_2	0 10	0 03	5·97	0·15	0·96	0 81	1·30	1·35	1·22	1·35	1 39	2 05
Al_2O_3	0·64	1·53	2·34	4 20	5·50	3·99	7·29	7·59	3 90	4·32	5·09	5 53
Fe_2O_3	1·88	0·03	13·06	2 19	2·62	2·51	4·28	4·46	5·15	5 70	7·43	8·07
FeO	11 87	38·07	28·72	9·40	9·90	9 84	9·08	9·46	4·14	4 58	3·40	3·69
MnO	0 21	0·72	0·40	0·26	—	0·21	0·25	0·26	0·06	0 07	0 10	0·11
MgO	43·16	22·09	21·95	36·43	30·79	34·02	24·31	25·32	31·29	34·63	26·63	28·91
CaO	0·75	1·43	0 57	2·98	4·78	3·46	7·15	7·45	6 80	7·53	6·78	7·36
Na_2O	0·31	0·26	0·34	0·38	0·81	0·56	1·06	1·10	0·34	0·38	0·37	0 40
K_2O	0·14	tr.	0·14	0·15	0·44	0·25	0·62	0·65	1·05	1·16	2·43	2·64
H_2O+	0·44	0 35	0·34	0·64	1·69	0 76	3·67	—	7·43	(0·56)	7·25	(1·07)
P_2O_5	0·04	0·03	tr.	0·05	0·08	0·05	0·38	0·40	0·87	0·96	0·66	0·72
CO_2	—	—	—	—	—	—	0·34	—	2·73	—	1·64	—
or	0·6	tr.	0·6	1·1	2·8	1·7		3·9		—		—
ab	2·1	—	—	3·1	6·8	4·7		6·3		—		—
an	0·6	3·0	2·8	9·2	10·0	7·5		13·9		6·4		5·6
lc	—	—	—	—	—	—		—		5·7		12·2
ne	0·3	1·1	1·4	—	—	—		1·7		1·7		1·7
C	—	—	0·7	—	—	—		—		—		—
$CaSiO_3$	1·1	0·9	—	2·3	5·6	3·9		8·5		6·2		9·9
$MgSiO_3$	8·9	0·4	—	12·3	6·8	14·8		6·4		5·2		8·5
$FeSiO_3$	0·1	0·5	—	2·0	1·3	2·6		1·2		0·1		—
Ca_2SiO_4	—	1·2	—	—	—	—		—		3·0		0·9
Mg_2SiO_4	74·9	38·3	38·5	55·2	49·1	49·1		39·8		57·0		44·7
Fe_2SiO_4	15·7	54·4	25·3	10·6	10·2	9·6		8·4		0·7		—
mt	2·8	tr.	19·0	3·2	3·7	3·7		6·5		8·4		6·3
il	0·5	tr.	11·4	0 5	1·8	1·5		2·6		2·6		3·8
ap	0·1	tr.	tr.	0·1	0·2	0·1		1·0		2·3		1·7
hm	—	—	—	—	—	—		—		—		3·8
No. of analyses	(9)	(2)	(7)	(11)	(5)	(23)	(12)		(10)		(4)	
	DUNITE	HORTONOLITE DUNITE	ORE DUNITE	PYROXENE PERIDOTITE	HORNBLENDE PERIDOTITE	<u>AVERAGE PERIDOTITE</u>	<u>AVERAGE ALKALI PERIDOTITE</u>	<u>AVERAGE ALKALI PERIDOTITE</u> (minus H_2O+ and CO_2)	"BASALTIC" KIMBERLITE	"BASALTIC" KIMBERLITE (minus CO_2 and excess H_2O+)	"MICACEOUS" KIMBERLITE	"MICACEOUS" KIMBERLITE (minus CO_2 and excess H_2O+)

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TABLE 10.—NEPHELINE SYENITES AND PHONOLITE: NEPHELINE MONZONITE AND NEPHELINE LATITE

	NEPHELINE SYENITES AND PHONOLITE							NEPHELINE MONZONITE AND NEPHELINE LATITE	
	1.	2.	3.	4.	I.	II.	III.	IV.	V.
SiO_2	53·11	55·14	55·84	56·47	55·38	47·42	56·90	50·38	52·95
TiO_2	0·83	0·68	0·43	0·43	0·66	1·66	0·59	2·49	1·43
Al_2O_3	21·39	21·22	21·07	21·26	21·30	16·03	20·17	19·97	19·14
Fe_2O_3	2·54	2·46	2·49	3·37	2·42	5·68	2·26	2·77	3·25
FeO	1·59	2·10	2·66	1·44	2·00	5·16	1·85	3·96	2·86
MnO	0·12	0·23	0·17	0·16	0·19	0·25	0·19	0·13	0·20
MgO	0·72	0·50	0·60	0·33	0·57	3·35	0·58	2·15	2·02
CaO	2·89	1·97	1·68	1·50	1·98	6·99	1·88	6·01	5·33
Na_2O	5·98	9·13	9·74	11·63	8·84	7·67	8·72	6·35	6·55
K_2O	9·23	5·26	3·88	2·21	5·34	3·50	5·42	3·97	4·37
H_2O+	0·79	0·87	1·02	0·77	0·96	1·36	0·96	1·37	1·12
P_2O_5	0·31	0·16	0·17	0·08	0·19	0·71	0·17	0·45	0·37
CO_2	0·26	0·11	0·23	0·24	0·17	0·22	—	—	—
Cl	0·07	0·14	0·02	0·14	—	—	0·23	—	0·09
SO_3	0·18	0·06	—	—	—	—	0·13	—	0·34
or	54·5	31·1	22·8	12·8	31·1	20·6	31·7	23·4	26·1
ab	4·7	30·9	41·4	52·9	32·0	13·6	36·2	23·6	29·3
an.	5·0	2·2	2·5	—	2·8	—	1·7	14·5	11·1
lc	—	—	—	—	—	—	—	—	—
ne	24·1	24·1	22·2	24·1	23·3	26·7	18·7	16·2	12·5
ac	—	—	—	—	—	1·8	—	—	—
$CaSiO_3$	1·4	2·5	1·5	2·3	2·1	12·1	2·9	5·2	5·4
$MgSiO_3$	1·8	1·2	0·6	0·8	1·2	8·2	1·4	3·9	4·4
$FeSiO_3$	—	0·9	0·9	—	0·8	2·8	0·9	0·8	0·4
Mg_2SiO_4	—	—	0·6	—	0·1	0·1	—	1·1	0·4
Fe_2SiO_4	—	—	1·1	—	0·1	tr.	—	0·2	0·1
mt	3·2	3·7	3·7	3·9	3·5	7·4	3·3	4·2	4·9
il	1·5	1·4	0·8	0·8	1·4	3·2	1·2	4·7	2·7
ap	0 7	0·3	0·3	0·2	0·4	1·7	0·3	1·0	0·9
hm	0·3	—	—	0·6	—	—	—	—	—
cc	0 6	0·2	0·5	0·5	0·4	0·5	—	—	—
NaCl	0·1	0·2	tr.	0·2	—	—	0·4	—	0·1
Na_2SO_4	0·3	0·1	—	—	—	—	0·3	—	0·6
No. of analyses	(10)	(38)	(8)	(9)	(80)	(25)	(47)	(7)	(16)
	NEPHELINE SYENITE (JUVET TYPE)	NEPHELINE SYENITE (FOYA TYPE)	NEPHELINE SYENITE (LITCHFIELD TYPE)	NEPHELINE SYENITE (MARIUPOL TYPE)	AVERAGE NEPHELINE SYENITE	AVERAGE MALIGNITE	AVERAGE PHONOLITE	AVERAGE NEPHELINE MONZONITE	AVERAGE NEPHELINE LATITE

TABLE 10A. NEPHELINE SYENITES AND MALIGNITES

	NEPHELINE SYENITE								MALIGNITE		
	1	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
SiO_2	55·59	56·54	53·69	55·31	54·45	53·35	53·55	57·33	52·92	44·55	41·65
TiO_2	0·37	1·13	1·12	0·79	0·82	0·97	0·49	0·49	1·13	1·77	2 11
Al_2O_3	21·45	20·63	19·77	21·08	21·49	18·99	21·61	22·75	15·24	17·52	14 69
Fe_2O_3	2·73	2·53	2·12	2 28	3·09	2·49	2·57	0·66	8·91	3·69	5 20
FeO	1·32	2·07	2·41	2 23	1·65	2·90	3·94	2·42	1·74	7·36	4 60
MnO	0·23	0·31	0·10	0·14	0·12	0·24	0·14	0·19	0·61	0·27	0 22
MgO	0·33	0·72	0·88	0·42	0·54	1·87	0·68	0·34	0·56	3·80	4 83
CaO	1·41	1·49	3·71	2·45	2·38	3·38	2·59	0·96	2·57	8·47	8 74
Na_2O	9·98	8·67	7·51	8·43	8·06	7·92	8·67	8·66	10·59	7·33	6 12
K_2O	4·89	4·85	5·33	5·73	6·36	5·72	3·89	5·19	3·10	3·59	4·32
H_2O+	1·03	0·77	2·09	0·91	0·64	1·24	1·20	0·67	2·15	0·85	1 09
P_2O_5	0·04	0·09	0·20	0·13	0·26	0 75	0·26	0·03	[illegible]	0·80	1 28
CO_2	—	—	0·87	—	0·14	0·18	0·41	0·31	—	—	0·15
F	0·25	—	—	0·10	—	—	—	—	—	—	—
Cl	0·23	—	—	—	—	—	—	—	—	—	—
SO_3	0·07	—	—	—	—	—	—	—	—	—	—
ZrO_2	0·24	—	—	—	—	—	—	—	0·48	—	—
or	28·9	28·4		33·9	37·8	33·9		30·6	18·3	19·5	25·6
ab	35·6	38·8		28·3	23·6	22 5		40·4	19·9	—	6 3
an	—	2·2		2·8	3·6	—		2·8	—	4·4	—
lc	—	—		—	—	—		—	—	1·3	—
ne	25·6	19·6		23·3	24·1	23·3		17·9	22·1	33·5	24·4
C	—	—		—	—	—		1·8	—	—	—
$CaSiO_3$	2·1	2·0		3·2	2·3	4·6		—	5·3	13·5	14·3
$MgSiO_3$	0·8	1·5		1·0	1·3	2·9		—	1·4	7·1	11·6
$FeSiO_3$	—	0·3		1·2	—	1·5		—	2·2	5·9	1·0
ac	—	—		—	—	0·9		—	25·4	—	—
Mg_2SiO_4	—	0·2		—	—	1·3		0·6	—	1·7	0·4
Fe_2SiO_4	—	0·1		—	—	0·6		1·7	—	1·6	0 1
mt	3·7	3·7		3·3	3·3	3·2		0·9	0·2	5·3	7·7
il	0·8	2·1		1·5	1·5	1·8		0·9	2·1	3·3	4·0
ap	0·1	0·2		0·3	0·7	1·8		tr.	—	1·9	3·0
hm	0·2	—		—	0·8	—		—	—	—	—
cc	—	—		—	0·3	0·4		0·7	—	—	0·3
fl	0·5	—		0·2	—	—		—	—	—	—
hl	0·3	—		—	—	—		—	—	—	—
Zr	0·4	—		—	—	—		—	0·7	—	—
No. of analyses	(24)	(9)	(3)	(11)	(14)	(5)	(6)	(6)	(4)	(6)	(9)
	WITH AEGIRINE-AUGITE (OR AEGIRINE)	WITH AEGIRINE AUGITE (OR AEGIRINE) AND SODA-AMPHIBOLE	WITH TITANAUGITE AND SODA-AMPHIBOLE	WITH SODA-AMPHIBOLE	WITH AEGIRINE-AUGITE (OR AEGIRINE) AND BIOTITE	WITH DIOPSIDIC AUGITE AND BIOTITE	WITH SODA-AMPHIBOLE AND BIOTITE	WITH BIOTITE	WITH AEGIRINE	WITH PYROXENE AND SODA-AMPHIBOLE	WITH PYROXENE AND BIOTITE

TABLE 11.—ESSEXITE, GLENMUIRITE, THERALITE, TESCHENITE, AND CORRESPONDING LAVAS

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	46·68	46·41	47·34	45·97	44·82	45·93	45·75
TiO_2	2·81	2·43	2·53	2·34	2·65	2·13	2·36
Al_2O_3	17·07	15·66	16·59	16·64	15·42	16·25	17·07
Fe_2O_3	3·62	4·28	4·50	2·94	4·28	3·81	5·44
FeO	5·94	6·31	5·72	8·27	6·61	7·36	3·82
MnO	0·16	0·22	0·20	0·26	0·16	0·20	0·14
MgO	4·85	5·40	5·04	5·73	7·27	6·13	6·36
CaO	9·49	8·13	8·65	10·45	10·32	8·83	9·67
Na_2O	5·09	4·44	5·33	5·06	5·30	3·97	4·99
K_2O	2·64	2·47	2·63	1·37	1·26	1·34	1·25
H_2O+	0·97	3·59	0·87	0·66	1·56	3·55	2·48
P_2O_5	0·48	0·66	0·60	0·31	0·35	0·50	0·67
or	15·6	15·0	15·6	8·3	7·8	7·8	7·8
ab	14·7	21·0	18·3	13·1	12·6	24·6	22·0
an	16·1	15·3	13·6	18·4	14·5	22·5	20·3
ne	15·3	9·1	14·5	16·2	17·3	4·8	10·9
$CaSiO_3$	11·6	8·7	10·7	13·2	14·3	7·7	9·5
$MgSiO_3$	8·2	6·0	7·8	7·6	10·4	4·9	8·2
$FeSiO_3$	2·4	2·0	1·8	5·0	2·5	2·2	—
Mg_2SiO_4	2·8	5·2	3·4	4·7	5·5	7·3	5·4
Fe_2SiO_4	0·8	1·9	0·8	3·4	1·5	3·9	—
mt	5·3	6·3	6·5	4·2	6·3	5·6	5·8
il	5·3	4·6	4·9	4·4	5·0	4·1	4·6
ap	1·2	1·5	1·4	0·7	0·8	1·2	1·6
hm	—	—	—	—	—	—	1·4
No. of analyses	(15)	(13)	(17)	(6)	(8)	(8)	(7)
	AVERAGE ESSEXITE	AVERAGE GLENMUIRITE	AVERAGE ORDANCHITE	AVERAGE THERALITE	AVERAGE NEPHELINE TEPHRITE	AVERAGE TESCHENITE	AVERAGE ANALCITE TEPHRITE

TABLE 12.—ULTRA-ALKALINE AND RELATED ROCKS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2	41·59	42·58	41·90	40·85	40·90	39·07	40·29	42·87	44·95
TiO_2	0·35	1·41	2·21	2·44	3·99	3·86	2·90	2·59	3·51
Al_2O_3	27.42	18·46	12·20	20·46	13·65	12·82	11·32	14·67	13·52
Fe_2O_3	2·49	4·01	6·41	3·86	6·67	8·75	4·87	3·54	5·42
FeO	1·89	4·19	4·32	5·08	7·14	6·39	7·69	7·73	5·07
MnO	0·09	0·20	0·22	0·09	—	0·26	0·12	0·30	0·15
MgO	0·69	3·22	5·45	3·56	8·35	6·14	13·28	6·64	8·02
CaO	4·38	11·38	16·60	10·06	13·28	14·20	12·99	11·81	9·78
Na_2O	14·12	9·55	5·10	8·71	3·06	4·09	3·14	4·69	4·65
K_2O	3·82	2·55	2·66	2·98	1·65	2·07	1·44	1·47	1·21
H_2O+	0·42	0·55	0·87	0·98	0·50	1·59	1·08	3·34	2·80
P_2O_5	0·44	1·52	1·24	0·53	0·81	0·76	0·78	0·35	0·92
CO_2	1·30	0·38	0·82	0·40	—	—	—	—	—
Cl	—	—	—	—	—	—	—	—	—
or	8·3	10·0	6·7	—	9·4	1·7	—	8·9	7·2
ab	—	—	—	—	1·6	—	—	3·1	22·5
an	0·6	—	2·5	8·1	18·6	10·3	12·8	14·5	12·2
lc	10·9	3·9	7·4	13·9	—	8·3	6·5	—	—
ne	64·5	43·7	23·3	39·2	13·1	18·7	14·2	19·9	9·1
ac	—	—	—	—	—	—	—	—	—
$CaSiO_3$	4·3	18·5	27·9	11·2	17·6	23·0	17·2	17·5	12·6
$MgSiO_3$	1·7	8·0	13·6	8·1	14·7	15·3	13·1	11·3	10·9
$FeSiO_3$	0·9	2·4	—	2·1	0·7	—	2·2	5·0	—
Ca_2SiO_4	—	—	—	2·7	—	—	1·6	—	—
Mg_2SiO_4	—	—	—	0·6	4·3	—	14·1	3·8	6·3
Fe_2SiO_4	—	—	—	0·2	0·2	—	2·7	1·8	—
mt	3·7	5·8	8·1	5·6	9·7	10·4	7·2	5·1	6·5
il	0·6	2·7	4·3	4·6	7·6	7·3	5·5	5·0	6·7
ap	1·0	3·6	2·9	1·3	1·9	1·8	1·8	0·8	2·2
hm	—	—	0 8	—	—	1·4	—	—	1·0
cc	3·0	0 9	1·8	0·9	—	—	—	—	—
NaCl	—	—	—	—	—	—	—	—	—
No. of analyses	(6)	(11)	(9)	(3)	(3)	(8)	(21)	(4)	(8)
	AVERAGE URTITE	AVERAGE IJOLITE	AVERAGE MELTEIGITE	IJOLITE WITH TITANAUGITE	MELTEIGITE WITH TITANAUGITE	AVERAGE NEPHELINITE	AVERAGE OLIVINE NEPHELINITE	AVERAGE BEKINKINITE	AVERAGE OLIVINE ANALCITITE

* SO_3 = 0.36.
† SO_3 = 0.06.

TABLE 12.—*Continued*

X.	XI.	XII.	XIII.	XIV.	XV.	
43·99	33·68	38·34	39·11	37·59	37·08	SiO_2
0·10	2·85	1·85	3·10	3·40	3·31	TiO_2
22·25	13·43	6·07	13·54	11·09	8·08	Al_2O_3
6·27	5·89	6·93	7·83	5·18	5·12	Fe_2O_3
1·99	4·33	4·62	3·51	6·77	7·23	FeO
0·06	0·29	0·20	0·32	0·35	0·18	MnO
0·52	6·37	8·12	8·25	13·47	16·19	MgO
0·94	20·76	28·98	15·81	14·73	16·30	CaO
17·90	4·40	2·25	3·55	3·62	2·30	Na_2O
1·59	2·78	0·27	2·50	1·33	1·36	K_2O
1·19	2·25	0·55	2·06	1·45	1·89	H_2O+
0·02	1·68	0·53	0·42	1·02	0·96	P_2O_5
—	0·93	0·79	—	—	—	CO_2
4·10	*	†	—	—	—	Cl
9·4	—	—	—	—	—	or
8·9	—	—	—	—	—	ab
—	9·4	6·1	13·3	10·3	7·5	an
—	13·1	1·3	11·8	6·1	6·5	lc
52·3	19·0	9·9	16·2	16·5	10·5	ne
13·9	—	—	—	—	—	ac
2·0	2·5	20 5	14·4	11·6	10·7	$CaSiO_3$
0·7	2·2	17·6	11·4	9·4	8·6	$MgSiO_3$
1·3	—	0·1	—	0·8	0·8	$FeSiO_3$
—	21·7	24·9	8·6	8·8	12·8	Ca_2SiO_4
0·4	9·7	1·8	6·4	17·0	22·3	Mg_2SiO_4
0·8	—	0·1	—	1·7	2·5	Fe_2SiO_4
2·1	6·5	10·0	3·3	7·7	7·4	mt
0 2	5 5	3 5	5·9	6·5	6·2	il
Tr.	4·0	1·3	1·0	2·3	2 3	ap
—	1·4	—	5·6	—	—	hm
—	2·	1·8	—	—	—	cc
6·8	th 0·6	th 0·1	—	—	—	NaCl
(3)	(5)	(1)	(3)	(8)	(10)	No. of analyses
AVERAGE TAWITE	AVERAGE TURJAITE	AVERAGE UNCOMPAHGRITE	AVERAGE MELILITE NEPHELINITE	AVERAGE OLIVINE-MELILITE NEPHELINITE	AVERAGE OLIVINE MELILITITE	

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TABLE 13.—LEUCITIC ROCKS

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	49·24	48·55	45·08	50·54	50·07	47·05	51·28	46 75
TiO_2	1·15	1·69	2·17	0 87	1·32	1·54	0·63	1·65
Al_2O_3	14·99	15 55	11·35	19·17	18·43	16·05	22·29	14·02
Fe_2O_3	2·18	1·69	4·83	3·55	2·13	3·49	1 24	3 47
FeO	4·33	5·00	4·31	3·46	4 96	5·78	0·48	3·50
MnO	0·16	0·15	—	0·28	0·16	0·17	0 03	0 08
MgO	6·59	6·68	8·60	2·79	4·45	6·20	0·09	8·17
CaO	11·88	12·25	20·09	7·83	8·39	10·80	1·82	11·13
Na_2O	1·53	1·93	0·75	3·31	2·44	2·35	1·47	1 76
K_2O	6 96	5·53	2·54	7·01	6·74	5·38	18·59	8 10
H_2O+	0·49	0·55	0·20	0·61	0·57	0·60	0·43	0·71
P_2O_5	0·50	0·43	0·08	0·43	0 34	0·59	0·10	0·66
Cl	—	—	—	0·19	—	—	—	—
SO_3	—	—	—	—	—	—	0·55	—
or	13·3	17·8	—	41·1	39·5	22·2	2·2	—
ab	—	—	—	3·1	1·1	—	—	—
an	13·3	17·2	20·0	17·8	19·5	17·5	1·1	6·4
lc	21·8	11·8	11·8	—	—	7·4	84·6	37·5
ne	7·1	8·8	3 4	12·5	10·5	10·8	4·8	7·9
$CaSiO_3$	17·9	17·0	26·7	7·7	8·4	13·6	2·9	17·2
$MgSiO_3$	12·8	11·9	21·5	5·2	5·3	4·3	0·2	14·3
$FeSiO_3$	3·4	3·7	0 4	1·9	2·5	3·2	—	0·6
Ca_2SiO_4	—	—	4·6	—	—	—	—	1·0
Mg_2SiO_4	2·7	3·4	—	1·3	4·1	4·3	—	4·2
Fe_2SiO_4	0·8	1·0	—	0·5	2·2	1·7	—	0·3
mt	3·2	2 6	7·0	5·1	3·0	5·1	—	5·1
il	2·1	3·2	4·1	·7	2·4	2·9	1·1	3·2
ap	1·2	1·0	0·2	1·0	0·8	1·3	0·2	1·5
hm	—	—	—	—	—	—	1 3	—
th	—	—	—	—	—	—	1·0	—
hl	—	—	—	0·4	—	—	—	—
sp	—	—	—	—	—	—	0·2	—
No. of analyses	(4)	(3)	(2)	(16)	(12)	(31)	(2)	(6)
	LEUCITE MONZONITE (SOMMAITE)	LEUCITE MANGERITE	LEUCITE GABBRO (PUGLIANITE)	LEUCITE LATITE (includes vicoite and campanite)	LEUCITE ORDANCHITE	LEUCITE TEPHRITE (S.S) (includes vesuvite, kivite, ottajanite, etc.)	ITALITE	MESOTYPE MISSOURITE

TABLE 13.—*Continued*

9.	10.	11.	12.	13.	14.	15.	
46 87	47·11	43·64	42·74	40·08	45·78	38·77	SiO_2
1·19	1·25	2·54	2·67	3·14	0·73	2·81	TiO_2
10·36	15·74	10·28	16·72	13·29	16·77	7·98	Al_2O_3
2·54	4·54	5·11	4·84	5·44	4·02	6·46	Fe_2O_3
3·79	4·54	5·89	5·90	7·36	4·28	4·38	FeO
0·05	0·27	0·15	0·22	0·28	—	0·20	MnO
13·31	5·24	13·86	4·43	9·06	5·15	14·60	MgO
14·73	11·01	10·66	10·73	13·17	10·86	15·20	CaO
0·90	2·02	2·16	5·46	3·37	2·40	1·35	Na_2O
5·43	6·72	4·09	5·18	3·16	8·71	4·12	K_2O
0·53	0 87	0·72	0·52	0·90	0·61	2·95	H_2O+
0·30	0·44	0·63	0·59	0·75	0·48	0·73	P_2O_5
—	—	—	—	—	—	—	Cl
—	—	—	—	—	—	—	SO_3
—	15·3	6·9	—	—	—	—	or
—	—	—	—	—	—	—	ab
8·1	14·2	6·1	5·8	11·7	9·2	3·3	an
25·3	19·0	13·8	24·0	14·8	40·5	19·2	lc
4·3	9·1	9·9	25·0	15·3	11·1	6·3	ne
19·6	15·7	17·8	16·2	14·2	11·0	11·4	$CaSiO_3$
15·8	11·4	14·5	9·9	10·7	7·9	9·8	$MgSiO_3$
1·4	2·8	1·1	2·5	2·0	2·1	—	$FeSiO_3$
5·0	—	—	1·5	4·6	4·7	12·4	Ca_2SiO_4
12·2	1·2	14·1	0·8	8·4	3·5	18·8	Mg_2SiO_4
1·2	0·3	1·2	0·2	1·8	1·0	—	Fe_2SiO_4
3·7	6·5	7·4	7·0	7·9	5·8	6·7	mt
2·3	2·3	4·9	5·2	5·9	1·4	5·3	il
0·7	1·0	1·5	1·3	1·7	1·2	1·7	ap
—	—	—	—	—	—	1·9	hm
—	—	—	—	—	—	—	th
—	—	—	—	—	—	—	hl
—	—	—	—	—	—	—	sp
(5)	(7)	(11)	(6)	(7)	(2)	(5)	No. of analyses
MELANOCRATIC MISSOURITE	LEUCITITE	OLIVINE LEUCITITE	ETINDITE	OLIVINE ETINDITE	MELILITE LEUCITITE	OLIVINE - MELILITE LEUCITITE	

TABLE 14.—GENERAL AVERAGES OF IGNEOUS ROCKS

	I.	II.	III.	IV.	V.	VI.
SiO_2	68·9	54·5	54·6	48·2	48·4	43·8
TiO_2	0·5	1·4	1·5	1·9	1·8	1·7
Al_2O_3	14·5	17·2	16·4	15·6	15·5	6·1
Fe_2O_3	1·7	3·2	3·3	3·0	2·8	4·5
FeO	2·2	4·6	5·2	7·8	8·1	8·7
MnO	0·07	0·16	0·15	0·17	0·17	0·18
MgO	1·1	3·2	3·8	8·2	8·6	22·5
CaO	2·6	5·8	6·5	10·5	10·7	10·1
Na_2O	3·9	5·1	4·2	2·6	2·3	0·8
K_2O	3·8	3·6	3·2	0·9	0·7	0·7
H_2O+	0·6	0·8	0·7	0·8	0·7	0·6
P_2O_5	0·16	0·39	0·42	0·30	0·27	0·30
	AVERAGE SILICIC IGNEOUS ROCK (794 analyses)	AVERAGE INTERMEDIATE IGNEOUS ROCK (INCLUDING NEPHELINE TYPES) (810 analyses)	AVERAGE INTERMEDIATE IGNEOUS ROCK (EXCLUDING NEPHELINE TYPES) (685 analyses)	AVERAGE SUBSILIC IGNEOUS ROCK (INCLUDING NEPHELINE TYPES) (721 analyses)	AVERAGE SUBSILIC IGNEOUS ROCK (EXCLUDING NEPHELINE TYPES) (657 analyses)	AVERAGE ULTRAMAFIC IGNEOUS ROCK (182 analyses)

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N.B. The tables referred to by letters are those in the text. Tables in Appendix I are denoted by numbers.

PLATE I CLASSIFICATION OF THE IGNEOUS ROCKS

(MODIFIED BY W. R. MORGAN FROM NOCKOLDS, 1954)

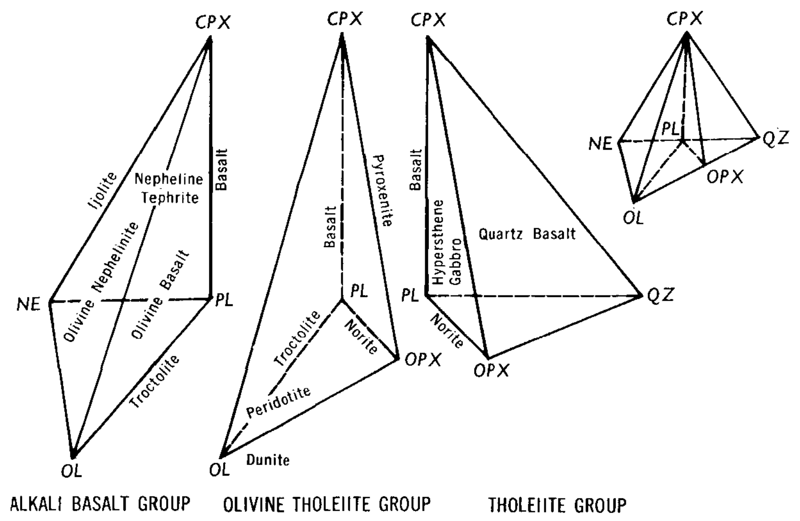
NOTE. On the main chart, Ferro-Magnesian Minerals and Muscovite associated with rock types are shown in brackets under the rock names; those most commonly associated with particular rocks are enclosed in rounded brackets; those less commonly associated are within square brackets.

QUARTZ FELDSPATHOID	GENERAL TYPE	COLOUR INDEX	GRAIN SIZE	*FELDSPARS*					
				ALKALI FELDSPAR ONLY		*POTASH FELDSPAR AND/OR LIME-BEARING PLAGIOCLASE*			
						POTASH FELDSPAR GREATER THAN 60% OF TOTAL FELDSPAR	*POTASH FELDSPAR 60% TO 40% OF TOTAL FELDSPAR*	*POTASH FELDSPAR 40% TO 10% OF TOTAL FELDSPAR*	*POTASH FELDSPAR LESS THAN 10% OF TOTAL FELDSPAR*
QUARTZ MORE THAN 10% OF TOTAL ROCK	ACID	*Less than 30*		← Late Stage Rocks: Pegmatite, Aplite (Granitic); Some Dolerite — Pegmatites →					
			Greater than 5 mm	Peralkaline Granite (Sodic Amphibole and Pyroxene)	Alkaline Granite (Biotite, Muscovite) [Hornblende]	Calc-Alkaline Granite (Biotite, Muscovite) [Hornblende]	Adamellite (Biotite, Muscovite) [Hornblende, Pyroxene]	Granodiorite (Biotite, Hornblende) [Pyroxene]	Tonalite (Hornblende) [Biotite, Pyroxene]
			1–5 mm	Peralkaline Microgranite	Alkaline Microgranite	Calc-Alkaline Microgranite	Microadamellite	Microgranodiorite	Microtonalite
			Less than 1 mm	Peralkaline Rhyolite (Sodic Amphibole and Pyroxene)	Alkaline Rhyolite ←	Calc-Alkaline Rhyolite	Dellenite (Biotite, Hornblende [Pyroxene, Fayalite]	Rhyodacite	Dacite →
			Glass	← Obsidian, Pitchstone, Felsite, Pumice →					
QUARTZ AND FELDSPATHOID LESS THAN 10% OF TOTAL ROCK	INTERMEDIATE	*Less than 5*	*Greater than 5 mm*	← Perthosite, Albitite →		Leucosyenite	Leucomonzonite		Oligoclasite, Andesinite, Anorthosite
		5 to 30		Peralkaline Syenite (Sodic Amphibole and Pyroxene)	Alkaline Syenite (Biotite) [Hornblende]	Calc-Alkaline Syenite (Hornblende, Biotite)	Monzonite (Hornblende, Biotite) [Pyroxene]	Mangerite (Hornblende Biotite) [Pyroxene, Sodic Amphibole and Pyroxene]	Diorite, Ferro-Diorite (Hornblende) [Biotite, Pyroxene]
			1–5 mm	Peralkaline Microsyenite	**Alkaline** Microsyenite	Calc-Alkaline Microsyenite	Micromonzonite	Micromangerite	Microdiorite
				← Minette, Vogesite, Soda Vogesite — — → (Lamprophyres — See B) (Biotite, Hornblende, Pyroxene) [Olivine, Sodic Amphibole and Pyroxene]			← — — Kersantite, Spessartite, Camptonite → (Lamprophyres — See B) (Biotite, Hornblende, Pyroxene) [Olivine, Sodic Amphibole and Pyroxene]		
			Less than 1 mm	Peralkaline Trachyte (Sodic Amphibole and Pyroxene)	Alkaline Trachyte ←	Calc-Alkaline Trachyte (Biotite, Hornblende, Pyroxene) [Olivine]	Latite	Doreite, Mugearite	Andesite, Hyaloandesite, Basaltic Andesite, Hawaiite →
				← Intermediate-Basic Pegmatites (Syenitic, Doleritic, etc.) →					
	BASIC	*30 to 60 (90)*	*Greater than 5 mm*	Shonkinite (Pyroxene, Olivine) [Biotite]			Kentallenite ← (Pyroxene, Olivine) [Amphibole, Biotite]		Gabbro, Norite, Troctolite, Ferrogabbro →
			1–5 mm	Microshonkinite			Microkentallenite		Dolerite, Micronorite Microtroctolite, Ferrodolerite
				← Minette, Vogesite, Soda Vogesite — — → (Lamprophyres — See B) (Biotite, Hornblende, Pyroxene) [Olivine, Sodic Amphibole and Pyroxene]			← — — Kersantite, Spessartite, Camptonite → (Lamprophyres — See B) (Biotite, Hornblende, Pyroxene) [Olivine, Sodic Amphibole and Pyroxene]		
			Less than 1 mm	Melatrachyte			Trachybasalt ← (Pyroxene, Olivine) [Amphibole, Biotite]		Basalt, Hypersthene-Basalt, Picrite Basalt, Andesitic Basalt →
	ULTRABASIC	*Greater than 90*	*Greater than 1 mm*						
			Less than 1 mm						
FELDSPATHOID MORE THAN 10% OF TOTAL ROCK	FELDSPATHOIDAL INTERMEDIATE, BASIC, AND ULTRA-ALKALINE	*Less than 30*	*Greater than 5 mm*	Foyaite (Sodic Amphibole and Pyroxene)					
			1–5 mm	Microfoyaite					
			Less than 1 mm	Phonolite (Sodic Amphibole and Pyroxene)					
				← Feldspathoidal Pegmatites — — — →					
		Greater than 30	*Greater than 5 mm*	Malignite (Pyroxene, Olivine, Biotite)				Theralite, Teschenite (Pyroxene, Olivine) [Amphibole]	
			1–5 mm					Microtheralite, Microteschenite	
			Less than 1 mm					Tephrite , Basanite (Pyroxene, Olivine) [Amphibole]	

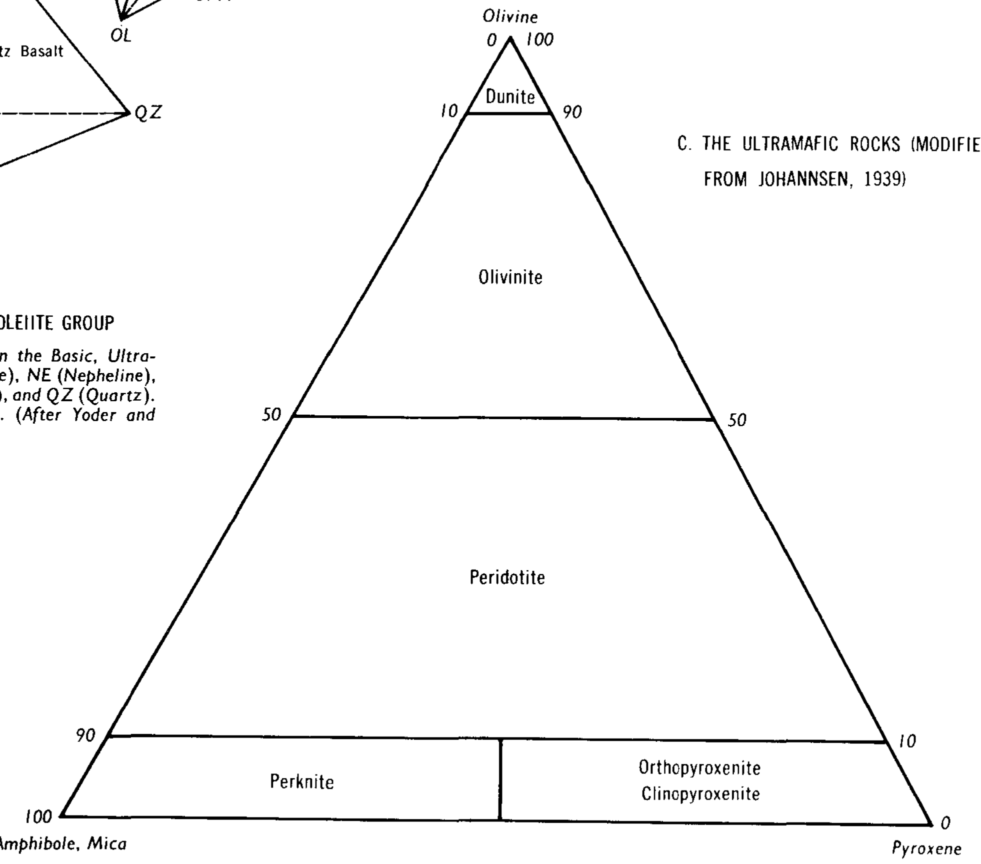
QUARTZ FELDSPATHOID	GENERAL TYPE	COLOUR INDEX	GRAIN SIZE	*FELDSPAR LESS THAN 10% OF TOTAL ROCK*						
				"FELDSPATHOIDAL" ROCKS						*NO FELDSPATHOID*
				Nepheline (± Sodalite)	Analcite	Noselite	Hauyne	Leucite	Melilite	
	ULTRABASIC	*Greater than 90*	*Greater than 1 mm*							Dunite, Olivinite, Peridotite, Serpentinite Pyroxenite, Perknite (See C) Magnetitite, Chromitite, Ilmenitite
			Less than 1 mm							
FELDSPATHOID MORE THAN 10% OF TOTAL ROCK	FELDSPATHOIDAL INTERMEDIATE, BASIC, AND ULTRA-ALKALINE	*Less than 30*	*Greater than 5 mm*							
			1–5 mm							
			Less than 1 mm							
				— — — →						
		Greater than 30	*Greater than 5 mm*	Ijolite, Melteigite	Monchiquite			**Fergusite**	Uncompahgrite	
			1–5 mm	← (Pyroxene, Alkaline Pyroxene, Olivine) [Biotite, Melanite] →						
			Less than 1 mm	Nephelinite ← (Pyroxene, Alkaline Pyroxene, Olivine) [Biotite, Melanite] →	Analcitite	Noselitite	Hauynitite	Leucitite	Melilitite	

B. LAMPROPHYRES (AFTER WILLIAMS, TURNER & GILBERT, 1954)

DOMINANT MAFIC	*CHIEF FELDSPAR ORTHOCLASE*	*CHIEF FELDSPAR PLAGIOCLASE*	*FELDSPAR-FREE*
Biotite	Minette	Kersantite	Alnoite
Amphibole, Pyroxene	Vogesite	Spessartite	—
Sodic Amphibole and Pyroxene	Soda-Vogesite	Camptonite	Monchiquite



A *Exploded tetrahedron showing the relationships between the Basic, Ultramafic and Ultra-Alkaline rocks in terms of PL (Plagioclase), NE (Nepheline), CPX (Clinopyroxene), OPX (Orthopyroxene), OL (Olivine), and QZ (Quartz). The complete tetrahedron is shown at the upper right. (After Yoder and Tilley, 1962).*



C. THE ULTRAMAFIC ROCKS (MODIFIED FROM JOHANNSEN, 1939)

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