A Simple Classification of Volcanic Rocks

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Summary

There is a considerable volume of information on the abundance, distribution and chemical composition of volcanic rocks. In this paper an attempt is made to use these data to construct a simple chemical classification of the volcanic rocks. Silica content is used to divide the rocks into seven major classes; and the major classes are then subdivided using soda, potash, alumina and lime.

Introduction

At the present time there is a reawakening of interest in the problem of the classification of igneous rocks (STRECKEISEN, 1965, 1967; IRVINE and BARAGAR, 1971). Much of this interest has been generated by attempts to use electronic computers to store and manipulate large volumes of petrological data (CHAYES, 1969*b*; HUBAUX, 1969; HARRISON and SABINE, 1970). It has also been shown that it is not possible to devise a single comprehensive classification of igneous rocks that can be used in both the fields of petrography and petrogenesis (MIDDLEMOST, 1971). Petrographic classifications are essentially concerned with producing a systematic framework that provides compartments into which rocks can be placed (*i.e.* JOHANNSEN, 1931). The needs of petrogenesis are different, as this branch of petrology is constantly searching for ways in which to adapt our vocabulary of rock names so that the language we use is able to change in response to new discoveries, or new ways of interpreting old discoveries.

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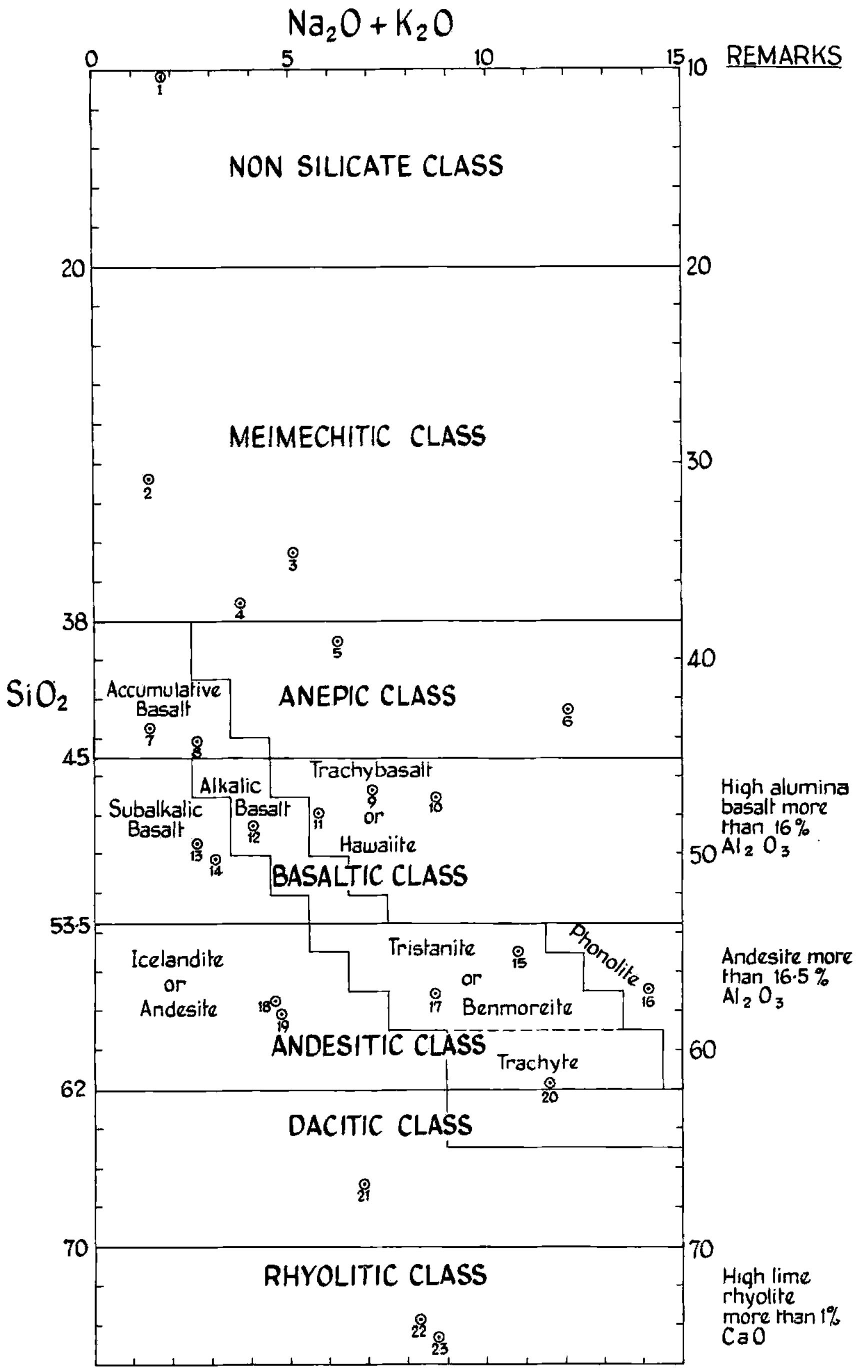
There is a large store of information on the abundance, composition and distribution of igneous rocks. If one examines these data one discovers that the volcanic rocks form an essentially coherent group of rocks and that their classification poses some unique problems. The main problem is that one is unable to determine the modal composition of the many volcanic rocks that are wholly, or partly, composed of glass or cryptocrystalline materials. It would thus seem that any meaningful classification of volcanic rocks should be based on a chemical, or quasi-chemical (CROSS *et al.*, 1902; NIGGLI, 1936), system of clasification, or a combination of both these systems of classifications (IRVINE and BARAGAR, 1971). The main disadvantages of these systems of classification is that (1) they generally require considerable preliminary calculation, and (2) they often use theoretical, and in part arbitrary, normative minerals.

If one investigates the abundance of volcanic rocks (DALY, 1933, p. 36; WEDEPOHL, 1969, p. 246) one discovers that there are only three common volcanic rocks. These rocks are basalt, andesite and rhyolite. One also finds that there is a considerable amount of chemical information on these three rock types (WALKER and POLDERVAART, 1949; NOCKOLDS, 1954; AHRENS, 1964; MANSON, 1967; MACDONALD, 1968; MELSON *et al.*, 1968; CHAYES, 1969*a*). If however, one examines the abundance, composition and distribution of the many less abundant volcanic rock types one soon realizes that form a « ...disorderly rabble of names » (SHAND, 1950, p. 207).

§ 1. Seven Classes of Volcanic Rocks

In the past a large number of different criteria have been used in the chemical and/or quasi-chemical classification of igneous rocks. The two criteria that seem to have been used the most are: (1) silica content (LOEWINGSON-LESSING, 1890, p. 329; RICHARDSON and SNEESBY, 1922; AHRENS, 1964), and (2) the « degree of alkalinity » (PEACOCK, 1931; RITTMANN, 1962; MACDONALD, 1968, p. 514; WRIGHT, 1969). If one investigates the silica content of the three most common volcanic rocks one finds that the average basalt contains 49.2 % silica with a standard deviation of 3.2 % (MANSON, 1967, p. 236); the average andesite contains 58.2 % silica with a standard deviation of 4.1 % (CHAYES, 1969*a*, p. 3); and the average rhyolite contains 73.0 % silica


$Na_2O + K_2O$
0
5
10
15
REMARKS
SiO_2
10
20
30
38
40
45
50
53·5
60
62
70
NON SILICATE CLASS
MEIMECHITIC CLASS
ANEPIC CLASS
Accumulative Basalt
BASALTIC CLASS
Trachybasalt or Hawaiite
Alkalic Basalt
Subalkalic Basalt
High alumina basalt more than 16 % Al_2O_3
ANDESITIC CLASS
Icelandite or Andesite
Tristanite or Benmoreite
Phonolite
Trachyte
Andesite more than 16·5 % Al_2O_3
DACITIC CLASS
RHYOLITIC CLASS
High lime rhyolite more than 1% CaO
1
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with a standard deviation of 3.3 % (AHRENS, 1964, p. 275). It would thus seem that the percentage of silica that can be used to distinguish between basalts and andesites lies betwenn 52.4 % (49.2 + 3.2) and 54.1 % (58.2 – 4.1); and for the purposes of this study the limiting silica value will be taken as 53.5 %.

From the data available on the abundance of silica in rhyolites and andesites it would seem that there is a hiatus between these two common rock types. However, in those suites of rocks that contain both andesites and rhyolites there usually are rocks that contain between 62 % and 69 % silica; and these rocks are generally called dacites. CHAYES (1969*b*, p. 177-179) has made a study of the abundance of silica in andesites and dacites, and he has shown that approximately 62 % silica is the most suitable limiting figure to divide the andesites from the dacites. If one compares the silica frequency distribution diagrams for dacites (CHAYES, 1969*b*, p. 179) and rhyolites (AHRENS, 1964, p. 276), one finds that whilst these diagrams overlap, one is able to separate the two groups by selecting 70 % silica as the limiting figure.

If one studies MANSON's (1967, pp. 226-227) mean values for the different basaltic rock groups one finds that all, but one, of these groups contains 45.8 %, or more, silica. The exception to this rule is

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FIG. 1 - Alkali: silica diagram that illustrates the classification proposed in this paper.
1 = *Average Carbonatite* (HEINRICH, 1966, p. 222)
2 = *Meimechite* (kimberlite) (CORRENS, 1969, p. 443)
3 = *Average Katungite* (HOLMES, 1950, p. 784)
4 = *Average Olivine Melilitite* (NOCKOLDS, 1954, p. 1029)
5 = *Average Nephelinite* (Ibid., p. 1028)
6 = *Average Ijolite* (Ibid., p. 1028)
7 = *Average* (Karroo) *Picrite* (WALKER and POLDERVAART, 1949, p. 648)
8 = *Average Alkalic Ankaramite* (MACDONALD, 1968, p. 502)
9 = *Average Trachybasalt* (BAKER *et al.*, 1964, p. 531)
10 = *Average Leucitite* (NOCKOLDS, 1954, p. 1031)
11 = *Average Hawaiite* (MACDONALD, 1968, p. 502)
12 = *Average Olivine Alkalic Basalt* (MANSON, 1967, p. 226)
13 = *Average Tholeiitic Basalt from Hawaii* (MACDONALD, 1968, p. 502)
14 = *Average High-alumina Basalt* (KUNO, 1960, p. 141)
15 = *Average Tristanite* (BAKER *et al.*, 1964, p. 531)
16 = *Average Phonolite* (NOCKOLDS, 1954, p. 1024)
17 = *Average Benmoreite* (MACDONALD, 1968, p. 502)
18 = *Average Icelandite* (JAKES and WHITE, 1971, p. 226)
19 = *Average Andesite* (CHAYES, 1969*a*, p. 3)
20 = *Average Trachyte* (MACDONALD, 1968, p. 502)
21 = *Calc-alkaline Dacite* (JAKES and WHITE, 1971, p. 226)
22 = *Average Calc-alkaline Rhyolite* (NOCKOLDS, 1954, p. 1012)
23 = *Average Alkali Rhyolite* (Ibid., p. 1012).

leucite basalt and it has a mean silica content of 41.7 %. MANSON (1967, pp. 246-247) claims that whilst the major element chemistry of all the other groups of basaltic rocks is gradational in character, the leucite basalts form a chemically discrete group. The most significant differences between the leucite basalts and the main body of basaltic rocks is that the former contain significantly less alumina and more magnesia than the latter. The leucite basalts share this chemical characteristic with the other volcanic rocks (*i.e.* picrite, olivine leucitite and ankaramite) that have mean silica contents in the range 40 % - 45 %; and because of this the leucite basalts will be considered to be a part of the low-silica (anepic) group of rocks, and not of the basaltic group of rocks.

The average basalt (MANSON, 1967, p. 236) contains 49.2 % silica and it has a standard deviation of 3.2 %. If one considers the more detailed data on the chemistry of the different groups of basaltic rocks that make up this mean value (MANSON, 1967, pp. 226-227) one discovers that the silica content of the alkalic basalts, and more particularly the nepheline basalts (mean SiO_2 = 45.8 %, standard deviation 2.2 %), grades into the silica range of the picrites (mean SiO_2 = 43.5 %: WALKER and POLDERVAART, 1949, p. 648), olivine leucitites (mean SiO_2 = 43.5 %: NOCKOLDS, 1954, p. 1031) and ankaramites (mean SiO_2 = 43.6: MACDONALD, 1968, p. 502). After taking into account the range in silica values found in the rocks designated picrites, olivine leucitites and ankaramites it was decided to use 45 % silica as the limiting figure to divide the basaltic group from the picrite-olivine leucitite-ankaramite group of rocks. It is pleasing to record that this limiting figure of 45 % silica coincides with the generally accepted boundary between the socalled basic and ultrabasic rocks (HOLMES, 1929; WYLLIE, 1967, p. 1).

If one studies the chemical composition of the volcanic rocks that contain less than 45 % silica one finds that the rocks that contain less than 20 % silica, such as the carbonatites (DAWSON, 1962*a*; HEINRICH, 1966, p. 222) and lacoites (or magnetite lavas: PARK, 1961; HAGGERTY, 1969), are all derived from essentially non-silicate melts; thus these rocks can be regarded as « non-silicate volcanic rocks ». The only relatively common volcanic rocks that contain less than 45 % silica are the picrites (WALKER and POLDERVAART, 1949, p. 648; DREVER and JOHNSTON, 1967, p. 57), ankaramites (MACDONALD, 1968, p. 502) and nephelinites (NOCKOLDS, 1954, p. 1028). As these rocks normally contain more than 38 % silica, it is proposed to call the rocks that contain between 38 % and 45 % silica the « anepic » group of volcanic rocks. The a-ne-pic is a mnemonic for the rock names ankaramite, nephelinite and picrite. The rare volcanic rocks that contain between 20 % and 38 % silica, and include the melilitites (NOCKOLDS, 1954, p. 1029), katungites (HOLMES, 1950, p. 784), and meimechites (or kimberlitic volcanic rocks: DAWSON, 1967, p. 269; FRANTSESSON, 1970, p. 72) will be designated the « meimechitic volcanic rocks ». Meimechite is defined as the effusive equivalent of kimberlite (WYLLIE, 1967, p. 3).

The volcanic rocks have thus been divided into seven classes on the basic of their silica content. These classes are: (1) the non-silicate rocks (0 %-20 % silica), (2) the meimechitic rocks (20 %-38 % silica), (3) the anepic (ankaramite + nephelinite + picrite) rocks (38 %-45 % silica), (4) the basaltic rocks (45 %-53.5 % silica), (5) the andesitic rocks (53.5 %-62 % silica), (6) the dacitic rocks (62 %-70 % silica), and (7) the rhyolitic rocks (70 %-100% silica). These major classes of volcanic rocks are all shown in Figure 1.

§ 2. Basaltic Rocks

As most volcanic rocks belong to the basaltic rock class (45 %-53.5 % silica), and as there is a considerable amount known about the chemical composition, and distribution, of these rocks, our first attempt at dividing one of the seven classes of volcanic rocks into smaller units will be made on this class of rocks. MANSON (1967, p. 246) has shown that with regards to major element chemistry, the main basaltic rock types form a continuous and gradational series. Yet there is a real need to subdivide the basaltic rocks because experience has shown that most basalts crop out in association with other rock types, and together, the basalts and associated rocks, form characteristic suites of volcanic rocks. The basalts from a particular suite of volcanic rocks (such as a suite of rocks that contains dacites and/or rhyolites), generally have a similar major element chemistry; but the chemistry of these basalts normally differs from that of basalts from another suite of volcanic rocks (such as a suite of rocks that contains trachytes and/or phonolites). It is as though basaltic magmas differentiate towards « ...end products that magnify chemical characteristics only subtly revealed in the parent basalt » (MCBIRNEY and WILLIAMS, 1970, p. 171).

In the past those suites of volcanic rocks that contained dacites and/or rhyolites have generally been considered to belong to either the tholeiitic series, or the calc-alkaline series of volcanic rocks. While those suites of volcanic rocks that have had trachytes and/or phonolites as end-members have been considered to belong to the alkalic (or alkali olivine basalt) series (IRVINE and BARAGAR, 1971, p. 524). If one compares the major element chemistry of the basalts from these two groups (ANDERSON, 1941, p. 387; KUNO, 1960, p. 141; WATERS, 1961, p. 595; BAKER *et al.*, 1964, p. 531; MANSON, 1967, pp. 226-227; MELSON *et al.*, 1968, p. 5930; MACDONALD, 1968, p. 502; JAKES and WHITE, 1971, p. 226) one discovers that the most significant difference between the groups is the amount of soda and potash that they contain; or more particularly their content of soda plus potash in relation to their silica content (BAKER *et al.*, 1964, p. 450; MACDONALD, 1968, p. 514; IRVINE and BARAGAR, 1971, p. 532).

If one examines the chemical data on the andesitic rock class (53.5 % SiO_2-62 % silica: MUIR and TILLEY, 1961, p. 190; WATERS, 1961, p. 595; BAKER *et al.*, 1964, p. 531; CHAYES, 1969*a*, p. 3; MACDONALD, 1968, p. 502) one finds that the amount of soda plus potash in relation to silica, is once again a suitable way of separating the subalkalic (tholeiite plus calc-alkaline) group and the alkalic group of volcanic rocks.

It is proposed that the rocks belonging to the basaltic class should be split into four divisions. The rocks of the first division contain between 45 % and 47 % silica, the second division 47 % and 50 % silica, the third division 50 % and 52 % silica and rocks of the fourth division contain between 52 % and 53.5 % silica. Rocks of division one that contain more than 2.5 % (Na_2 + K_2O) will be called alkalic, while those that contain less than 2.5 % (Na_2O + K_2O) will be termed subalkalic. The limiting figure will be taken as 3.5 % (Na_2O + K_2O) in the second division, 4.5 % in the third, and 5.5 % in the fourth division. This subdivision of the basaltic rocks is shown in Figure 1.

If one considers the alkalic basaltic rock group as a whole, one finds that this group contains not only *alkalic basalts*, but also « hyperalkalic rocks », such as trachybasalts, hawaiites, tahitites and mugearites (BAKER *et al.*, 1964, p. 520; MACDONALD, 1968, p. 502; MCBIRNEY and AOKI, 1968, p. 535). In order to determine whether an alkalic basaltic rock is alkalic or hyperalkalic, it is proposed to split the alkalic basaltic rock group into the same four divisions as before; that is, division one 45 % to 47 % silica, division two 47 % to 50 %

silica, division three 50 %-52 % silica, and division four contains between 52 % and 53.5 % silica. The hyperalkalic basalts are taken to contain (1) more than 4.5 % ($Na_2O + K_2O$) in division one, (2) more than 5.5 % ($Na_2O + K_2O$) in division two, (3) more than 6.5 % ($Na_2O + K_2O$) in division three, and (4) more than 7.5 % ($Na_2O + K_2O$) in division four. The alkalic basalts of each division contain less soda plus potash than the limiting figure given above.

The hyperalkalic basaltic rocks can be further divided into rocks of either the potassic or the sodic series. If the Na_2O/K_2O ratio is less than two then a hyperalkalic basaltic rock belongs to the potassic series and it is a *trachybasalt*; if the Na_2O/K_2O ratio is greater than two then the hyperalkalic basaltic rocks belong to the sodic series and the rock is a hawaiite (BAKER *et al.*, 1964, p. 520; MACDONALD, 1968, p. 502). There are, however, a number of rocks that fall within this definitition of trachybasalt but have a Na_2O/K_2O ratio that is less than one. These rocks include the absarokites, banakites, leucite basalts, leucite basanites and leucitites (DALY, 1933, pp. 23, 24 and 26). After considering the major element chemistry of these rocks it was decided to call those trachybasaltic rocks that have a Na_2O/K_2O ratio that is less than 0.5 *leucitites* (DALY, 1933, p. 24; NOCKOLDS, 1954, p. 1031).

After considering the major element chemistry of numerous tholeiitic and calc-alkaline rocks of the subalkalic basaltic group, it was decided to use the Al_2O_3 content of these rocks to divide them into *tholeiitic* basalts and *high-alumina basalts*. The limiting figure between the types of basalt was placed at 16 % Al_2O_3 (KUNO, 1960, p. 141).

The basaltic rock class (45 %-53.5 % silica) has thus been divided into six sub-classes: (1) tholeiitic basalt, (2) high alumina basalt, (3) alkalic basalt, (4) trachybasalt, (5) hawaiite and (6) leucitite.

§ 3. Andesitic Rocks

It has been shown at an earlier stage in this paper that the andesitic class of rocks (53.5 %-62 % silica) can also be divided into subalkalic and alkalic groups. In order to do this it is proposed to split the andesitic class into four divisions. Division one is taken to contain between 53.5 % and 55 % silica, division two between 55 % and 57 % silica, division three between 57 % and 59 % silica and division four contains between 59 % and 62 % silica. Rocks of division one that contain more than 5.5 % ($Na_2O + K_2O$) will be termed alkalic. The limiting figure of ($Na_2O + K_2O$) will be taken as 6.5 % in division two, 7.5 % in division three and 9.0 % in division four. Rocks containing less than the limiting figure of ($Na_2O + K_2O$) will be regarded as subalkalic (See Fig. 1).

The alkalic rocks of the andesitic class are essentially tristanites, benmoreites, trachytes and phonolites. A study of the major element chemistry of these rock species (NOCKOLDS, 1954, p. 1024; TILLEY and MUIR, 1964, p. 437; BAKER *et al.*, 1964, p. 520; MACDONALD, 1968, p. 502) reveals that the soda plus potash content of the phonolites is consistently higher than that of the other alkalic rocks of this class. It has also been found that one can use the same divisions as were used to divide the alkalic from the subalkalic group, in separating the phonolites from the other alkalic rocks. In division one the limiting ($Na_2O + K_2O$) figure is 11.5 %, in division two 12.5 %, in division three 13.5 %, and in division four the limiting figure is 14.5 % soda plus potash. The class of rocks designated phonolite does not only include normal phonolites but it also includes the potash-rich leucite phonolites (DALY, 1933, p. 25).

If one studies the chemistry of the *trachytes*, one discovers that they can be separated from the tristanites and benmoreites, because the former (the trachytes) normally contain more, and the latter (tristanites and benmoreites) less, than 59 % silica (See Figure 1). The *benmoreites* belong to the sodic series of alkalic rocks (MACDONALD, 1968, p. 502), while the *tristanites* belongs to the potassic series (BAKER *et al.*, 1964, p. 520). In the benmoreites the Na_2O/K_2O ratio is greater than 1.5 and in the tristanites it is less than 1.5.

The subalkalic andesitic class of rocks, like the subalkalic basaltic class, can also be divided into two groups, and these groups approximate to the tholeiitic series and the calc-alkalic series. Alumina content is once again used to separate the two groups. Those subalkalic andesitic rocks that contain more than 16.5 % alumina are regarded as *andesites*, and those that contain less than 16.5 % alumina are designated *icelandites* (CHAYES, 1969*a*, p. 3; JAKES and WHITE, 1971, p. 226).

§ 4. Dacites and Rhyolites

The vast majority of rocks in the dacitic class (62 %-70 % silica) belong to the subalkalic group. If a silica versus soda plus potash diagram is constructed, it is found that the field occupied by the subalkalic group expands continuously as one proceeds from the basaltic to the dacitic class. The few alkalic group rocks that are found in the dacitic class are mainly trachytes. These rocks can be accounted for if one regards as *trachytes*, all the rocks that contain between 62 % and 65 % silica and have a soda plus potash content in excess of 9.0 %.

If one considers the major element chemistry of the main group of dacitic rocks together with the rhyolitic class of rocks (70 %-100 % silica), one discovers that one can use the lime (CaO) content of the common calc-alkalic dacites and rhyolites as a means of separating them from the so-called « alkaline and peralkaline » rhyolites, commendites and pantellerites. Dacites and rhyolites that are associated with the calc-alkalic suite normally carry more than 1 % lime; and the so-called « alkalic and peralkalic » dacites and rhyolites normally carry less than 1 % lime (NOCKOLDS, 1954, pp. 1012-1013). Those dacitic rocks, other than the trachytes, that carry over 1 % lime will be called *high-lime dacites*, and those rocks that carry less will be called *low-lime dacites*. In the same manner, those rhyolites that carry more than 1 % lime will be called *high-lime rhyolites*, and those that carry less will be called *low-lime rhyolites*.

§ 5. Accumulative Basalts and Nephelinites

The volcanic rocks of the anepic class (38 %-45 % silica) are all essentially « alkalic » in the sense that this term was used when discussing the basaltic and andesitic class of rocks (MACDONALD, 1968, p. 514). It is convenient to divide the anepic class of rocks into two groups. The first group consists of rocks such as picrite and ankaramite (WALKER and POLDERVAART, 1949, p. 648; MACDONALD, 1968, p. 502) that are essentially accumulative basaltic rocks. The rocks of the second group are normally significantly undersaturated with regards to silica; and they mainly consist of basanites, nephelinites, etindites and ijolitic volcanic rocks. In order to distinguish between these two groups, the anepic rocks are split into three divisions. Division one consists of rocks with a silica content between 38 % and 41 %, division two between 41 % and 44 % silica, and division three consists of rocks that contain between 44 % and 45 % silica. If the content of soda plus potash is less than 2.5 % in division one, less than 3.5 % in division two, or less than 4.5 % in division three, then the rock is an *accumulative basalt*; but if the rock contains more soda plus potash than these limiting values then the rock is either a *nephelinite* or a *leucitite*. The nephelinites contain more soda than potash and the leucitites contain more potash than soda. The term nephelinite is thus extended to include the ijolitic volcanic rocks that are found associated with carbonatite lavas (Dawson, 1962*b*).

§ 6. Meimechites and Melilitites

The meimechitic class of volcanic rocks (20 %-38 % silica) essentially consists of meimechites, melilitites, melilite nephelinites and katungites (Holmes, 1950, p. 784; Nockolds, 1954, pp. 1023 and 1029). The meimechites form a separate and distinctive group; and those meimechitic class rocks that contain less than 10% ($Al_2O_3+Na_2O+K_2O$) will be called *meimechites*. Of the other rocks of the meimechitic class those rocks that contain more soda than potash will be called *melilitites* whilst those that contain more potash than soda will be called *katungites*.

It is proposed that the non-silicate volcanic rocks (0 %-20 % silica) should be named after their most abundant chemical components, thus one would have iron-rich (Park, 1961), carbonate-rich (Dawson, 1962*a*; Du Bois *et al.*, 1963) or sulphur-rich (Macdonald and Abbott, 1970, p. 47) *non-silicate volcanic rocks*. It is of considerable interest to note that the carbonatic volcanic rocks of Oldoinyo Lengai in Tanzania (Dawson, 1962*a*) contain approximately 1 % SiO_2, 15.5 % CaO, 29.6 % Na_2O, 7.1 % K_2O and 31.7 % CO_2 (Heinrich, 1966, p. 223).

§ 7. Alkalic Rocks

Anyone who has considered the problems related to the chemical classification of igneous rocks has probably noted the inconsistent and often arbitrary manner in which the term alkalic (or alkaline) rock is used. For the purposes of the present classification one might define an alkalic volcanic rock as a rock that contains more soda plus potash than is normal in the *class* of rocks to which it belongs;

and by using this definition the term alkalic rhyolite would have a clear meaning. This definition of the term alkalic rock is broadly consistent with the manner in which the term is generally used in igneous petrology. The term does, however, seem to have acquired a more subtle meaning in the study of volcanic rocks. The majority of volcanic rocks belong to either the basaltic or the andesitic class (WEDEPOHL, 1969, p. 246); and in this basalt-andesite field the terms alkalic and subalkalic have come to have a special meaning. If, for example, one examines the alkali: silica diagram prepared by MACDONALD (1968, p. 514) to divide the alkalic from the subalkalic (or tholeiitic) Hawaiian lavas, one finds that the subalkalic field commences at approximately 39 % silica and it is the dominant field at 60 % silica. It could thus be said that most rocks of the dacitic, and all rocks of the rhyolitic class, fall within the subalkalic field; while most rocks of the anepic and meimechitic classes fall within the alkalic field. It is believed that our ideas on what is, or is not, an alkalic volcanic rock are strongly conditioned by our ideas on what this term means in the basaltic and alkalic classes of rocks.

It is proposed that when discussing volcanic rocks the terms alkalic and subalkalic should only be used to describe basaltic or andesitic rocks. If rocks that contain less than 45 % silica are strongly enriched in soda plus potash, such as the nephelinites or katungites they should be called *hyperalkalic*. Rhyolitic rocks are considered to belong to the subalkalic field, and if a few of them, such as the pantellerites, contain more than 10 % soda plus potash they should be called either *soda-rich or potash-rich rhyolites*, depending upon which of these alkali metals is dominant.

§ 8. Common Volcanic Suites

In para. 2 it was noted that volcanic rocks often occur in suites. If one uses the classification proposed in this paper one discovers that the four most common suites are: (1) tholeiitic basalt - icelandite, (2) high alumina basalt-andesite-high lime dacite-high lime rhyolite, (3) accumulative basalt - alkalic basalt - hawaiite - benmoreite - trachyte, (4) accumulative basalt-trachybasalt-tristanite-trachyte. When considering suites 3 and 4 it is important to recall that in para. 1 we observed that the alkalic basalts, and in particular the feldspathoid-bearing alkalic basalts pass gradationally into the accumulative basalts.

§ 9. Classification

The volcanic rock to be classified is first of all placed in one of the following major classes:

	SiO_2%	Class
a.	0 - 20	Non-silicate
b.	20 - 38	Meimechitic
c.	38 - 45	Anepic (Ankaramite + Nephelinite + Picrite)
d.	45 - 53.5	Basaltic
e.	53.5- 62	Andesitic
f.	62 - 70	Dacitic
g.	70 -100	Rhyolitic

The rock is then more precisely classified using that section of the following more comprehensive classification that is applicable to that particular class of rocks.

a. The rocks of the non-silicate class are named after their most abundant chemical component, or components.

b. The rocks of the meimechitic class that contain less than 10 % (Al_2O_3 + Na_2O + K_2O) are called *meimechites.* The remaining rocks are *melilitites* if Na_2O is greater than K_2O, and *katungites* if K_2O is greater than Na_2O.

c. The rocks of the anepic class that contain between 38 % and 41 % SiO_2 and less than 2.5 % Na_2O + K_2O, or between 41 % and 44 % SiO_2 and less than 3.5 % Na_2O + K_2O, or between 44 % and 45 % SiO_2 and less than 4.5 % Na_2O + K_2O, are called *accumulative basalts.* The remaining rocks in this class are *nephelinites* if Na_2O is greater than K_2O, and *leucitites* if K_2O is greater than Na_2O.

d. The rocks of the basaltic class are called subalkalic if they contain between 45 % and 47 % SiO_2 and less than 2.5 % Na_2O + K_2O, or between 47 % and 50 % SiO_2 and less than 3.5 % Na_2O + K_2O, or between 50 % and 52 % SiO_2 and less than 4.5 % Na_2O + K_2O, or between 52 % and 53.5 % SiO_2 and less than 5.5 % Na_2O + K_2O. The subalkalic basaltic rocks are called *tholeiitic basalts* if they contain less than 16 % Al_2O_3 and *highalumina basalts* if they contain more than 16 % Al_2O_3. The remaining rocks of the basaltic class are called *alkalic basalts* if they contain between 45 % and 47 % SiO_2 and less than 4.5 % $Na_2O + K_2O$, or between 47 % and 50 % SiO_2 and less than 5.5 % $Na_2O + K_2O$, or between 50 % and 52 % SiO_2 and less than 6.5 % $Na_2O + K_2O$, or between 52 % and 53.5 % SiO_2 and less than 7.5 % $Na_2O + K_2O$. The basaltic rocks that contain more $Na_2O + K_2O$ than the limiting figures given above are *hawaiites* if their Na_2O/K_2O ratio is greater than 2; *trachybasalts* if this ratio is between 2 and 0.5; and *leucitites* if it is less than 0.5.

e. The rocks of the andesitic class that contain between 53.5 % and 55 % SiO_2 and less than 5.5 % $Na_2O + K_2O$, or between 55 % and 57 % SiO_2 and less than 6.5 % $Na_2O + K_2O$, or between 57 % and 59 % SiO_2 and less than 7.5 % $Na_2O + K_2O$, or between 59 % and 62 % SiO_2 and less than 9 % $Na_2O + K_2O$ are subalkalic. The subalkalic andesitic rocks are called *andesites* if they contain more than 16.5 % Al_2O_3, and *icelandites* if they contain less than 16.5 % Al_2O_3. The remaining andesitic rocks are either benmoreites or tristanites if they contain between 53.5 % and 55 % SiO_2 and less than 11.5 % $Na_2O + K_2O$, or between 55 % and 57 % SiO_2 and less than 12.5 % $Na_2O + K_2O$, or between 57 % and 59 % SiO_2 and less than 13.5 % $Na_2O + K_2O$. The Na_2O/K_2O ratio is greater than 1.5 in *benmoreites* and less than 1.5 in *tristanites*. Those *trachytes* that belong to the andesitic class of rocks contain between 59 % and 62 % SiO_2 and between 9 % and 14.5 % $Na_2O + K_2O$. The remaining rocks of this andesitic class are all strongly enriched in $Na_2O + K_2O$ and are called phonolites.

f. The rocks of the dacitic class are called *trachytes* if they contain between 62 % and 65 % SiO_2 and more than 9 % $Na_2O + K_2O$. The remaining rocks are called *high-lime dacites* if they contain more than 1 % CaO, and *low-lime dacites* if they contain less than 1 % CaO.

g. The rocks of the rhyolitic class are called *high-lime rhyolites* if they contain more than 1 % CaO and *low-lime rhyolites* if they contain less than 1 % CaO.

References

AHRENS, L. H., 1964, *Element distribution in igneous rocks - 7: A reconnaissance survey of the distribution of SiO_2 in granitic and basaltic rocks*. Geochim. Cosmoch. Acta, *28*, p. 271-290.

ANDERSON, C. A., 1941, *Volcanoes of the Medicine Lake Highland, California.* Univ. Calif. Publ., Bull. Geol. Sci., *25*, p. 347-422.

BAKER, P. E., GASS, I. G., HARRIS, P. G. and LEMAITRE, R. W., 1964, *The volcanological report of the Royal Society expedition to Tristan da Cunha, 1962.* Phil. Trans. R. Soc. Lond., Ser. A, *256*, p. 439-578.

CHAYES, F., 1969*a*, *The chemical composition of Cenozoic andesite.* In MCBIRNEY, A. R. (Ed.), *Proceedings of the andesite conference.* State of Oregon, Dept. of Geol. and Mineral. Ind., Bull., *65*, p. 1-11.

————, 1969*b*, *Experimentation in the electronic storage and manipulation of large numbers of rock analyses.* Yb. Carnegie Instn. Wash., *68*, p. 174-187.

CORRENS, C. W., 1969, *Introduction to Mineralogy, Crystallography and Petrology.* Springer Verlag, New York, 484 pp.

CROSS, W., IDDINGS, J. P., PIRSSON, L. V., and WASHINGTON, H. S., 1902, *A quantitative chemico-mineralogical classification and nomenclature of igneous rocks.* J. Geol., *10*, p. 555-690.

DALY, R. A., 1933, *Igneous Rocks and the Depths of the Earth.* McGraw Hill, New York, 598 pp.

DAWSON, J. B., 1962*a*, *Sodium carbonate lavas from Oldoinyo Lengai, Tanganyika.* Nature, Lond., *195*, p. 1075-1076.

————, 1962*b*, *The geology of Oldoinyo Lengai.* Bull. Volcanol., *24*, p. 349-387.

————, 1967, *Geochemistry and origin of kimberlite.* In WYLLIE, P. J. (Ed.), *Ultramafic and related rocks.* John Wiley & Sons Inc., p. 269-278.

DREVER, H. I. and JOHNSTON, R., 1967, *The ultrabasic facies in some sills and sheets.* In WYLLIE, P. J. (Ed.), *Ultramafic and related rocks.* John Wiley & Sons Inc., p. 51-63.

DU BOIS, C. G. B., FURST, J., GUEST, N. J. and JENNINGS, D. J., 1963, *Fresh natrocarbonatite lava from Oldoinyo L'Engai.* Nature, Lond., *197*, p. 445-446.

FRANTSESSON, E. V., 1970, *The Petrology of the Kimberlites.* Australian Nat. Univ. Dept. Geol. Pub. 150, 195 pp.

HAGGERTY, S. E., 1969, *The Laco magnetite lava flow, Chile.* Yb. Carnegie Instn. Wash., *68*, p. 329-330.

HARRISON, R. K. and SABINE, P. A., 1970, *A petrological-mineralogical code for computer use.* U. K. Nat. Environment Res. Council, Inst. Geol. Sci. Rep. 70/6, 134 pp.

HEINRICH, E. W., 1966, *The geology of carbonatites.* Rand McNally & Co., Chicago, 555 pp.

HOLMES, A., 1929, *Nomenclature of Petrology*, 2nd ed., Thomas Murby & Co., London, 284 pp.

————, 1950, *Petrogenesis of Katungite and its associates.* Am. Miner., *35*, p. 772-792.

HUBAUX, A., 1969, *Archival files of geological data.* Math. Geol., *1*, p. 41-52.

IRVINE, T. N. and BARAGAR, W. R. A., 1971, *A guide to the chemical classification of the common volcanic rocks.* Can. J. Earth Sci., *8*, p. 523-548.

JAKES, P. and WHITE, A. J. R., 1971, *Composition of island arcs and continental growth.* Earth Planet. Sci. Letters, *12*, p. 224-230.

JOHANNESEN, A., 1931, *A descriptive petrography of the igneous rocks;* 1. Univ. Chicago Press, Chicago, 318 pp.

KUNO, H., 1960, *High alumina basalt.* J. Petrology, *1*, p. 121-145.

LOEWINSON-LESSING, F., 1890, *Etude sur la composition chimique des rockes éruptives.* Bull. Soc. Belge Geol., *4*, p. 221-235.

MACDONALD, G. A., 1968, *Composition and origin of Hawaiian lavas.* Mem. Geol. Soc. Am., *116*, p. 477-522.

———— and ABBOTT, A. T., 1970, *Volcanoes in the sea.* Univ. Hawaii Press, Honolulu, 441 pp.

MANSON, V., 1967, *Geochemistry of basaltic rocks: major elements.* In HESS, H. H. & POLDERVAART, A. (Eds.), *Basalts*, 1, Interscience Pub., New York, p. 215-269.

MCBIRNEY, A. R. and AOKI, K., 1968, *Petrology of the island of Tahiti.* Mem. Geol. Soc. Am., *116*, p. 523-556.

———— and WILLIAMS, H., 1970, *Geology and petrology of the Galapagos Islands.* Mem. Geol. Soc. Am., *118*, 197 pp.

MELSON, W. G., THOMPSON, G. and VAN ANDEL, T. H., 1968, *Volcanism and metamorphism in the mid-Atlantic Ridge 22° N latitude.* J. Geophys. Res., *73*, p. 5925-5941.

MIDDLEMOST, E. A. K., 1971, *Classification and origin of the igneous rocks.* Lithos, *4*, p. 105-130.

MUIR, I. D. and TILLEY, C. E., 1961, *Mugearites and their place in alkali igneous rock series.* J. Geol., *69*, p. 186-203.

NIGGLI, P., 1936, *Die Magmentypen.* Schweiz. Min. Petr. Mitt., *16*, p. 335-399.

NOCKOLDS, S. R., 1954, *Average chemical composition of some igneous rocks.* Bull. Geol. Soc. Am., *65*, p. 1007-1032.

PARK, C. F., 1961, *A magnetite 'flow' in northern Chile.* Econ. Geol., *56*, p. 431-436.

PEACOCK, M. A., 1931, *Classification of igneous rock series.* J. Geol., *39*, p. 54-67.

RICHARDSON, W. A. and SNEESBY, G., 1922, *The frequency distribution of igneous rocks.* Mineralog. Mag., *19*, p. 303-313.

RITTMANN, A., 1962, *Volcanoes and their activity.* Interscience Pub., New York, 305 pp.

SHAND, S. J., 1950, *Eruptive Rocks*, 4th ed., John Wiley & Sons, New York, 488 pp.

STRECKEISEN, A. L., 1965, *Die klassifikation der Eruptiugesteine.* Geol. Rdsch., *55*, p. 478-491.

————, 1967, *classification and nomenclature of igneous rocks.* N. J. b. Miner. Abh., *107*, p. 144-240.

TILLEY, C. E. and MUIR, I. D., 1964, *Intermediate members of the oceanic basalt-trachyte association.* Geol. Foren. Stockholm Forh., *85*, p. 434-443.

WALKER, F. and POLDERVAART, A., 1949, *The Karroo dolerites of the Union of South Africa.* Bull. Geol. Soc. Am., *60*, p. 591-706.

WATERS, A. C., 1961, *Stratigraphic and lithologic variation in the Columbia River basalt.* Am. J. Sci., *259*, p. 583-611.

WEDEPOHL, K. H., 1969, *Composition and abundance of common igneous rocks.* In WEDEPOHL, K. H. (Ed.); *Handbook of Geochemistry* 1, Springer Verlag, Berlin, p. 227-249.

WRIGHT, J. B., 1969, *A simple alkalinity ratio and its application to questions of non-orogenic granite genesis.* Geol. Mag., p. 370-384.

WYLLIE, P. J., 1967, *Petrography and petrology.* In WYLLIE, P. J. (Ed.); *Ultramafic and related rocks.* John Wiley & Sons, New York, p. 1-7.

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