A Chemical Classification of Volcanic Rocks Based on the Total Alkali–Silica Diagram

by M. J. LE BAS,[1] R. W. LE MAITRE,[2] A. STRECKEISEN[3] AND B. ZANETTIN[4]

(on behalf of the IUGS Subcommission on the Systematics of Igneous Rocks)

[1]*Department of Geology, University of Leicester, LE1 7RH, U.K.*
[2]*Department of Geology, University of Melbourne, Parkville 3052, Victoria, Australia*
[3]*78 Manuelstrasse, 3006 Berne, Switzerland*
[4]*Instituto di Mineralogia e Petrologia, Universita di Padova, 35100 Padova, Italy*

(*Received 14 November 1985; revised typescript accepted 12 December 1985*)

ABSTRACT

This contribution summarizes and brings up to date the recommendations made by the IUGS Subcommission on the Systematics of Igneous Rocks for the classification of volcanic rocks when modal analyses are lacking. The classification is on a non-genetic basis using the total alkali-silica (TAS) diagram, and is as nearly consistent as possible with the QAPF modal classification. The diagram is divided into 15 fields, two of which contain two root names which are separated according to other chemical criteria, giving the following 17 root names: basalt, basaltic andesite, andesite, dacite, rhyolite, trachybasalt, basaltic trachyandesite, trachyandesite, trachyte, trachydacite, picrobasalt, basanite, tephrite, phonotephrite, tephriphonolite, phonolite and foidite. Using Na–K criteria, trachybasalt may be further divided into the sub-root names hawaiite and potassic trachybasalt, basaltic trachyandesite into the sub-root names mugearite and shoshonite, and trachyandesite into the sub-root names benmoreite and latite.

INTRODUCTION

It has long been the policy of the Subcommission on the Systematics of Igneous Rocks that the classification of the volcanic rocks should be based on modal contents (Streckeisen, 1976*a*, 1980), and consistent with the classification of the plutonic rocks (IUGS Subcommission, 1973; Murray, 1981). However, the Subcommission recognizes that modal contents cannot be accurately determined in many cases because of the fine grain size or presence of glassy material. It therefore investigated the problems of a chemical classification of volcanic rocks in a series of meetings held in Grenoble (1975), Sydney (1976), Prague (1977), Padua (1979), Paris (1980), Cambridge (1981), Granada (1983), Moscow (1984), and London (1985). The modal mineralogical QAPF classification of volcanic rocks (Streckeisen, 1978, 1980) remains, where possible, the primary classification of the volcanic rocks. Proposals for a classification of the pyroclastic volcanic rocks based on non-genetic features have already been published (Le Bas & Sabine, 1980; Schmid, 1981).

This short contribution outlines the principal recommendations of the Subcommission for the chemical classification of the non-pyroclastic volcanic rocks when no modal data are available, and hence the QAPF classification cannot be used. It revises and updates the proposals published by Le Maitre (1984) and Zanettin (1984).

THE RECOMMENDED CLASSIFICATION

The chemical classification of volcanic rocks should be non-genetic and consistent with the QAPF classification for the plutonic rocks which is based on modes. Several attempts have been made in the past to calculate modal contents from chemical analyses (e.g. Washington (1917) and Rittmann (1973)), but none has been found fully satisfactory. Normative methods to reproduce QAPF parameters were tried but found unsatisfactory because exact correspondence between mode and calculated norm could not be obtained without the prior input of the nature of the feldspar and similar other considerations (Streckeisen & Le Maitre, 1979; Le Maitre, 1984). Many other systems were also examined (e.g. Streckeisen, 1976*b*; De La Roche *et al.*, 1980) before the total alkali–silica diagram was finally accepted.

The choice of such simple chemical parameters as silica and total alkalis was also influenced by the existing use of such diagrams (e.g. Irving & Baragar, 1971; Cox *et al.*, 1979; Middlemost, 1980; Bogatikov *et al.*, 1981). It was also recognized that simplicity was an essential ingredient of classification, and hence straight lines are used to define the fields distinguished. The outcome is the total alkali–silica (or TAS) classification shown on Figs. 1 and 2. It is hierarchical (Table 1).

It should be noted that this recommended TAS classification differs from earlier versions recently presented (Le Maitre, 1984; Zanettin, 1984) in a few minor respects. The intersection point of field boundaries defined at 69,8 (Fig. 1) is 68,9 in the earlier versions. The change arises from the recognition of trachydacites within the trachyte field. The change has had a slight 'knock-on' effect, moving a few boundaries very slightly.

The construction of the TAS classification was based on the following criteria:

(i) the fields identified were chosen to accord as closely as possible with current usage of the terms employed;

(ii) the data plotted to test the fields were taken from the CLAIR and PETROS computer data bases (Le Maitre, 1982) which include some 24000 different chemical analyses of fresh volcanic rocks carrying the names used in this classification;

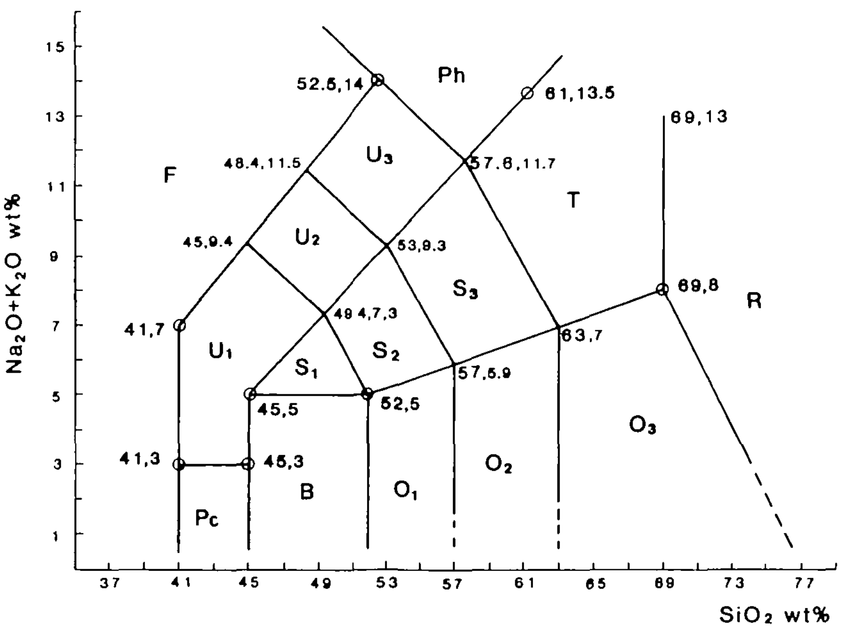

FIG. 1. The total alkali–silica (TAS) diagram showing the location and symbols of the 15 fields together with the coordinates of definitive points (shown by small circles) required to construct the diagram. The larger numbers are coordinates which are exactly defined, while the smaller numbers are only approximate coordinates, generally being determined by the intersection to two exactly defined lines. The letters O, S, and U indicate the general state of silica saturation: O oversaturated, S saturated, U undersaturated.

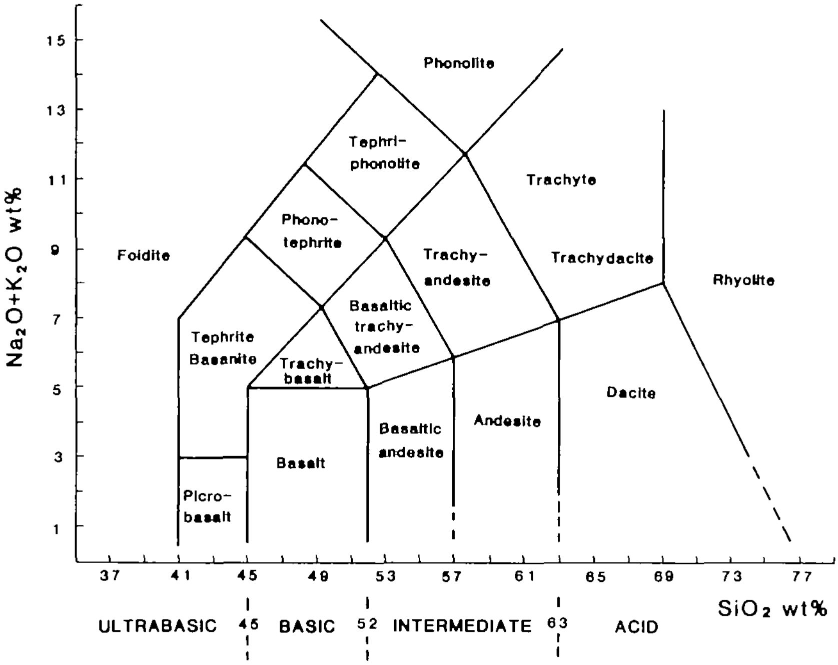

FIG. 2. The total alkali-silica (TAS) diagram showing the 17 root names.

TABLE 1

The relationship between field symbols, root names, and sub-root names

Field symbol	*Root name*	*Sub-root name*
Pc	Picrobasalt	
B	Basalt	Alkali basalt (Nen)
		Subalkali basalt (Hyn, Qn)
O1	Basaltic Andesite	
O2	Andesite	
O3	Dacite	
R	Rhyolite	Peralkaline rhyolite (PI > 1)
S1	Trachybasalt	Hawaiite (Na)
		Potassic trachybasalt (K)
S2	Basaltic trachyandesite	Mugearite (Na)
		Shoshonite (K)
S3	Trachyandesite	Benmoreite (Na)
		Latite (K)
T	Trachyte (Q < 20 in QAPF)	Peralkaline trachyte (PI > 1)
	Trachydacite (Q > 20 in QAPF)	
U1	Basanite (ol > 10%)	
	Tephrite (ol < 10%)	
U2	Phonotephrite	
U3	Tephriphonolite	
Ph	Phonolite	
F	Foidite	

Nen = nepheline normative (CIPW).
PI (peralkaline index) = $(Na_2O+K_2O)/Al_2O_3$ molecular ratio.
ol = normative olivine.

(iii) fresh rocks were taken to be those with $H_2O^+ < 2$ per cent and $CO_2 < 0{\cdot}5$ per cent;

(iv) all analyses were recalculated to 100 per cent on a H_2O- and CO_2-free basis;

(v) the principle of minimum overlap between adjoining fields was employed;

(vi) The silica boundaries between the fields picrobasalt, basalt, basaltic andesite and dacite at 45, 52, and 63 wt. per cent SiO_2 were chosen to agree closely with those commonly in use (e.g. Peccerillo & Taylor, 1976). The value of 52 as the upper limit of basalt had already been considered by the Subcommission (Streckeisen, 1978). These silica boundaries are also close to the boundaries distinguishing ultrabasic, basic and intermediate igneous rocks (Carmichael *et al.*, 1974);

(vii) some boundaries were determined by locating their counterparts in the QAPF classification;

(viii) the boundary between the S and U fields was placed closely along the contour of the 10 per cent normative foid in the normative QAPF (i.e. the F value); and

(ix) the boundaries between fields S1-S2, S2-S3 and S3-T are parallel to the total normative content of felsic minerals.

The TAS classification should be used bearing in mind several restraints.

(a) The classification is purely descriptive.

(b) It is independent of field location or field association except that the rock in question is volcanic.

(c) No genetic relationships are implied.

(d) It was designed for unaltered volcanic rocks. The application of TAS for altered volcanic rocks is discussed by Sabine *et al.* (1985) who found that many low grade metavolcanic rocks can be satisfactorily classified by TAS.

(e) Analyses with $H_2O^+ > 2$ weight per cent or with $CO_2 > 0{\cdot}5$ per cent should be regarded with suspicion. All analyses must be recalculated to 100 per cent and free of H_2O and CO_2.

(f) The ratio of FeO to Fe_2O_3 is taken as that stated by the analyst. If none is stated, then a standard iron oxidation ratio is calculated following the method of Le Maitre (1976).

(g) The classification is not suitable for rocks that have undergone crystal enrichment or suffered metasomatism.

(h) The boundary separating field F from fields U is not entirely satisfactory since several nephelinites and leucitites overlap particularly into field U1. This problem is being investigated, and it appears to be related to the variable mafic content of these rocks.

In addition to the classification shown on Fig. 2, the following further distinctions are made.

(i) Basalts (field B) may be further subdivided into alkaline and subalkaline basalts depending on whether or not they have normative nepheline. This distinction, reconfirmed at the London 1985 meeting, was established as long ago as 1892 by Iddings, and has been in common use since then. Unfortunately this usage is at variance with that proposed by the USSR Terminological Commission (Bogatikov *et al.*, 1981, and reiterated by Andreeva *et al.*, 1983). They considered subalkaline basalts to be mildly alkaline basalts, and apply the term 'normal' basalts to those without normative nepheline.

(j) In field U1, the root name basanite is used if olivine exceeds 10 per cent in the CIPW norm; or tephrite if it is less.

(k) In field T, the trachydacite-trachyte distinction depends on trachydacites having more than 20 per cent normative Q in QAPF and trachyte having less. The limit 20 per cent normative Q in QAPF approximates to $Na_2O+K_2O = 9$ per cent by weight.

(l) Trachybasalt may be subdivided into hawaiite and potassic trachybasalt depending on

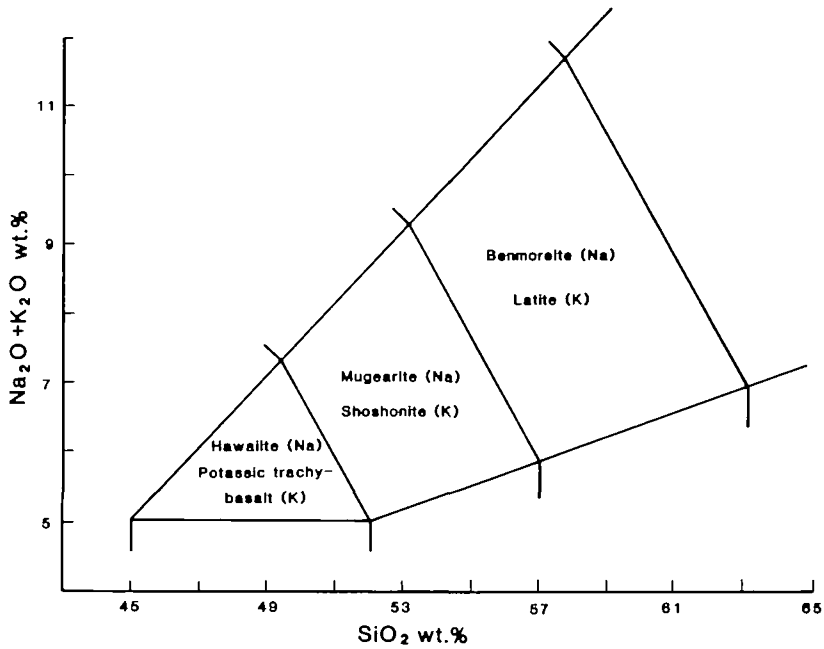

FIG. 3 The six sub-root names of the S fields, with (Na) after the sodic types and (K) after the potassic types.

the relative amounts of Na_2O and K_2O (by weight). If $(Na_2O-2) > K_2O$ then the rock may be considered 'sodic' and the name hawaiite employed. If $(Na_2O-2) < K_2O$ then potassic trachybasalt is appropriate.

(m) Using the same criteria, the sodic rocks mugearite and benmoreite are distinguished from the potassic rocks shoshonite and latite in fields S2 and S3 (Fig. 3).

(n) If desired, the prefixes 'sodic' and 'potassic' may be applied to all root names depending on whether $(Na_2O-4) > K_2O$ or $Na_2O < K_2O$ respectively.

(o) In fields T and R, if the peralkaline index $(Na_2O+K_2O)/Al_2O_3$ molecular ratio > 1, then the term peralkaline may be prefixed in accordance with normal usage (see Table 1).

(p) If the minerals in the rock require mentioning, then put them as prefixes in order of increasing amount, e.g. a hypersthene-augite andesite contains more augite than hypersthene.

These recommendations are the product of much correspondence and many meetings culminating in the gatherings at Granada, Moscow and London where the following members of the Subcommission were present at one or more meetings: G. Bellieni (Padua, Italy), F. Chayes (Washington, U.S.A.), H. De La Roche (Orleans, France), A. Dudek (Prague, Czechoslovakia), S. V. Efremova (Moscow, U.S.S.R.), J. Keller (Frieburg, W. Germany), J. Lameyre (Paris, France), M. J. Le Bas (Leicester, U.K.; chairman), R. W. Le Maitre (Melbourne, Australia), N. P. Mikhailov (Leningrad, U.S.S.R.), P. A. Sabine (London, U.K.), R. Schmid (Zurich, Switzerland), H. Sørensen (Copenhagen, Denmark), A. Streckeisen (Berne, Switzerland; ex-chairman), V. Szeky-Fux (Debrecen, Hungary), A. R. Woolley (British Museum, London; secretary) and B. Zanettin (Padua, Italy; ex-chairman). Further contributions and suggestions were also received from D. S. Barker (Austin, Texas, U.S.A.), I. Berbeleac (Bucharest, Romania), J. H. Brandle (Madrid, Spain), J. M. V. Coutinho (Sao Paulo, Brazil), K. G. Cox (Oxford, U.K.), A. Cundari (Melbourne, Australia), E. Justin-Visentin (Padua, Italy), E. A. K. Middlemost (Sydney, Australia), N. N. Pertsev (Moscow, U.S.S.R.), E. M. Piccirillo (Trieste, Italy), G. L. Snyder (Denver, U.S.A.), M. Stefanova (Sofia, Bulgaria), S. V. Sveshnikova (Moscow, U.S.S.R.), B. J. G. Upton (Edinburgh, U.K.), W. J. Wadsworth (Manchester, U.K.), M. K. Wells (London, U.K.) and J. F. G. Wilkinson (Armidale, Australia).

The Subcommission intends to conduct further discussions on improving the classification of the fields of foidites, ultrabasic and ultramafic volcanic rocks.

REFERENCES

Andreeva, E. D., Baskina, V. A., Bogatikov, O. A., Borodeavskaja, M. B., Gonshakova, V. I., Egorov, L. S., Efremova, S. V., Kovalenko, V. I., Lazko, E. E., Markovskii, B. A., Masaitis, V. L., Michailov, N. P, Nasedkin, V. V., Negrei, E. V., Petrova, M. A., Polunina, L A., Rotman, V. K., Rumjantseva, N. A., Simonova, L. I., Sobolev, R. N., Filippova, T. P., Frolova, T. I., & Jashina, R. M., 1983. Magmaticheskie gornye porody: klassifikatziva, nomenklatura, petrographiva. 2 vols. Akad. Sci. USSR. Moscow, (in Russian).

Bogatikov, O. A., Gonshakova, V. I., & Efremova, S. V., 1981. Klassifikatziva i nomenklatura magmaricheskich gornich porod. Moskow Nedra (in Russian).

Carmichael, I. S. E., Turner, F. J., & Verhoogen, J., 1974. *Igneous Petrology*. New York: McGraw-Hill.

Cox, K. G., Bell, J. D., & Pankhurst, R. J., 1979. *The Interpretation of Igneous Rocks*. London: Allen & Unwin.

De La Roche, H., Leterrier, P., Grandclaude, P., & Marchal, M., 1980. A classification of volcanic and plutonic rocks using the R1-R2 diagram and major element analyses. Its relationships with current nomenclature. *Chem. Geol.* **29**, 183-210.

Iddings, J. P., 1892. Origin of igneous rocks. *Bull. Phil. Soc. Washington*, **12**, 89-213.

Irvine, T. N., & Baragar, W. R. A., 1971 A guide to the chemical classification of the common volcanic rocks. Can. *J. Earth Sci.* **8**, 523-48.

Le Bas, M. J., & Sabine, P. A., 1980. Progress in 1979 on the nomenclature of pyroclastic materials. *Geol. Mag* **117**, 389-91.

Le Maitre, R. W., 1976. Some problems of the projection of chemical data into mineralogical classifications. *Contr. Miner. Petrol.* **56**, 181-9.

—— 1982. *Numerical Petrology*. Amsterdam: Elsevier.

—— 1984. A proposal by the IUGS Subcommission on the Systematics of Igneous Rocks for a chemical classification of volcanic rocks based on the total alkali silica (TAS) diagram. *Australian J. Earth Sci.* **31**, 243-55.

Middlemost, E. A. K., 1980. A contribution to the nomenclature and classification of volcanic rocks. *Geol. Mag.* **117**, 51-7.

Murray, J. W., 1981. *A Guide to Classification in Geology*. Chichester: Ellis Horwood Ltd.

Peccerillo, A., & Taylor, S. R., 1976. Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northern Turkey. *Contr. Miner. Petrol.* **58**, 63-81.

Rittmann, A., 1973. *Stable Mineral Assemblages of Igneous Rocks*. Heidelberg: Springer-Verlag.

Sabine, P. A., Harrison, R. K., & Lawson, R. I., 1985. Classification of volcanic rocks of the British Isles on the total alkali oxide-silica diagram, and the significance of alteration. British Geological Survey Report, Vol. 17, no. 4.

Schmid, R., 1981. Descriptive nomenclature and classification of pyroclastic deposits and fragments: recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks. *Geology*, **9**, 41-3.

Streckeisen, A., 1973. Classification and nomenclature of plutonic rocks: recommendations *N. Jb. Miner. Monat Jg.* 1973, 149-64.

—— 1976*a*. To each plutonic rock its proper name. *Earth-Sci. Rev.* **12**, 1-33.

—— 1976*b*. Classification of the common igneous rocks by means of their chemical composition: a provisional attempt *N. Jb. Miner. Mh. Jg.* 1976, 1-15.

—— 1980. Classification and nomenclature of volcanic rocks, lamprophyres, carbonatites and melilitic rocks. *Geol Rundschau*, **69**, 194-207.

—— & Le Maitre, R. W., 1979. A chemical approximation to the modal QAPF classification of the igneous rocks. *N Jb. Miner. Abh.* **136**, 169-206.

Zanettin, B., 1984. Proposed new chemical classification of volcanic rocks. *Episodes*, **7**, 19-20.