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The IUGS systematics of igneous rocks

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Abstract: In order to create a sustainable classification of igneous rocks which all geologists might use, an international body was set up by the IUGS: the IUGS Subcommission on the Systematics of Igneous Rocks. In the course of creating the classification, the Subcommission has established ten principles for its construction and for defining an appropriate nomenclature. The principles are: (1) use descriptive attributes; (2) use actual properties; (3) ensure suitability for all geologists; (4) use current terminology; (5) define boundaries of rock species; (6) keep it simple to apply; (7) follow natural relations; (8) use modal mineralogy; (9) if mode not feasible, use chemistry; (10) follow terminology of other IUGS advisory bodies. These principles and their rationale have not previously been enunciated.

The classification separates and individually classifies the pyroclastic, carbonatitic, melilitic, lamprophyric and charnockitic rocks before entering the main QAPF classification for plutonic and volcanic rocks which is based on the modal mineral proportions of quartz (Q), alkali feldspar (A) and plagioclase (P) or of alkali feldspar (A), plagioclase (P) and feldspathoids (F). Rocks with mafic content >90% have their own classification. If the mineral mode cannot be determined as is often the case for volcanic rocks, then a chemical classification of total alkalis versus silica (TAS) is used. The nomenclature for these classifications necessitates only 297 rock names out of the *c.* 1500 that exist.

200 years ago, the Academy of Sciences of St Petersburg (at present Leningrad) offered a prize for the best essay on the classification of rocks. Soon after, Kirwan (1794) coined the phrase 'igneous rock'. Today, the study of igneous rocks is a vast subject, and the task is still to create a systematic and sustainable classification of the many different types now recognized.

Early attempts to classify igneous rocks varied. Some were based on petrography and mineralogy (e.g. von Cotta 1866; Rosenbusch 1887), some utilized a notation of symbols for minerals and textures (e.g. Michel-Levy 1889), and a few looked to chemistry (e.g. Roth 1861). In the early part of this century and well recorded by Johannsen (1939), Loewinson-Lessing, Lacroix, Niggli and Washington independently produced *c.* 70 papers which attempted to systematize igneous rock nomenclature. Loewinson-Lessing emphasized the petrographical and mineralogical assemblage as the prime means for defining different rocks. Lacroix included rock chemistry in his classification and produced a complex hierarchy of terms with a mathematical notation to characterize each rock. Washington used chemical analyses to calculate a standard (the CIPW normative) mineral assemblage which formed the basis of another complex hierarchy of classes, orders and rangs. These and others like them never found broad acceptance. They were too cumbersome. Igneous classifications based on supposed genesis have also failed, usually owing to the inadequacies of the genesis proposed, although a truly genetic classification may ultimately be constructed.

Despite these failures, the mineralogical and chemical approaches to rock classification have continued to modern times as the basis for differentiating igneous rocks, with identification of the mineral assemblage becoming the dominant means of distinguishing one rock from another. This is despite the knowledge that it is not always easy to determine the precise mineral assemblage of many fine-grained igneous rocks.

Rock names were often given after the type locality for the rock, e.g. gabbro, from the village of Gabbro near Florence in northern Italy; and urtite from Lujavr-Urt in the Lovozero complex, Kola Peninsula, USSR. Sometimes a more useful name was derived from the mineral assemblage, e.g. peridotite. Either way, new names proliferated, particularly for alkaline rocks. Johannsen sought to systematize the growing nomenclature, and published 'A descriptive petrography of the igneous rocks' in four volumes (1932–1939), which came to dominate the thoughts of petrologists in the English-speaking world.

At much the same time, Niggli (1931) presented a system for the classification and nomenclature of igneous rocks according to modal mineral contents. He followed this (1936*a*, *b*) with a system of classifying igneous rocks by their chemical compositions, which system was based on molecular numbers ('Niggli numbers'), systematized as 'magma types'. These 'magma types' were not rock names but adjectival attributes. The thoroughness of Niggli's scientific work dominated the minds of petrologists in the German-speaking world. Tröger (1935) published a most useful compendium of igneous rock types, listing for each type the mineral content, rock chemistry, systematic position in the Niggli and other classifications, original type locality and reference to the original description.

With the establishment of the IUGS in 1961, a greater awareness developed of the advantages of international cooperation in science, although some had been possible through the meetings every four years of the International Geological Congress (IGC). At the IGC meeting in Prague in 1968, a meeting under the leadership of Mehnert was planned to discuss the earlier and widely circulated proposals by Streckeisen (1967) on the classification and nomenclature of igneous rocks. Regrettable political events prevented any thorough discussion, and therefore IUGS created a Subcommission which should deliberate the various problems and present definite recommendations to IUGS. The Subcommission on the Systematics of Igneous Rocks began its work in 1969, held a working meeting in Berne in 1972, and then presented its first report at the 1972 IGC in Montreal. Since then, the Subcommission has met at Grenoble (1975), Sydney (IGC, 1976), Prague (1977), Padua (1979), Paris (IGC, 1980), Cambridge (1981), Granada (1983), Moscow (IGC, 1984), London (1985), Freiburg im Breisgau (1986), Copenhagen (1988) and Washington DC (IGC, 1989). 419 people from 49 countries have participated in the discussions and recommendations made at these meetings, and through discussion papers and questionnaires circulated between the meetings.

Such sustained discussion brought together the different lines of thought that previously existed. International co-operation had been achieved, and the outcome is the book 'A Classification of Igneous Rocks and Glossary of Terms: Recommendations of the International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks' (R. W. Le Maitre *et al.* 1989). Although the international language of science is English, the book is being translated in whole or in part to other leading languages.

The book is based on principles established by the Subcommission, and gives recommendations on classification and nomenclature agreed by the Subcommission. It also provides a glossary of over 1500 igneous rock names that have been used in the past. The Subcommission decided that fewer than 300 igneous rock names were sufficient to characterize all igneous rocks. Fewer than a hundred is all that is required when dealing with the more common igneous rocks. Unanimity of nomenclature was not reached for all igneous terms, and debate continues about how best to classify the potassic, the lamprophyric and a few other groups of rocks.

Principles of classification

Ten principles have been established over the 20 year period of the deliberations of the Subcommission, but the rationale of their development has not previously been stated.

Objects being classified must be well identified. Their distinction usually results in the object being given a name or some identity tag. The purpose of classification is to promote a systematic means of distinguishing one object from another, using unequivocal terms of identification. For igneous rocks, the unequivocal terms available are their evident physical and chemical properties. It is also necessary that the properties are intrinsic to the rock itself and not to the environment in which it occurs. Thus, even an isolated sample obtained from a borehole or from a glacial erratic should be capable of being given a name which conveys to another geologist the identity of the rock sample. *The first principle, therefore, is that igneous rock nomenclature should be based on descriptive attributes.*

The descriptive attributes of a rock must be distinguished from interpretative attributes. The interpreted characters of a rock are those deduced from a conceptual understanding of it, and they may differ from person to person. Since they can differ, they are not factual. The most common interpretations made by geologists are petrogenetical, but there could also be aesthetic considerations. Even such properties as the age of a rock can be uncertain and therefore not suitable for primary rock classification. *The second principle is that classification should depend on actual attributes and not on interpreted characters.*

Classifications must be intelligible to all who use them. In the present case, igneous rock classification must be usable by all geologists. A granite identified by a field geologist or mining engineer should also be given that name by the specialist petrologist or geochemist. Conversely, the same name should not be given to two different rocks. Such names are best removed from current usage owing to their ambiguity. *Thus the third principle is that the basic or root name given to a rock should be one that is suitable for all geologists to use.*

There is considerable logic in the statement that 'if a new classification is set up, it should employ new terms, i.e. new rock names'. The aim would be to avoid ambiguity and equivocal definition in the terminology. However, with several hundred igneous rock names currently in use, to create new ones, which would effectively mean more in at least the short term, would lead to unacceptable confusion. This point is contentious, and the balance of the argument has been whether the present terminology is so bad that a totally new one is preferable. The Subcommission has taken the view, but not without lively argument, that radical new nomenclature is not usually accepted. It has been tried before in igneous rock classification, and the merits of the various systems proposed are evident in some of the terms which have been adopted. The normative scheme of Cross, Iddings, Pirsson, Washington (1902) for realising the properties of rocks through their chemistry is widely used, as are several of the terms formulated by Shand for his chemically-based classification (1949). But their classifications never gained wide acceptance. *The fourth principle is that the terms to be used in any classification should follow, as far as possible, those which are currently and widely accepted as being useful terms.*

A useful classification necessitates the recognition of boundaries between the different classes of objects being identified. In contrast, some classifications are based on the characterization of a typical or average sample. One for example, is the classification of Johannsen, quoted above, in which full petrographic descriptions supported by chemical analyses are given for each compartment within the classification. The more recent two-volume work of Andreeva *et al.* (1983) follows this procedure with even greater emphasis on the chemistry of each rock type. The problem here is what to do if a sample is not a close match to any type sample but has similarities to two or three. Since most rocks form a continuum of types rather than falling into discrete groups, as most biological samples do, it is necessary to erect notional boundaries which divide one category from the next. Since the boundaries are not natural, they can be drawn at any convenient place. *The fifth principle is that the classification must consist of classes which are separated by boundary conditions.*

Many sophisticated igneous rock classifications have been created, such as that by Johannsen into families, orders and other subdivisions. But the complexity, like that for the CIPW and Shand systems mentioned above, led to it never being widely applied. The only classifications that have been widely used, are those which are simple to apply. It is a natural and inevitable corollary that geologists have and will create more complex classifications, often devised for limited fields of investigation. These have their clear uses. The aim of the Subcommission is to produce a classification which will provide a sufficiently sound and broadly based classification of least controversy, on which the science of igneous petrology can build. *Well-established simplicity is the sixth principle.*

In a pragmatic manner, it is reasonable to discover what other considerations cause classifications to be adopted. It is evident that classifications that correlate with unequivocal inter-relationships, are commonly adopted. The relationships may be those observed in the field or they may be relationships deduced from petrogenetic considerations. The simpler these relationships, the greater the use that has been made of them. *The seventh principle is that any classification of igneous rocks should follow fundamental geological relationships.*

The vindication of this last principle is the success of the division into the plutonic versus volcanic classification which has been accepted since its formalization by Rosenbusch over 100 years ago. It would not have been acceptable 200 years ago in the days of Werner who thought granites were sediments. But the division raises the problem that the terms plutonic and volcanic are fundamentally interpretative. However, their identification with rocks that have respectively phaneritic or aphanitic textures, has permitted the terms plutonic and volcanic to be validated. To most geologists, these two terms imply coarse-grained and fine-grained characters; for some, an intermediate category is required, and then hypabyssal and medium-grained are employed. The difficulty of the trio of terms 'plutonic', 'hypabyssal' and 'volcanic' is that the boundaries between them are often impossible to establish. Use of grain size would solve the problem, and would be in accord with the first principle. Thus the sixth principle is not without its hazards.

There is a choice of properties which might be used in describing an igneous rock, but the one which has consistently received the widest use over the last 100 years, is the mineral assemblage. It is not denied that other characters, such as geophysical or geochemical or mechanical, are of value, but the prime property to be used in all cases is the mineral assemblage together with the relative proportions of the minerals in that assemblage. *The eighth principle is that classification should be based on modal mineralogy, as far as possible.*

In many cases, igneous rocks are too fine-grained for the minerals to be identified, even under the microscope. Some, even with identifiable minerals, are so fine-grained that the modal proportions cannot be determined accuractely. The latter is also impossible if the rock contains glass. In these cases, the Submission decided that chemical analysis was the next best descriptive property to be employed in characterizing an igneous rock, but that the mineralogical approach should always be applied first. To ensure that chemical analyses may be comparable, all must be recalculated anhydrous to 100%. *The ninth principle is that if the modal mineralogy of an igneous rock cannot be determined satisfactorily, then chemical analytical parameters should be the next property used.*

The use of chemical analyses does bring its problems. Not only is there the difficulty for many to obtain chemical analyses, but even with such data, two visibly different rocks can have identical chemical analyses. In such cases as the gabbro–basalt pair, there is no difficulty because the gabbro, being coarse-grained, would already have been classified modally using the above principles. But with many fine-grained potassic and lamprophyric rocks, for example, there is the difficulty of heteromorphic equivalents. One rock may be mica-rich another feldspar-rich, but they can give indistinguishable chemical compositions, apart from water content. This is a problematical area of classification that is still not resolved by the Subcommission.

The final principle concerns the use of geological terms which are more properly defined by other international bodies rather than by this Subcommission. The correctness of mineral names is the concern of the International Mineralogical Association, and the Subcommission has endeavoured to follow its recommendations. For example, barkevikite is no longer an accepted term, and in any new definitions of rocks, such discredited terms are not used. In cases where original definitions of rocks are quoted however, a discredited term may have to be used since, taking the example of barkevikite, it may not be known whether the original author meant kaersuitite or another brown amphibole. When the Subcommission came to deal with the pyroclastic rocks, it wanted to use internationally accepted divisions of grain size for sediments, but none exist. The recent establishment of a Subcommission on the Systematics of Sedimentary Rocks will, no doubt, create divisions which we will adopt, but in the meantime we have used those most widely quoted. *The tenth principle is that all terminology should be internationally acceptable.*

Having established the ten principles which should be followed in naming and defining rocks and in constructing a classification, the next step is to determine the methodology of the classification.

Tools of the IUGS classification

The first question is: how are the igneous rocks recognized and separated from other rocks? If igneous rocks are those which solidify from molten material, then very few, apart from lavas, can be observed to be igneous although many are so interpreted. Using the term 'igneous' violates principle 2, but the certainty of the interpretation is such that the violation can be overlooked. Nevertheless, there are cases where the igneous origin is in doubt; for instance, some granites are said to be metasomatic. Thus Rosenbusch's term 'Massige Gesteine' is the best simple description of an igneous rock because it implies a crystalline (or glassy) rock which, when observed in outcrop, has a uniform texture and massive character unlike metamorphic and sedimentary rocks. By this definition, charnockites, eclogites and the rocks of the mantle could all be included with the igneous rocks. Some would say all three are strictly metamorphic, but the Subcommission took the pragmatic view that eclogite is metamorphic but the others can be igneous. Dividing igneous rocks into plutonic and volcanic again violates principle 2, but again is accepted as a practicable procedure.

The prime tools of rock identification are the constituent minerals (principle 8), and the Subcommission uses the feldspars, together with quartz and the feldspathoids, as the principal component minerals for classification. This follows the long established choice of petrologists. It was

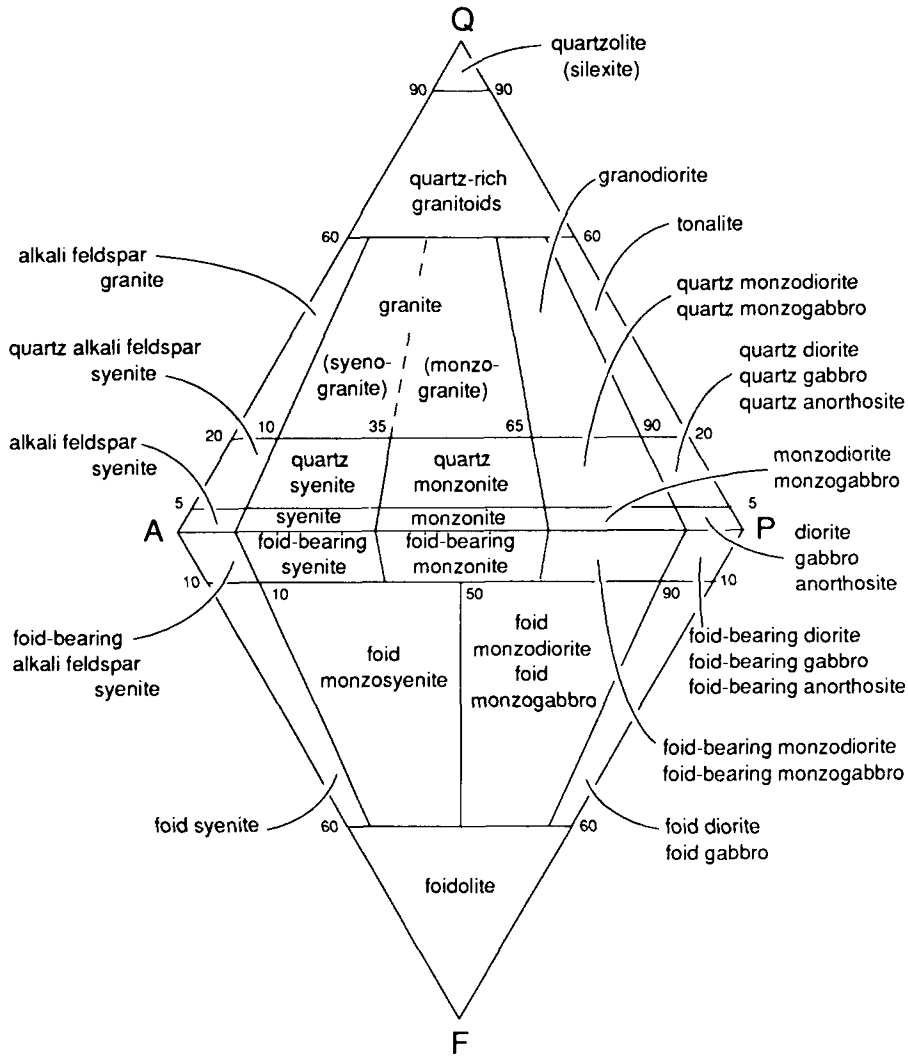

Fig. 1. Classification and nomenclature of the plutonic igneous rocks according to their felsic modal contents when mafic mineral content is less than 90%. Q, quartz; A, alkali feldspar; P, plagioclase; F, feldspathoid (foid). The equivalent classification for volcanic rocks is given in Le Maitre *et al.* (1989, fig. B.10) Figs. 1–6 in this paper are after Le Maitre *et al.* (1989).

recommended that the useful abbreviation 'foid' for feldspathoid be a permissable synonym.

Classifications based on these felsic minerals tend to be displayed either on a two-component diagram, such as that of Nockolds (1954), or on the double three-component plot of Johannsen which is now formalized as the IUGS QAPF system for rocks with felsic minerals >10% and mafic minerals <90% by volume (Fig. 1). The system works well mineralogically, but attempts to deduce the same classification from chemical data have not been satisfactory owing to the problem of how to divide the albite component between alkali feldspar and plagioclase. The problem has not been solved, although Streckeisen (1976) showed that with minor adaptation of the CIPW norm, a fair agreement could be reached between the mineral assemblage deduced from chemical analysis and the mode, for leucocratic, non-foidal rocks. Streckeisen & Le Maitre (1979) obtained better agreement between mode and norm by dividing the feldspar components according to the ratio An/(An + Or) although ultramafic rocks and foidal rocks still did not fit.

Most of the fields within the QAPF system have long been established, but some names and boundaries required adjustment following principles 4 and 5. An attempt to have the same boundaries in both the QAP and APF triangles was discussed, but found to be untenable; it did not fit current terminological usage. It was necessary to put Q at 20 in QAP whilst F must be at 10 in APF.

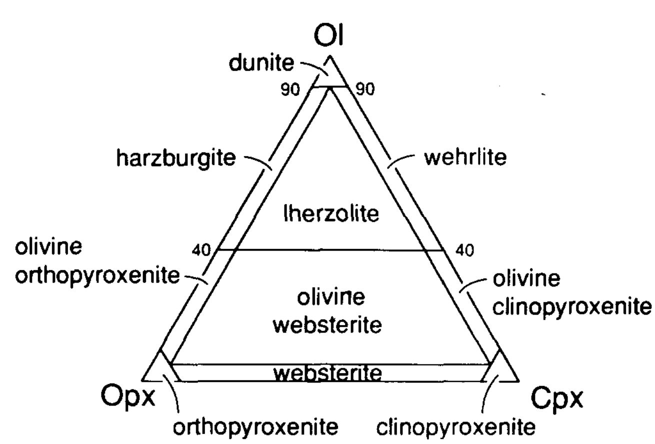

Fig. 2. Classification and nomenclature of the ultramafic rocks (M > 90%) based on the modal proportions of olivine (Ol), orthopyroxene (Opx) and clinopyroxene (Cpx).

Table 1. *The classification of the pyroclastic rocks based on clast size*

Clast size in mm	Pyroclast	Pyroclastic deposit: Mainly unconsolidated: tephra	Pyroclastic deposit: Mainly consolidated: pyroclastic rock
	Bomb, block	Agglomerate, bed of blocks or bomb, block tephra	Agglomerate, pyroclastic breccia
64			
	Lapillus	Layer, bed of lapilli or lapilli tephra	Lapilli tuff
2			
	Coarse ash grain	Coarse ash	Coarse (ash tuff)
1/16			
	Fine ash grain (dust grain)	Fine ash (dust)	Fine (ash) tuff (dust tuff)

(After Le Maitre *et al.* (1989).

When the felsic minerals component falls below 10% of the mode, triangular plots involving olivine, pyroxene and hornblende satisfactorily classify the peridotitic, pyroxenitic and hornblenditic ultramafic rocks (Fig. 2). The prefixes leuco- and mela- can be applied to all the rocks in the QAPF fields. The simple division by which leucocratic might have >50% light-coloured minerals and melanocratic <50%, unfortunately does not correspond to current usage. Therefore, following principle 4, each field has had to have its own limits set. For instances, a leuco-granite has <5% mafic minerals, and a mela-granite >20% mafic minerals, but a leuco-gabbro has <35% mafic minerals and a mela-gabbro has >65% mafic minerals. The leuco-/mela-divisions for other rock types are given in Le Maitre *et al.* (1989, fig. B.7a, b).

The ultramafic and QAPF classifications work well for the majority of the plutonic and coarse-grained rocks, but not for all. The lamprophyres, the charnockites, the melilite-rich rocks and the carbonatites have each received entirely independent modal classifications, some more satisfactory than others. Pyroclastic rocks have also been classified independently. A Working Group was set up to consider the pyroclastic rocks and numerous questionnaires were circulated to more than 150 geologists. Several more detailed classifications were proposed before the simple size versus pyroclast type was agreed, following principles 4 and 6 (Table 1).

The discussions on carbonatite nomenclature quickly dismissed the usage of the plethora of exotic names formerly favoured by alkaline rock petrologists, because current workers prefer straight-forward terms such as calcite-carbonatite, dolomite-carbonatite and ferrocarbonatite to characterize the modal properties evident in the name. If the type of carbonate cannot be determined optically, then a chemical classification is used (Fig. 3).

Melilite is deemed to be a mafic mineral although light-coloured. Of the QAPF minerals, it is compatible only with the feldspathoids, and any rock containing significant melilite usually has less than 10% felsic minerals, thereby excluding it from the QAPF classification. Nor do these rocks fit the ultramafic classification, and thus a special classification was constructed that is based on the modal proportions of melilite, clinopyroxene and olivine (Fig. 4).

At an early stage in the Subcommission's discussions, charnockites were included because they have both igneous-looking textures and an association with igneous rocks. The presence of hypersthene (more accurately now, orthopyroxene) in a granite or a granodiorite characterized by perthitic feldspar, was taken to indicate a charnockitic rock.

Whilst the Subcommission has outline agreement on how the lamprophyres should be classified modally, it is not clear how lamproites and kimberlites should be treated, and how

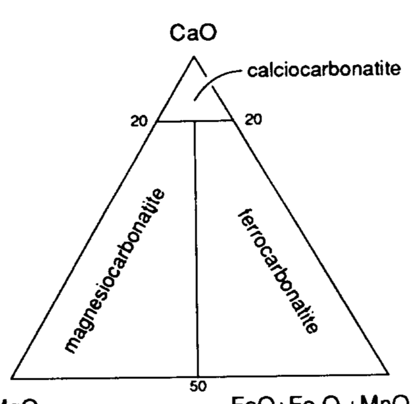

Fig. 3. The chemical classification of carbonatites using weight percent oxides.

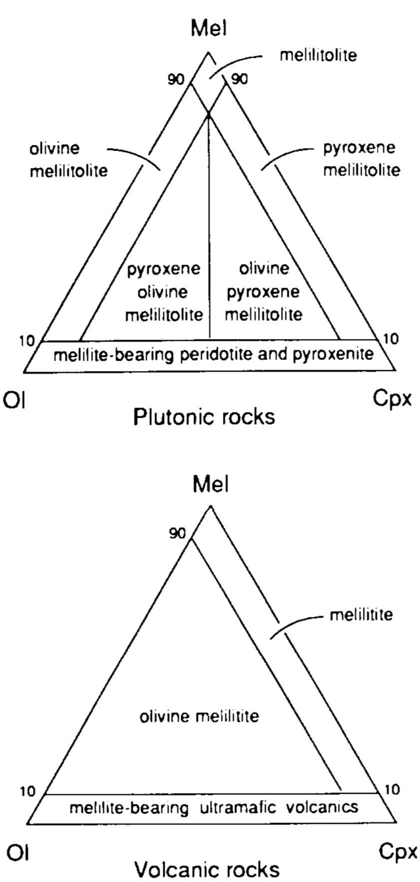

Fig. 4. The classification of the melilitic igneous rocks based on modal composition. Mel, melilite; Cpx, clinopyroxene; olivine.

Table 2. *The present classification of the lamprophyres*

Light-coloured constituents		Predominant mafic minerals			
Feldspar	Foid	Biotite, diopsidic augite, (±olivine)	Hornblende, diopsidic augite, (±olivine)	Amphibole, (barkevikite, kaersutite), Ti-augite, olivine, biotite	Melilite, biotite, ±Ti-augite, ±olivine, ±calcite
or > pl	—	Minette	Vogesite	—	—
pl > or	—	Kersantite	Spessaritite	—	—
or > pl	Feld > foid	—	—	Sannaite	—
pl > or	Feld > foid	—	—	Camptonite	—
—	Glass or foid	—	—	Monchiquite	Polzenite
—	—	—	—	—	Alnöite

Or, alkali feldspar; pl, plagioclase; feld, feldspar; foid, feldspathoid. (After Le Maitre *et al.* 1989).

they may relate to the lamprophyres. In order that the publication of the IUGS book on igneous classification should not be held up, the compromise was made to put these three groups of rocks under the general heading 'lamprophyric rocks' (Table 2), and that they should receive attention later. There is now (1991) a Working Group trying to resolve the several different opinions that exist on these rocks, particularly those expressed by Rock (1990).

If the mineral mode of a volcanic rock can be determined, then it is classified by QAPF, following a similar procedure to that for the plutonic rocks (Fig. 1). If the mode cannot be determined, then principle 9 is followed and chemical analysis is used. The chemical parameters it was decided to use were silica (SiO_2) weight per cent and total alkalis ($Na_2O + K_2O$) wt.% because they appeared to be the best and were already widely used. The proposal that ($Na_2O + 0.7K_2O$) be used instead of ($Na_2O + K_2O$) was considered. Using ($Na_2O + 0.7K_2O$) wt.% brings this parameter into relative equivalence with ($Na_2O + K_2O$) molec.% Despite this useful aspect, the simpler parameter was chosen following principle 6; the point being made that the sum of the oxides in whichever parameters were used was an artefact, and therefore the simpler it was, the easier it was to use (Fig. 5). A proposal to substitute MgO for the SiO_2 parameter was abandoned since MgO is not well tested for distinguishing volcanic rocks across the whole spectrum from basic to acid compositions. The R1–R2 diagram of de La Roche *et al.* (1980) in which $R1 = 4Si - 11(Na + K) - 2(Fe + Ti)$ and $R2 = Al + 2Mg + 6Ca$ cations per mil was looked at closely because it had the merit of encompassing the use of all the major oxides, which is advantageous when compared with the total alkalis–silica system. It was not adopted, partly because the two cation per mil parameters were difficult to calculate without electronic assistance, and partly because some of the boundaries were thought to be misplaced. The Subcommission considered it wiser, in such a fundamental issue as classification, to remain closer to a scheme that already had a long record of usefulness (principle 4).

Two decisions were made for determining the bound-

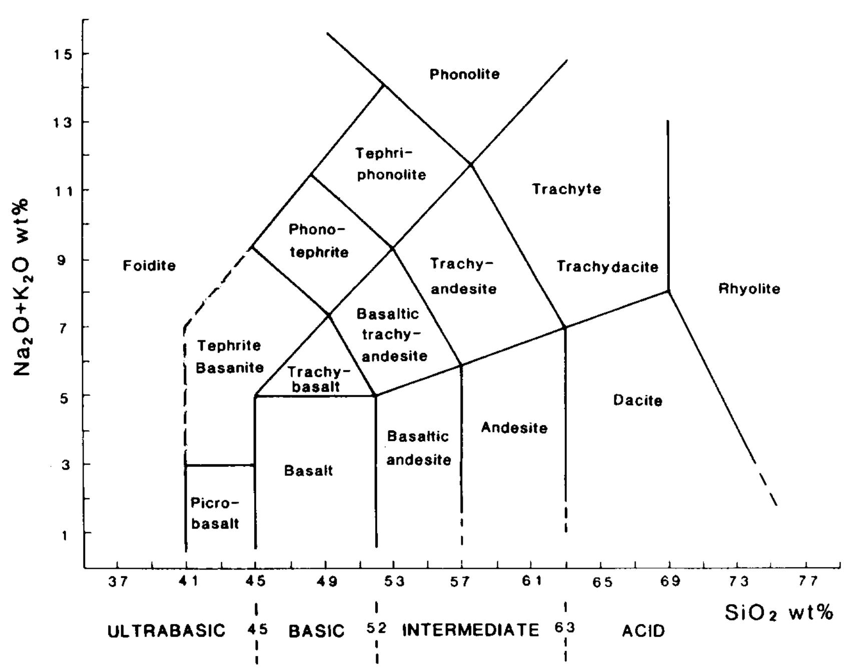

Fig. 5. The chemical classification of the volcanic rocks based on total alkalis versus silica (TAS). The line between the fields of foidite and basanite–tephrite is dashed because other criteria are necessary to distinguish those rock types (see Fig. 7). Basanite has normative olivine >10%; tephrite has normative olivine <10%; trachyte has quartz <20% of sum of felsic minerals; trachydacite has quartz >20% of sum of felsic minerals.

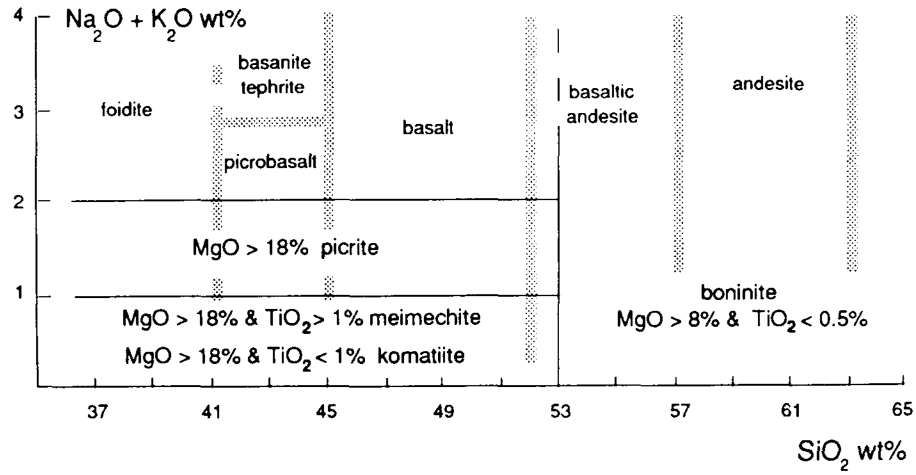

Fig. 6. The classification and nomenclature of the 'high-Mg' volcanic rocks (picrite, meimechite, komatiite, boninite) using TAS (thick boundaries) together with MgO and TiO_2 wt% (thin boundaries).

aries within the total alkali–silica (TAS) system (Fig. 5). First, to use the SiO_2 categories of ultrabasic, basic, intermediate and acid established by Loewinson–Lessing (1889) to distinguish the boundaries of the basalts ($45 < SiO_2 < 52$ wt.%), andesites ($52 < SiO_2 < 63\%$), dacites and rhyolites ($63 < SiO_2\%$). Second, to utilize the large computerized data base CLAIR (Le Maitre & Ferguson 1978) which contains not only chemical analyses of igneous rocks but also the rock-name of each analysis. The data base could be used to plot each volcanic rock (e.g. all trachytes) on frequency distribution diagrams and so put best-fit boundaries between adjacent fields. Despite some overlap between adjacent frequency distribution plots, the clear clustering of the points for any one rock type indicated where boundaries should be placed according to generally accepted usage. Rather than choosing curved boundaries between the fields, the Subcommission decided to employ straight lines between easily determined points to divide them. Thus, basalt is now defined chemically as having between 45 and 52 wt.% SiO_2 and <5 wt.% ($Na_2O + K_2O$). One of the merits of the TAS system is that the boundaries are definitive although they could be criticized as over simplistic. Definitive boundaries remove the ambiguity in naming a rock which plots near a boundary between two adjacent rock types. The simple boundaries of the TAS system also enable the classification to be constructed in a few minutes by pencil and ruler.

The TAS system works well for the common rocks but is inadequate for many low-silica rocks. The high-Mg volcanic rocks (picrite, komatiite, meimechite and boninite) form a group not classified by the TAS system. Instead picrite, komatiite and meimechite are distinguished by >18% MgO and <52% SiO_2 and are further separated by their ($Na_2O + K_2O$) and TiO_2 contents. Boninite has ($52 < SiO_2 < 63$ wt.%), MgO > 8% and $TiO_2 < 0.5\%$ (Fig. 6).

Likewise the alkaline low-silica rocks also require classification apart from TAS. Owing to the small numbers of well identified nephelinitic, basanitic and tephritic rocks in the geological literature, the seriousness of the overlap of the nephelinitic rocks into the TAS field of the basanites and tephrites was not fully appreciated. To overcome this, rocks in those TAS fields were found to be better distinguished using CIPW parameters (Fig. 7): normative nepheline and normative albite (Le Bas 1989). The failure of TAS to discriminate these rock types is because at such low values of SiO_2, the individual contents of CaO, MgO and Al_2O_3 significantly influence the formation of plagioclase (abundant in basanite and tephrite but absent in nephelinite) at the same ($Na_2O + K_2O$) contents.

The details of the individual classifications are not given here, but can be found in Le Maitre *et al.* (1989).

Nomenclature

An universally acceptable classification must use universally acceptable nomenclature (principle 3). There exist over 1500 rock names of which only a few hundred are completely obsolete. Some rocks have many names. Some are synonyms, such as liparite and rhyolite, dellenite and rhyodacite. Many are names given to varieties of common rocks, such as domite for biotite trachyte, or cortlandtite for a pyroxene olivine hornblendite with a specific poikilitic texture. Some are now considered to be self-contradictory, such as nepheline basalt for nephelinite, because basalt by modern definition has plagioclase but nephelinite does not contain plagioclase. When the term nepheline basalt was

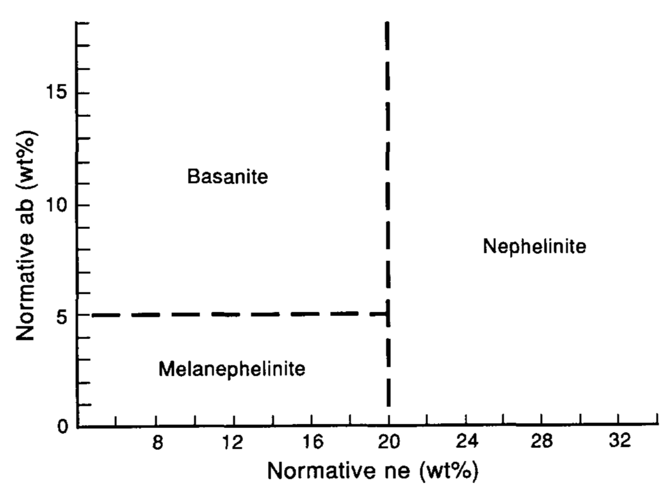

Fig. 7. The CIPW normative ne versus ab classification and nomenclature of non-melilitic volcanic rocks with $Na_2O > K_2O$ that plot in the TAS fields (Fig. 5) of foidite and basanite–tephrite (after Le Bas 1989).

coined in 1850, the presence of plagioclase was not implied by that term.

Instead of trying to decide which rock names are not necessary, the Subcommission investigated what names were best for the categories created by the QAPF, TAS and minor classifications. Plutonic and volcanic QAPF require less than 50 root names although some pre-fixing is required, such as nepheline syenite and quartz diorite, to obtain the full range needed. TAS requires fewer than ten further names, but did require three new names to occupy fields otherwise nameless; picrobasalt, potassic trachybasalt and basaltic trachyandesite. Together with the specialized classifications for ultramafic, charnockitic, pyroclastic, lamprophyric, melilitic and carbonatitic rocks, a total of 297 names and terms are used in the IUGS classification. Following principle 4, most are ones already in common use and most have required only little alteration from their previous definition. The alterations were nearly all minor changes in the positions of the boundaries to the fields defining them. Some rock types had not previously been defined in this way, merely characterized (e.g. tonalite).

Of the 297 names recommended for use by the IUGS, about 100 are necessary for pre-fixed root-names in order to define and distinguish such rock types as olivine gabbro, pyroxene hornblendite, quartz monzonite and analcime phonolite from ordinary gabbro, hornblendite, monzonite and phonolite. Another approximately 100 names are for the less common rocks, many of them alkaline, such as hauynite, ijolite, italite and kugdite. This leaves less than 100 names as all that are required by a geologist dealing with the more common igneous rocks.

Since igneous petrology is an international science, the Subcommission wishes all terms to have the same validity in all countries, allowing for variations arising from problems of translation. Care was taken, as far as possible, to ensure that translation would not present misinterpretations. One area where there was variation in the meaning of a standard term was with the use of the term subalkali basalt. It arose from a mis-translation and has caused much misunderstanding. In the USSR, basaltic rocks have been divided into 'alkali' (>5% norm ne), 'sub-alkali' (norm ne <5%) and 'normal' (norm ne 0%, norm (hy + ol) > 0%). In the rest of the world, basalt is defined as 'alkali' (norm ne >0%) or as 'sub-alkali' (norm ne 0%, norm (hy + ol) > 0%), as defined by Iddings in 1895. This has been resolved in the USSR by substituting the term 'mid-alkali' for USSR 'sub-alkali' and thus permitting 'sub-alkali' to be used everywhere for 'normal' basalts in order to conform with IUGS recommendations.

Procedure

The aim of the IUGS classification of igneous rocks is that it should be capable of being used in a logical sequence to name any igneous rock. The flow-chart (Fig. 8) gives the sequence of that logic. The first step is to confirm that the rock is igneous and therefore suitable for the classification. Then the suitability of the rock for special classification must be tested before going on to the main QAPF and possibly TAS classifications. The following questions must be asked in sequence.

(1) Is it a pyroclastic rock? If it is, use the pyroclastic classification, if not, go to the next question.

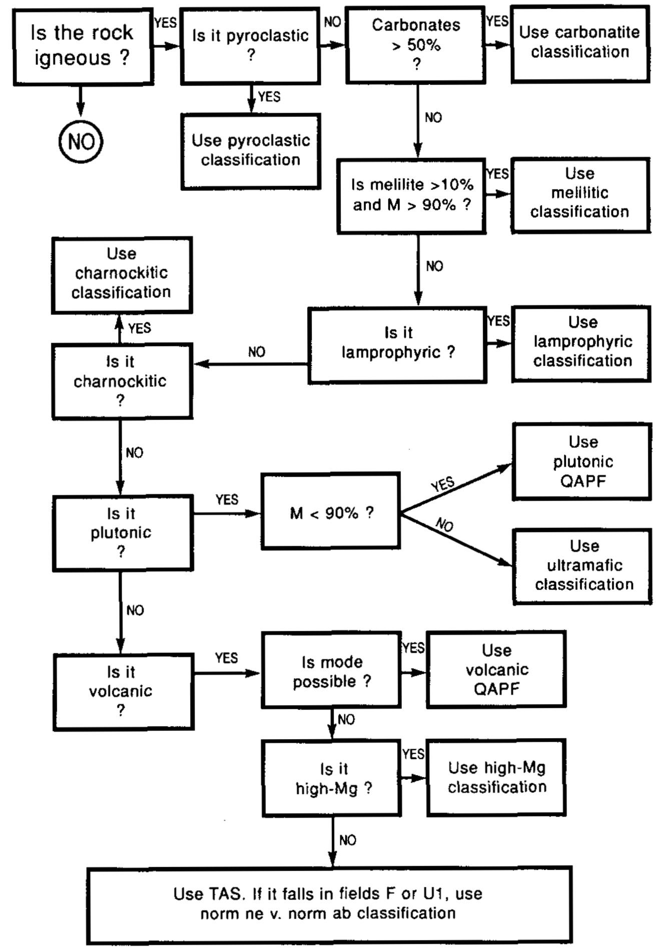

Fig. 8. Simplified flow chart, beginning at the top left, showing the sequence followed by the IUGS scheme for naming an igneous rock using the individual classifications described.

(2) Does the rock have more than 50% modal carbonate minerals? If so, use the carbonatite classification.
(3) If the rock is ultramafic and contains more than 10% modal melilite, use the melitic rocks classification.
(4) Is the rock lamprophyric? This is generally understood to mean that it forms a minor intrusion, is strongly porphyritic with only mafic phenocrysts, usually biotite, amphibole or pyroxene, and that feldspar, if any, is confined to the groundmass. If so then use the lamprophyric classification.
(5) If the rock is orthopyroxene-bearing, plutonic and belongs to the granitic association, use the charnockitic classification.
(6) If the rock is plutonic, then use the QAPF classification for plutonic rocks, noting that if the modal content of mafic minerals is more than 90%, then the minor classifications for ultramafic rocks should be used.
(7) If the rock is volcanic and the mineral mode can be determined, then use the QAPF classification for volcanic rocks.
(8) If the rock is volcanic and the mineral mode cannot be determined, then the chemical classifications related to TAS should be used.

All classifications are regrettably imperfect, and the Subcommission continues to seek to improve them. All comments and contributions for improvement would be gratefully received.

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