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CLASSIFICATION OF LAMPROPHYRES, LAMPROITES, KIMBERLITES, AND THE KALSILITIC, MELILITIC, AND LEUCITIC ROCKS*

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Abstract

The nomenclature and classification of lamprophyres, lamproites, kimberlites and the kalsilitic, melilitic and leucitic rocks are inadequately defined. The recommendations of three working groups established by the IUGS Subcommission on the Systematics of Igneous Rocks to resolve aspects of the problem are presented for discussion. New definitions of the above are given, variously in mineralogical and geochemical terms, and a revised sequence for the systematic classification of the rocks is provided, which integrates with the existing IUGS hierarchical system.

Keywords: lamprophyre, lamproite, kimberlite, kalsilitic rocks, melilitic rocks, leucitic rocks, classification.

Sommaire

La nomenclature et la classification du clan des lamprophyres, lamproïtes, kimberlites, et des roches à kalsilite, mélilite, et leucite n'ont jamais été définies de façon satisfaisante. Nous présentons ici pour fins de discussion les recommandations de trois groupes de travail établis par la sous-commission chargée de la systématisation des roches ignées de l'Union Internationale des Sciences Géologiques. Nous présentons des définitions nouvelles des membres de ce clan, en termes soit minéralogiques, soit géochimiques, et une séquence nouvelle de classification systématique, intégrée au schéma hiérarchique du système existant de l'IUGS.

(Traduit par la Rédaction)

Mots-clés: lamprophyre, lamproïte, kimberlite, roches à kalsilite, roches à mélilite, roches à leucite, classification.

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* Recommendations of the International Union of Geological Sciences (IUGS), Subcommission on the Systematics of Igneous Rocks.

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Introduction

In 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"* (Le Maitre *et al.* 1989), lamprophyres, lamproites and kimberlites were amalgamated under the heading "lamprophyric rocks". This was regarded as a provisional expedient until, as noted in the Preface of the book, a more satisfactory classification could be established. In the book *"Lamprophyres"*, Rock (1991) went even further and placed lamproites and kimberlites in his "lamprophyre clan". However, to many petrologists, inclusion of lamproite and kimberlite with the lamprophyres is either inappropriate or incorrect because the term *lamprophyre* is devalued, whereas the classification of lamproites and kimberlites is not furthered.

During a meeting of the Subcommission at the International Geological Congress in Washington in 1989, three working groups were established to reconsider the classification of these rocks, together with certain feldspathoidal and leucitic, melilitic, and kalsilitic rocks, which are also inadequately defined in Le Maitre *et al.* (1989). The working groups included members of the Subcommission, and several specialists, particularly in the areas of kimberlitic and lamproitic rocks, were invited to participate. This contribution brings together the findings of the working groups and the Subcommission on these topics, and is presented as the best *compromise* currently achievable. The recommendations are presented for discussion and should not be regarded as the definitive statement on the topic.

The objective of the Subcommission is not to create a highly detailed taxonomy, either mineralogical or chemical, but to provide a broadly based classification to be used in a logical manner by any geologist. The classification suggested follows the principles established by Le Bas & Streckeisen (1991).

The classification of these exotic alkaline rocks is not a trivial task, and there will probably never be, at least in our lifetimes, a truly practical and workable scheme. Advances have been made in the past two decades in kimberlite and lamproite nomenclature, primarily because of their economic importance. In contrast, the vast array of lamprophyres has not received the same amount of attention, and there will be a slow natural evolution of our ideas regarding their classification as a consequence of subsequent investigations.

Integration with the IUGS Hierarchical System

Any classification should be capable of integration with the IUGS hierarchical system described by Le Maitre *et al.* (1989) and Le Bas & Streckeisen (1991, Fig. 8). In the published hierarchical system, lamprophyres, lamproites and kimberlites were combined under "lamprophyric rocks", but if this portmanteau term is to be abandoned, then it must be replaced by a logical hierarchy of classification for these three groups of rocks that integrates them with the melilitic and leucitic rocks.

Lamprophyres do not lend themselves to either mineralogical or chemical classification on account of their very variable H_2O and CO_2 contents, which are primary in some instances and secondary in others, and which are not taken into account in most proposed classifications. Nevertheless, the members of the working groups and the Subcommission agreed almost unanimously that the following proposals were a step in the direction of establishing a nomenclature with minimum ambiguity and maximum usefulness.

It must be stressed, however, that the hierarchical system presented here is not definitive and has minimal genetic content. Any classification of a rock as a lamprophyre, kimberlite or lamproite using this system should be considered provisional until further investigations have been undertaken using the specialized literature as a key to correct classification.

Proposed System for the Classification of Melilitic, Kalsilitic, Kimberlitic, Lamproitic and Leucitic Rocks and Lamprophyres

Classification of melilitic rocks

The melilite-bearing rock classification is used for rocks with >10% modal melilite. Triangular plots are presented for plutonic (melilitolite) (Fig. 1) and volcanic (melilitite) rocks (Fig. 2), and Table 1 is intended for melilitic rocks containing kalsilite.

If the mode cannot be determined, then one should apply the total alkalis *versus* silica (TAS) chemical classification, as follows: (a) The rock should plot in the foidite field. (b) If the rock does not contain kalsilite but has larnite in the norm, then one should apply Figure 3. (c) If normative larnite is greater than 10% and K_2O is less than Na_2O (wt%), then it is a melilitite or olivine melilitite. (d) If K_2O is greater than Na_2O and K_2O exceeds 2 wt%, then it is a potassic melilitite or potassic olivine melilitite. The latter can be termed a *katungite*, which mineralogically is a kalsilite – leucite – olivine melilitite. (e) If normative larnite is less than 10%, then the rock is a melilite nephelinite or a melilite leucitite according to the nature of the dominant feldspathoid mineral.

Classification of kalsilitic rocks

The principal minerals of the kalsilitic rocks include clinopyroxene, kalsilite, leucite, melilite, olivine and phlogopite (Table 2). These rocks cannot be called

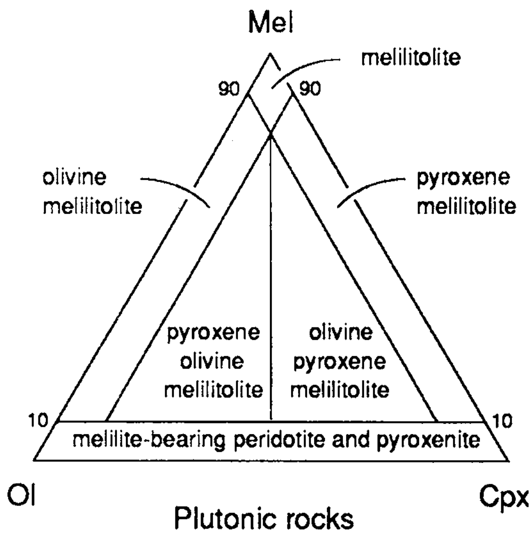

FIG. 1. Classification of the plutonic (melilitolite) melilitic rocks with modal melilite >10% (Le Maitre *et al.* 1989 Fig. B.3).

pyroxenite because that term is reserved for plutonic rocks. The rock types mafurite and katungite, together with the closely associated leucitic rock ugandite (which is excluded from Table 1, as it does not contain kalsilite and is more logically classified as an olivine leucitite), constitute the kamafugitic series of Sahama

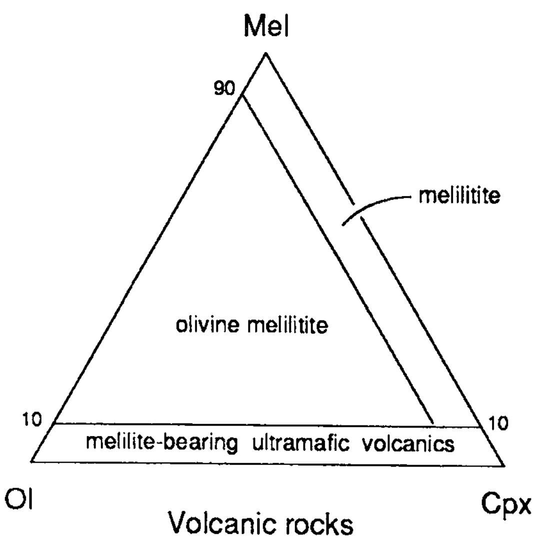

FIG. 2. Classification of the volcanic (melilitite) melilitic rocks with modal melilite >10% (Le Maitre *et al.* 1989, Fig. B.3).

TABLE 1. SUGGESTED NOMENCLATURE FOR KAMAFUGITIC ROCKS

Rock name	Mineral Assemblage
Mafurite	Olivine-pyroxene kalsilitite
Katungite	Kalsilite-leucite-olivine melilitite
Venanzite	Kalsilite-phlogopite-olivine-leucite melilitite
Coppaelite	Kalsilite-phlogopite melilitite

(1974). From the point of view of the IUGS system of classification, the presence of essential melilite or leucite (or both) indicates that either the classification that deals with melilitic or leucitic rocks should be applied. However, the presence of kalsilite and leucite is considered petrogenetically so distinctive and important that the accepted term, kamafugite, should be retained for this consanguineous series of rocks. Table 1 indicates their nomenclature as a function of mineral assemblage.

Plutonic kalsilitic rocks of the Aldan and North Baikal petrological provinces of Russia, which are not kamafugitic, may be distinguished by the prefix "kalsilite". Thus, synnyrite becomes kalsilite syenite, and yakutite becomes kalsilite–biotite pyroxenite.

Classification of kimberlites

Kimberlites are currently divided into Group I and Group II (Smith *et al.* 1985, Skinner 1989). Group-I kimberlites correspond to archetypal rocks from Kimberley, South Africa, which were formerly termed "basaltic kimberlites" by Wagner (1914). Group-II kimberlites correspond to the micaceous or lamprophyric kimberlites of Wagner (1914).

Petrologists actively studying kimberlites have concluded that there are significant petrological differences between the two groups, although opinion is divided as to the extent of the revisions required to their nomenclature. Some wish to retain the *status quo* (Skinner 1989), whereas others (Mitchell & Bergman 1991, Mitchell 1994b) believe that the terminology should be completely revised (see below). Regardless, the working group is unanimous in agreeing that a single definition cannot be used to describe both rock types. Because of the mineralogical complexity of the rocks, a simple succinct definition cannot be devised. Following a concept originally developed by Dawson (1980), the rocks may be recognized as containing a characteristic assemblage of minerals.

The following characterization of Group-I kimberlites is after Mitchell (1995), which is based essentially on that of Mitchell (1986, 1994b), and

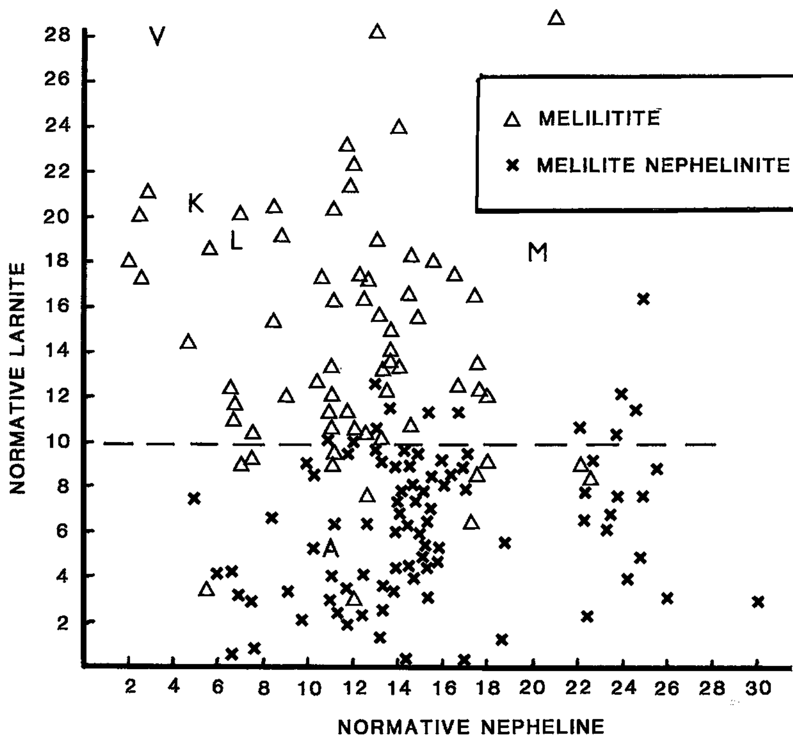

FIG. 3. Plot of normative nepheline *versus* normative larnite for melilitic lavas showing the proposed boundary (dashed line) between the melilitites and melilite nephelinites. The data plotted are taken from eastern, western and southern Africa, Europe, the former USSR, Australia, and U.S.A., including Hawaii, and are variously described as olivine melilitite, melilitite or melilite nephelinite (see Le Bas 1989, Table 2). Also plotted are typical potassic melilitic volcanic rocks: A, melilite ankaratrite; K, katungite; L, leucite melilitite; M, potassic olivine melilitite; V, venanzite (kalsilite – phlogopite – olivine – leucite melilitite).

evolved from earlier "definitions" given by Clement *et al.* (1984) and Mitchell (1979).

Group-I kimberlites consist of volatile-rich (dominantly CO_2) potassic ultrabasic rocks commonly exhibiting a distinctive inequigranular texture resulting from the presence of macrocrysts (a general term for large crystals, typically 0.5–10 mm in diameter) and, in some cases, megacrysts (larger crystals, typically 1–20 cm) set in a fine-grained matrix. The assemblage of macrocrysts and megacrysts, at least some of which are xenocrystic, includes anhedral crystals of olivine, magnesian ilmenite, pyrope, diopside (in some cases subcalcic), phlogopite, enstatite and Ti-poor chromite. Olivine macrocrysts are a characteristic and dominant constituent in all but fractionated kimberlites. The matrix contains a second generation of primary euhedral to subhedral olivine, which occurs together with one or more of the following primary minerals: monticellite, phlogopite, perovskite, spinel (magnesian ulvöspinel – magnesiochromite – ulvöspinel – magnetite solid solutions), apatite, carbonate and serpentine. Many kimberlites contain a late-stage poikilitic mica belonging to the barian phlogopite – kinoshitalite series. Nickeliferous sulfides and rutile are common accessory minerals. The replacement of earlier-formed olivine, phlogopite, monticellite and apatite by deuteric serpentine and calcite is common. Evolved members of the Group may be poor in,

TABLE 2. MINERAL ASSEMBLAGES OF KALSILITIC ROCKS

	Phl	Cpx	Lct	Kal	Mel	Ol	Gls
Mafurite	-	x	-	x	-	x	x
Katungite	-	-	x	x	x	x	x
Venanzite	x	x	x	x	x	x	-
Coppaelite	x	x	-	x	x	-	-

Symbols: Phl: phlogopite, Cpx: clinopyroxene, Lct: leucite, Mel: melilite, Ol: olivine, Gls: glass. x: present, -: absent. After Mitchell & Bergman (1991, Table 2.3).

or devoid of, macrocrysts, and composed essentially of second-generation olivine, calcite, serpentine and magnetite, together with minor phlogopite, apatite and perovskite.

It is evident that kimberlites are complex hybrid rocks in which the problem of distinguishing the primary constituents from the entrained xenocrysts precludes simple definition. The above characterization attempts to recognize that the composition and mineralogy of kimberlites are not entirely derived from a parent magma, and the nongenetic terms macrocryst and megacryst are used to describe minerals of cryptogenic, *i.e.*, unknown, origin. Macrocrysts include forsteritic olivine, chromian pyrope, almandine–pyrope, chromian diopside, magnesian ilmenite and phlogopite crystals, that are now generally believed to originate by the disaggregation of mantle-derived lherzolite, harzburgite, eclogite and metasomatized peridotite xenoliths. In most cases, diamond, which is excluded from the above "definition", belongs to this suite of minerals but is much less common. Megacrysts are dominated by magnesian ilmenite, titanian pyrope, diopside, olivine and enstatite that have relatively Cr-poor compositions (<2 wt% Cr_2O_3). The origin of the megacrysts is still being debated (*e.g.*, Mitchell 1986), and some petrologists believe that they may be cognate. Both of these suites of minerals are included in the characterization because of their common presence in kimberlites.

It can be debated whether reference to these characteristic constituents should be removed from the "definition" of kimberlite. Strictly, minerals that are known to be xenocrysts should not be included in a petrological definition, as they have not crystallized from the parental magma. Smaller grains of both the macrocryst- and megacryst-suite minerals also occur, but may be easily distinguished on the basis of their compositions. In this respect, it is important to distinguish pseudoprimary groundmass diopside from macrocrystic or megacrystic clinopyroxene. Group-I kimberlites do not usually contain the former except as a product of crystallization induced by the assimilation of siliceous xenoliths (Scott Smith *et al.* 1983). The primary nature of groundmass serpophitic serpentine was originally recognized by Mitchell & Putnis (1988).

Recent studies (Smith *et al.* 1985, Skinner 1989, Mitchell 1994b, 1995, Tainton & Browning 1991) have demonstrated that Group I and Group II kimberlites are mineralogically different and petrogenetically separate rock-types. A definition of Group-II kimberlites has not yet been agreed upon, as they have been insufficiently studied. Mitchell (1994b, 1995) has suggested that these rocks are not kimberlitic at all, and should be termed "orangeite", in recognition of their distinct character and unique occurrence in southern Africa. Wagner (1928) previously suggested that the rocks which he initially termed micaceous kimberlite (Wagner 1914) be renamed "orangite" (*sic*). The following characterization of the rocks currently described as Group-II kimberlites or micaceous kimberlites follows that of Mitchell (1995).

Group-II kimberlites (or orangeites) belong to a clan of ultrapotassic, peralkaline rocks rich in volatiles (dominantly H_2O), characterized by phlogopite macrocrysts and microphenocrysts, together with groundmass micas that vary in composition from phlogopite to "tetraferriphlogopite". Rounded macrocrysts of olivine and euhedral primary crystals of olivine are common, but are not invariably major constituents. Characteristic primary phases in the groundmass include: diopside, commonly zoned to, and mantled by, titanian aegirine; spinels ranging in composition from Mg-bearing chromite to Ti-bearing magnetite; Sr- and *REE*-rich perovskite; Sr-rich apatite; *REE*-rich phosphates (monazite, daqingshanite); potassian barian titanates belonging to the hollandite group; potassium triskaidecatitanates ($K_2Ti_{13}O_{27}$); Nb-bearing rutile and Mn-bearing ilmenite. These are set in a mesostasis that may contain calcite, dolomite, ancylite and other rare-earth carbonates, witherite, norsethite and serpentine. Evolved members of the group contain groundmass sanidine and potassium richterite. Zirconium silicates (wadeite, zircon, kimzeyitic garnet, Ca–Zr-silicate) may occur as late-stage groundmass minerals. Barite is a common deuteric secondary mineral.

Note that these rocks have a greater mineralogical affinity to lamproites than to Group-I kimberlites. However, there are significant differences in the compositions and overall assemblage of minerals, as detailed above, that permit their discrimination from lamproites (Mitchell 1994b, 1995).

Classification of lamproites

The classification system of lamproites described by Mitchell & Bergman (1991) is recommended; it involves mineralogical and geochemical criteria, as follows:

Lamproites are characterized by the presence of widely varying amounts (5–90 vol.%) of the following primary phases: (1) titanian (2–10 wt% TiO_2), aluminum-poor (5–12 wt% Al_2O_3) phenocrystic phlogopite, (2) titanian (5–10 wt% TiO_2) groundmass poikilitic "tetraferriphlogopite", (3) titanian (3–5 wt% TiO_2) potassium (4–6 wt% K_2O) richterite, (4) forsteritic olivine, (5) aluminum-poor (<1 wt% Al_2O_3), sodium-poor (<1 wt% Na_2O) diopside, (6) non-stoichiometric iron-rich (1–4 wt% Fe_2O_3) leucite, and (7) iron-rich sanidine (typically 1–5 wt% Fe_2O_3). The presence of all the above phases is not required in order to classify a rock as a lamproite. Any one mineral may be dominant, and this, together with the two or three other major minerals present, suffices to determine the petrographic name.

Minor and common accessory phases include priderite, wadeite, apatite, perovskite, magnesiochromite, titanian magnesiochromite, and magnesian titaniferous magnetite; less commonly, but characteristically, jeppeite, armalcolite, shcherbakovite, ilmenite and enstatite also are present.

The presence of the following minerals precludes a rock from being classified as a lamproite: primary plagioclase, melilite, monticellite, kalsilite, nepheline, Na-rich alkali feldspar, sodalite, nosean, hauyne, melanite, schorlomite or kimzeyite.

Lamproites conform to the following chemical characteristics: molar $K_2O/Na_2O > 3$, *i.e.*, ultrapotassic, (2) molar $K_2O/Al_2O_3 > 0.8$ and commonly > 1, (3) molar $(K_2O + Na_2O)/Al_2O_3$ typically > 1 *i.e.*, peralkaline, (4) typically <10 wt% each of FeO and CaO, TiO_2 1–7 wt%, >2000 and commonly >5000 ppm Ba, >500 ppm Zr, >1000 ppm Sr and >200 ppm La.

The subdivision of the lamproites should follow the scheme of Mitchell & Bergman (1991), in which the historical terminology is discarded in favor of compound names based on the predominance of phlogopite, richterite, olivine, diopside, sanidine and leucite, as given in Table 3. It should be noted that the term "madupitic" in Table 3 indicates that the rock contains poikilitic groundmass phlogopite, as opposed to phlogopite lamproite, in which phlogopite occurs as phenocrysts.

The complex compositional and mineralogical criteria required to define lamproites result from the diverse conditions involved in their genesis, compared with those of rocks that can be readily classified using the IUGS system. The main petrogenetic factors contributing to the complexity of composition and mineralogy of lamproites are the variable nature of their metasomatized source-regions in the mantle, depth and extent of partial melting, coupled with their common extensive differentiation.

TABLE 3. NOMENCLATURE OF LAMPROITES

Historical name	Revised name
Wyomingite	diopside-leucite-phlogopite lamproite
Orendite	diopside-sanidine-phlogopite lamproite
Madupite	diopside madupitic lamproite
Cedricite	diopside-leucite lamproite
Mamilite	leucite-richterite lamproite
Wolgidite	diopside-leucite-richterite madupitic lamproite
Fitzroyite	leucite-phlogopite lamproite
Verite	hyalo-olivine-diopside-phlogopite lamproite
Jumillite	olivine-diopside-richterite madupitic lamproite
Fortunite	hyalo-enstatite-phlogopite lamproite
Cancalite	enstatite-sanidine-phlogopite lamproite

after Mitchell & Bergman (1991)

Classification of volcanic leucitic rocks

The leucitic rocks, after elimination of the lamproites and kamafugites, should be named according to the QAPF (volcanic) diagram with the prefix "leucite" or "leucite-bearing" as appropriate. Rocks containing little or no feldspar, *i.e.*, falling in field 15 (foidite) of QAPF (Le Maitre *et al.* 1989, Fig. B.10), are leucitites, which are divisible into three subfields: (a) QAPF subfield 15a, phonolitic leucitite: Foids 60–90% of light-colored constituents, and alkali feldspar > plagioclase; (b) QAPF subfield 15b, tephritic leucitite: Foids 60–90% of light-colored constituents, and plagioclase > alkali feldspar; (c) QAPF field 15c, leucitite *sensu stricto*: Foids 90–100% of light-colored constituents, and leucite practically the sole feldspathoid.

The essential mineralogy of the principal groups of leucitic rocks is given in Table 4. No unambiguous chemical criteria have been found to distinguish this group of rocks. In terms of the TAS plot, leucitites extend significantly beyond the foidite field into adjacent fields (Fig. 4). They are better distinguished from lamproites by other compositional parameters, although even here some overlap occurs. The chemical characteristics of the potassic rocks, and attempts at distinguishing lamproites from certain leucitic rocks, using a variety of criteria, are explored by Foley *et al.* (1987) and Mitchell & Bergman (1991).

Classification of lamprophyres

Lamprophyres are mesocratic to melanocratic igneous rocks, usually hypabyssal, with a panidiomorphic texture and abundant mafic phenocrysts of dark mica or amphibole (or both) with or without pyroxene, with or without olivine, set in a matrix of the same minerals, and with feldspar (usually alkali feldspar) restricted to the groundmass. For the general classification of these rocks, see Le Maitre *et al.* (1989), and for detailed descriptions, see Rock (1991).

TABLE 4. MINERALOGY OF THE PRINCIPAL GROUPS OF LEUCITIC ROCKS

Rock	Cpx	Lct	Pl		Sa	Ol
Leucitite	x	x	-		-	>10%
Tephritic leucitite	x	x	x	>	x	-
Phonolitic leucitite	x	x	x	<	x	-
Leucite tephrite	x	x	x		-	<10%
Leucite basanite	x	x	x		-	>10%
Leucite phonolite	x	x	-		x	-

Symbols: Cpx: clinopyroxene, Lct: leucite, Pl: plagioclase, Sa: sanidine (products of its exsolution), Ol: olivine. x: present, -: absent. All these rocks may contain some nepheline.

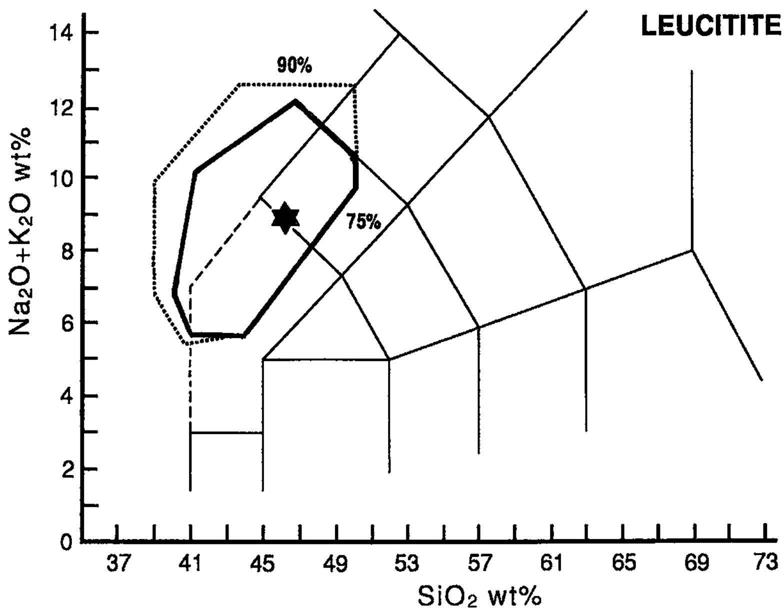

FIG. 4. Percentage frequency distribution diagram for 112 samples of leucitite plotted in the TAS diagram, showing that only about 50% plot in the foidite field, with major concentrations in the basanite–tephrite and phonotephrite fields. Reproduced from Fig. 23 of Le Bas *et al.* (1992). Star indicates the peak of the frequency distribution.

The Subcommission no longer endorses the terms "lamprophyric rocks", or "lamprophyre clan", as used by Le Maitre *et al.* (1989) and Rock (1991) to encompass lamprophyres, lamproites and kimberlites, because lamproites and kimberlites are best considered independently of lamprophyres.

Revised Sequential System for Classifying Igneous Rocks

The revised hierarchy, which modifies that of the wall chart accompanying Le Maitre *et al.* (1989) and Figure 8 of Le Bas & Streckeisen (1991), is given below (Figs. 5, 6). Each statement is a precondition for the next in the sequence.

1. If the rock is fragmental, the rock should be classified as a PYROCLASTIC ROCK.

2. If the rock contains more than 50% primary carbonate, the rock should be classified as a CARBONATITE.

3. If the rock contains >10% modal melilite and M > 90%, the rock should be classified as a MELILITIC ROCK.

4. If the rock contains kalsilite, the rock should be classified as a KALSILITIC ROCK.

5. If the rock is fine-grained or glassy and has larnite in the norm, the rock should be classified as a MELILITIC ROCK.

6. If the volcanic rock contains essential leucite, with or without phlogopite (biotite), or is from a minor intrusion with mafic phenocrysts only (generally mica or amphibole, or both), apply the following criteria sequentially:
(a) If the rock is free of leucite but rich in olivine (typically 35–55 modal % including macrocrysts, xenocrysts and phenocrysts), and one or more dominant primary minerals in the groundmass are monticellite, phlogopite, carbonate, serpentine or diopside, the rock should be classified as a KIMBERLITE.
(b) If the rock contains titanian phlogopite as Al-poor phenocrysts or groundmass grains (or both), together with common Fe-rich leucite or forsteritic olivine (or both), as well as one or more of titanian potassium richterite, Al–Na-poor diopside, Fe-rich sanidine, accessory wadeite and priderite in the groundmass, then the rock should be classified as a LAMPROITE.
(c) Any remaining leucitic rocks should be classified using the terms provided in the classification of VOLCANIC LEUCITIC ROCKS.
(d) Apart from certain pyroxene- and olivine-bearing rocks, *e.g.*, ankaramite and oceanite, which are not lamprophyres (for these rocks proceed to the

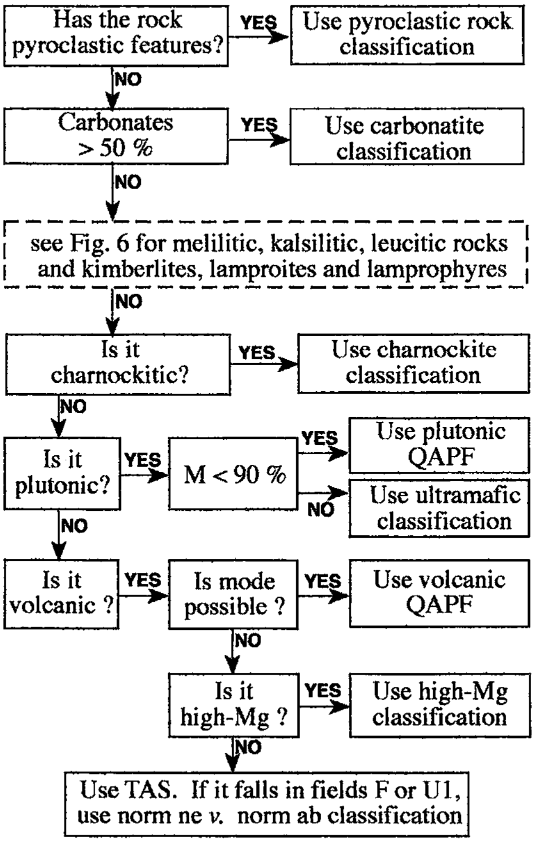

FIG. 5. Flow chart (after Le Bas & Streckeisen 1991) for the classification of igneous rocks following the IUGS scheme (Le Maitre *et al.* 1989), but modified for the proposals presented in this report paper (dashed box). The "norm *ne versus* norm *ab* classification" is that given by Le Bas (1989).

QAPF/TAS systems), any remaining rocks containing phlogopite (biotite) or amphibole (or both) and those from minor intrusions with only mafic phenocrysts, go to the LAMPROPHYRE classification (Le Maitre *et al.* 1989).

7. If the rock is glassy or the mode is not otherwise determinable, the rock may be lamproitic, if molar K_2O/Na_2O is greater than 3, molar K_2O/Al_2O_3 greater than 0.8 and molar $(K_2O + Na_2O)/Al_2O_3$ greater than 1 (peralkaline); then go to the LAMPROITE classification.

8. The classification of the charnockitic, plutonic and remaining volcanic rocks proceeds as described in Le Maitre *et al.* (1989).

The Problems of Classification

Many schemes of classification for igneous rocks, such as that based on the total alkali *versus* silica method (TAS), have a major petrogenetic component, and ultimately all taxonomy of igneous rocks will incorporate genetic factors. For no other igneous rocks is the petrogenetic component of classification more important than for lamprophyres, lamproites and kimberlites. One criticism of the IUGS classification of rocks, discussed by Le Bas & Streckeisen (1991), is that it is deficient in a strong genetic component. This is essentially an historical artifact of the pragmatic approach originally adopted by Streckeisen to attain a consensus. Because of the plethora of classification systems that have been suggested and applied in the past, the Subcommission followed a consensual approach. The widespread adoption of the IUGS system would seem to have justified this approach for many igneous rocks. However, although much of the IUGS system undoubtedly has some petrogenetic significance, and is used in genetic discussion, for example the TAS system, purely descriptive terms may have to be applied where there is disagreement as to interrelationships of rock suites. This would seem to apply at present to the lamprophyres, for which difficulties remain in erecting a petrogenetic classification.

The main problems of the classification of lamprophyres, lamproites, kimberlites, feldspathoidal, kalsilitic, melilitic, and leucitic rocks are briefly outlined below.

Lamprophyres

The lamprophyres are a complex group of rocks that have mineralogical similarities to some kimberlites and lamproites. Lamprophyres are difficult to classify unambiguously using existing criteria. They are not amenable to classification according to modal proportions, such as the system QAPF, nor compositional discrimination diagrams, such as TAS (Le Maitre *et al.* 1989). It seems unlikely that a simple taxonomic system will be found unless appropriate genetic criteria are applied, that is, unless the classification takes into account the genesis of the rocks.

The term "lamprophyre" was introduced by von Gumbel in 1874 for a group of dark rocks that form minor intrusions, contain phenocrystal brown mica and hornblende, but lack feldspar phenocrysts. Following its introduction, the term was used by Rosenbusch (1877) to encompass a wide variety of hypabyssal rocks containing ferromagnesian phenocrysts, *e.g.*, minette, kersantite, camptonite and vogesite. Eventually, spessartite, monchiquite and alnoite also were included in the group. Thus, the group became a repository for any mafic-phenocryst-rich rock that was

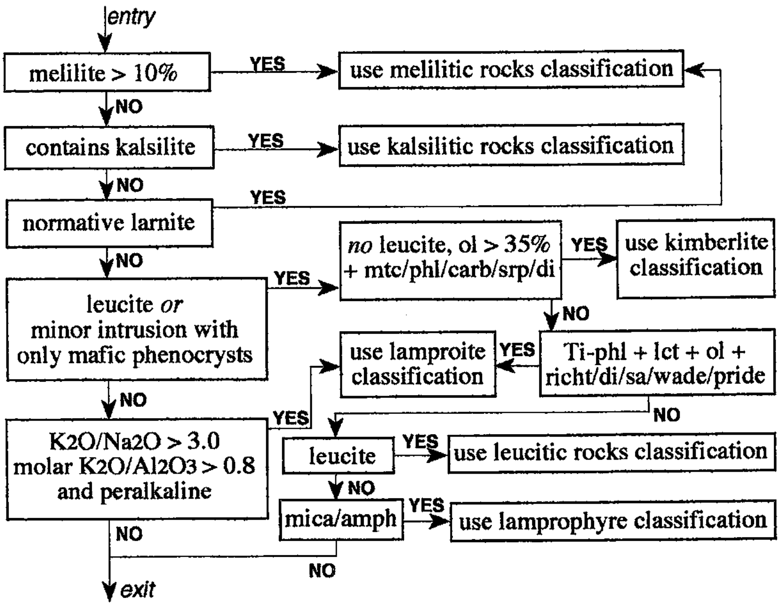

FIG. 6. Flow chart for the melilitic, kalsilitic and leucitic rocks and the kimberlites, lamproites and lamprophyres (dashed box of Fig. 5). It is entered after the "carbonates >50%" box and exits to the "charnockitic" box of Fig. 5. The symbols used follow those of Kretz (1983) where possible.

difficult to categorize. Subsequently, Middlemost (1986) and Rock (1986, 1991) extended the definition further to include kimberlites, lamproites and even rocks containing feldspar and leucite phenocrysts. Reviews of the history of lamprophyre nomenclature can be found in Rock (1991), Mitchell & Bergman (1991) and Mitchell (1994a).

Rock (1991) used "lamprophyre" synonymously with "lamprophyre clan", a term that included lamprophyres, lamproites and kimberlites. To many petrologists working on lamproites and kimberlites, "lamprophyre" is an inappropriate general term. Consequently, the working group and Subcommission overwhelmingly rejected the use of the term "lamprophyre clan" to encompass lamprophyres (*sensu* Rosenbusch), kimberlites and lamproites.

Mitchell (1994a) discussed at some length the inadequacies of the concept of the "lamprophyre clan" and proposed adoption of the term "lamprophyre facies" to convey the concept that some members of a petrological clan crystallized under different conditions than other members of the clan. Mitchell's approach to the problem is determined by a conviction that systems of classification should be genetic in character.

The working groups found it impossible to devise a definition of "lamprophyric rocks" that is not so broad as to be almost petrologically meaningless. For the lamprophyres (*sensu* Rosenbusch or Rock), the working group could not draft a satisfactory definition, in part because Rock (1991) included a number of rock types that differ mineralogically from the generally accepted characteristics of lamprophyres. However, of greater significance is the realization that members of the lamprophyre group have distinctly different origins, and thus it is unwise to describe or group together rocks that are genetically different.

Among the rocks included in the lamprophyre group by Rock (1991) are alnoite and polzenite. These contain more than 10 vol.% melilite, and thus are now considered as varieties of melilitic rocks. Similarly, the abundant carbonate in aillikite suggests that it may be considered a variety of silicocarbonatite.

Minette is a biotite-rich lamprophyre. However, certain mica-rich rocks that usually occur in minor intrusions should not be called minette because the mica is phlogopite (commonly titaniferous), and the rock is alkaline. Such rocks might be better termed "alkali minette" rather than "glimmerite" or "phlogopitite", as it is the alkalinity rather than the Fe/Mg ratio that is their characteristic feature.

The widespread usage of the term *lamprophyre* in English, French and German petrological literature is in marked contrast to its infrequency in the extensive Russian literature. There the term is usually reserved for alkaline rocks. Specific rock types, such as kersantite, are considered as varieties of diorite. Similarly, camptonite and alnoite are regarded as variants of gabbro and melilitite, respectively (Andreeva *et al.* 1985, Kononova 1984). This approach to lamprophyre nomenclature is similar to the facies concept proposed by Mitchell (1994a).

Lamproites

Lamproites have always been a difficult group of rocks in terms of their identification and nomenclature. Recent interest in them has been prompted by the discovery of economically viable diamond-bearing varieties, which has led to a detailed re-examination of the group and complete revision of the nomenclature (Scott Smith & Skinner 1983, Mitchell & Bergman 1991). These revisions have resulted in the reclassification as lamproites of some rocks previously regarded as kimberlites (*e.g.*, Prairie Creek, Arkansas, and Majhgawan, India).

It is only in the last few decades that lamproites have been considered to crystallize from a distinct type of magma. Formerly, the presence of leucite, the similarity of some olivine-bearing lamproite to kimberlite, and the presence of some "lamprophyric" characteristics, *e.g.*, abundant phenocrysts of phlogopite, led not only to a plethora of names, but to an ill-defined place in petrological taxonomy. The problem was further exacerbated by their geochemical characteristics, with the magma chemistry stabilizing a large number of unusual minerals (K–Ba titanates and silicates, K–Zr silicates), some of which can be used as discriminants for these rocks. For most examples of lamproite, the presence of these minerals reflects derivation from a source enriched in incompatible and large-ion-lithophile elements; this enrichment distinguishes lamproitic rocks from Group-I kimberlites and lamprophyres. A full discussion of the nomenclature of lamproites, their relationships to other potassic and ultrapotassic rocks, in both mineralogical and chemical terms, together with a suggested revised nomenclature, is found in Mitchell & Bergman (1991). The Subcommission essentially accepted the detailed work of Mitchell & Bergman (1991) and Scott Smith & Skinner (1983), and needed only to integrate these rocks into the IUGS hierarchical system.

Kimberlites

The Subcommission considered it inappropriate to re-investigate the nomenclature and definition of kimberlites in detail, because this has been done extensively in the last few years by the many specialists of kimberlites (Skinner & Clement 1979, Dawson 1980, Clement *et al.* 1984, Mitchell 1986). Nevertheless, a clear definition of kimberlite should be formulated, particularly for purposes of distinguishing these rocks from olivine lamproite, and for placing kimberlites in the hierarchical classification system. Currently, the classification of kimberlite is undergoing revision, and the nomenclature advanced by Mitchell (1994b) has not yet been fully explored.

Melilitic rocks

The main problems here concern volcanic melilitic rocks. In Le Maitre *et al.* (1989), the coarser-grained melilitolite is classified on the basis of modal proportions, but a completely satisfactory classification for the finer-grained rocks was not attained. A definition based on rock chemistry is desirable, but unfortunately these rocks cannot be distinguished adequately from other volcanic rocks in the TAS system. However, the presence of melilite in more than trace modal amounts results in the formation of larnite (or calcium orthosilicate) in the CIPW norm, and this can be used as a potential discriminant. Although larnite may appear in the norm of some melilite-free nephelinitic rocks containing clinopyroxene rich in the Tschermaks component (H.S. Yoder, Jr., pers. comm.), we find that the latter is typically expressed in the norm as anorthite.

A further problem remains, that there is a continuous series from melilitite, through melilite nephelinite to nephelinite. Investigation of this problem indicates that a reasonably clear discriminant between melilitite and melilite nephelinite is normative larnite. In Figure 3, samples of melilitite and nephelinite are plotted in terms of normative larnite *versus* normative nepheline. The best division appears to be at 10% larnite.

When classifying the melilitic rocks, the following should be taken into consideration: (a) The present classification for melilitic rocks in Le Maitre *et al.* (1989, p. 12) is based on the presence of modal melilite exceeding 10 vol.% in either plutonic (melilitolite) or volcanic (melilitite) occurrences, in combination with M > 90%. (b) In the IUGS scheme (see flow chart accompanying Le Maitre *et al.* 1989), their identification is made after excluding the lamprophyres but before entering QAPF. It is now considered preferable to identify melilitic rocks before lamproites, kimberlites and lamprophyres. (c) Even in fine-grained rocks, melilite can usually be identified in thin section where it occurs in essential proportions, *i.e.*, >10 vol.%. This assumes the rock is not altered; if it is, melilite is usually carbonated. (d) Some fine-grained melilitic rocks are strongly potassic, *e.g.* katungite, the potassic character usually being reflected in the presence of modal leucite or kalsilite (or both). (e) Melilitite is characterized by the presence of melilite and perovskite and contains less than 38 wt% SiO_2 and greater than 13 wt% CaO.

Kalsilitic rocks

Kalsilitic rocks have not previously been considered by the Subcommission. These fall into two groups: the kamafugitic series of Sahama (1974), and the kalsilite-bearing syenites and pyroxenites, *e.g.*, synnyrite and yakutite, occurring in the Aldan and North Baikal petrological provinces of Russia (Kogarko *et al.* 1995, Kostyuk *et al.* 1990). Some of the kamafugitic rocks contain leucite or melilite (or both) and might be considered feldspathoidal or melilitic rocks. However, the presence of kalsilite is considered so important that it requires assignment of these rocks to a special group.

Foiditic and leucitic rocks

The problems posed by these rocks are restricted to the fine-grained members. The coarser-grained rocks of equivalent composition containing nepheline or leucite (or both) and, despite heteromorphism in some cases (Yoder 1986), can be satisfactorily classified using the QAPF and other mineralogical systems (Le Maitre *et al.* 1989).

The boundaries between the feldspathoidal field and the basanite–tephrite, phonotephrite, tephriphonolite and phonolite fields in the TAS system are not wholly satisfactory, as they do not provide an acceptable boundary for the nephelinitic and leucitic rocks. The problem with regard to the leucitic rocks is illustrated by Figure 4.

It is evident that leucitic rocks cannot be distinguished chemically on the TAS diagram. However, as leucite is, with few exceptions, a phenocryst phase, or forms small but identifiable crystals, a modal system should be feasible. This approach was not adopted by Le Maitre *et al.* (1989). The distinction between nephelinite and basanite has been considered by Le Bas (1989).

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Sadly, Nick Rock died in February of 1992, before he saw the final draft of these recommendations. He is included as a coauthor here not only because of his significant participation in the discussions of the working groups, but also because of his immense contribution to the investigations of lamprophyres and related rocks and the enthusiasm with which he studied them. Although he may not have agreed with all the ideas and conclusions presented in this report, he saw most of its components, supported them, and was active in their discussion almost to the final stage, including the meeting in Brazil (1991), during the Fifth International Kimberlite Conference, when agreement was reached on some of the major problems.

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