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Integrating Ultramafic Lamprophyres into the IUGS Classification of Igneous Rocks: Rationale and Implications

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We introduce a modification to the current IUGS classification system for igneous rocks to include ultramafic lamprophyres, which are currently entirely omitted. This is done by including a new step in the sequential system, after the assignment of pyroclastic rocks and carbonatites, that considers ultramafic inequigranular textured rocks with olivine and phlogopite macrocrysts and/or phenocrysts. At this step ultramafic lamprophyres are considered together with kimberlites, orangeites (former Group 2 kimberlites) and olivine lamproites. This proposal allows the correct identification and classification of ultramafic lamprophyres within the IUGS scheme. Only three end-members are required for describing the petrographic and compositional continuum of ultramafic lamprophyres: alnöite (essential groundmass melilite), aillikite (essential primary carbonate) and damtjernite (essential groundmass nepheline and/or alkali feldspar). It is argued that all ultramafic lamprophyre rock types can be related to a common magma type which differs in important petrogenetic aspects from kimberlites, orangeites, olivine lamproites and the remainder of lamprophyres such as alkaline and calc-alkaline varieties. Ultramafic lamprophyres can be readily distinguished from olivine lamproites by the occurrence of primary carbonates, and from kimberlites by the presence of groundmass clinopyroxene. In other cases distinction between aillikites, kimberlites and orangeites must rely on mineral compositions in order to recognize their petrogenetic affinities.

KEY WORDS: *alkaline rocks; aillikite; alnöite; damtjernite; classification*

STATEMENT OF THE PROBLEM

The International Union of Geological Sciences (IUGS) has played an important role in establishing a systematic classification scheme for igneous rocks and simplifying their nomenclature (Streckeisen, 1978; Le Maitre, 1989, 2002). The main principle in their hierarchical approach is to deal with 'exotic' or 'special' rocks first, thus clearing the way for the classification of the 'normal', or majority of, igneous rocks. Included amongst the 'special' rocks are pyroclastics, carbonatites, kimberlites, lamproites and lamprophyres.

Unfortunately, a widely recognized group of exotic alkaline rocks, the ultramafic lamprophyres (UML; Rock, 1986, 1991), were never integrated into IUGS classification schemes. Some of the group members (e.g. alnöite and polzenite) were considered within early versions of the IUGS system (Streckeisen, 1978; Le Maitre, 1989), whereas others were ignored from the beginning (e.g. aillikite and damtjernite). In the most recent IUGS classification scheme (Le Maitre, 2002) all ultramafic lamprophyre group members have been entirely omitted.

Several lines of evidence point to the exclusion of UML from the IUGS classification scheme as having been a serious omission. First, the term ultramafic lamprophyre continues to be used as a collective term for melanocratic to holomelanocratic, silica-undersaturated potassic rocks,

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with essential hydrous phenocrysts (e.g. Foley *et al.*, 2002; Coulson *et al.*, 2003; Riley *et al.*, 2003; Upton *et al.*, 2003; Tappe *et al.*, 2004). Second, many inequigranular textured, ultramafic olivine–phlogopite rocks do not fulfill the criteria for being kimberlites, orangeites or lamproites (see Mitchell, 1986) and would erroneously be classified as 'mica peridotites'. Third, the close association and even gradation between ultramafic lamprophyres and carbonatites in rift tectonic settings is in strong contrast to macroscopically similar kimberlites, orangeites and olivine lamproites and points to important differences in their petrogenesis. Fourth, no satisfactory explanation has been given (e.g. Woolley *et al.*, 1996) for the dismissal of most of the chemical and mineralogical arguments cited by Rock (1986, 1987) for treating the UML as a separate group of rocks.

Our own recent experience with trying to apply the IUGS classification scheme to the numerous carbonate-rich, melilite-free, ultramafic alkaline rocks of West Greenland, northern Quebec and Labrador also highlights the shortcomings of the current scheme. These rocks have been variably described as kimberlites (Emeleus & Andrews, 1975; Andrews & Emeleus, 1976; Collerson & Malpas, 1977; Scott, 1981; Larsen & Rønsbo, 1993; Davis *et al.*, 2001; Jensen *et al.*, 2002; Wilton *et al.*, 2002), ultramafic lamprophyres (Malpas *et al.*, 1986; Foley, 1989; Larsen & Rex, 1992; Wardle *et al.*, 1994; Pearce & Leng, 1996; Mitchell *et al.*, 1999; Digonnet *et al.*, 2000; Tappe *et al.*, 2004) and more vaguely as carbonatitic lamprophyres or meimechites (Dimroth, 1970; Walton & Arnold, 1970; Hansen, 1980). We have extensively investigated the petrography, mineral and whole-rock composition of these rocks in Labrador and New Quebec in an attempt to understand their petrogenesis (e.g. Tappe *et al.*, 2004, and in preparation). Using the current IUGS scheme, we were led to point 12 of Le Maitre (2002): 'if you get to this point, either the rock is not igneous or you have made a mistake'. The result of this shortcoming is that many UML occurrences are arbitrarily termed 'kimberlites' or worse 'kimberlitic' by non-specialists. This gap in classification severely hampers systematic attempts to decipher the petrogenesis of alkaline rocks. Furthermore, the correct identification of ultramafic lamprophyres is also of practical importance during exploration programs, as they may also be diamond-bearing (Hamilton, 1992; Janse, 1994; Mitchell *et al.*, 1999; Digonnet *et al.*, 2000; Birkett *et al.*, 2004).

Herein, we provide a mechanism by which to integrate and correctly identify ultramafic lamprophyres within the IUGS system and distinguish them from other inequigranular textured olivine- and phlogopite-bearing ultramafic rocks.

PREVIOUS TERMINOLOGY OF ULTRAMAFIC LAMPROPHYRES

Kranck (1939) observed that carbonate-rich varieties of lamprophyres are highly abundant in the Aillik Bay area of Labrador. He defined this so far unknown or unreported rock type as 'aillikite'. These rocks could not be classified as alnöite because they lack melilite. Unfortunately, this important distinction became lost. For example, in one of the most successful classification schemes of igneous rocks, devised by Streckeisen (1978), aillikites were not included but the term 'melilitic lamprophyres' was introduced, including alnöites and polzenites.

Rock (1986) introduced the term ultramafic lamprophyre and included melilitic lamprophyres (i.e. alnöite) as well as the melilite-free carbonate-rich and feldspar-/foid-bearing varieties such as aillikite and damtjernite/ouachitite, respectively. All of these rocks have in common an ultramafic, silica-undersaturated nature. Rock (1986) noted that there are strong textural and petrographic similarities between ultramafic lamprophyres and kimberlites.

A new classification concept for all 'lamprophyres' was presented by Rock (1987, 1991), where he included kimberlites and lamproites with ultramafic, alkaline and calc-alkaline lamprophyres into his 'lamprophyre clan'. Mitchell (1994*a*, 1994*b*) disputed the concept of a lamprophyre clan and suggested its use be discontinued. The similarities between ultramafic lamprophyres, olivine lamproites, orangeites and kimberlites are best explained by hypabyssal crystallization from volatile-rich magmas, which none the less strongly differ in important aspects of their petrogenesis [the lamprophyric facies concept of Mitchell (1994*a*)]. Nevertheless, although Rock's UML group (Rock, 1986) was a great improvement on previous lamprophyre classification schemes and recognized that such rocks were being confused with kimberlites, it was not accepted by the IUGS subcommittee on classification (Le Maitre, 1989, 2002; Woolley *et al.*, 1996).

Woolley *et al.* (1996) removed alnöites and polzenites from the lamprophyre classification of Le Maitre (1989) and assigned them to the melilitic rocks. Aillikites were considered for the first time by the IUGS, but classified as silicocarbonatites, despite the fact that the modal carbonate content is less than the 50 vol. % required to classify them as carbonatites, as Rock (1986) had previously noted. In the most recent IUGS scheme (Le Maitre, 2002) alnöites and polzenites were included in the melilite-bearing group of rocks following Woolley *et al.* (1996), whereas aillikite and damtjernite were simply overlooked.

The use of the acronym 'melnoite' (melilite plus alnöite) as a stem name for all ultramafic lamprophyres was

Table 1: Classification of ultramafic lamprophyres based on their diagnostic mineralogy

	Melilite (grdm.)	Carbonate (grdm., primary)	Nepheline (grdm.)	Alkali feldspar (grdm.)
Alnöite	MN	m	m	—
Aillikite	—	MN	—	—
Damtjernite	—	m	mN*	mN*

Olivine and phlogopite are common to all three rock types; Ti-rich primary garnets may occur. grdm., groundmass; M, major constituent; m, minor constituent; N, necessary; N*, presence of only one 'star' phase necessary; —, absent.

suggested by Mitchell (1994*b*), a collective term that was until then only used by exploration geologists for potentially diamondiferous rocks different from kimberlites and lamproites. Mitchell (1994*b*) favoured 'melnoite' over type locality names, because the latter have an inherent petrographic connotation. However, because melnoite implies 'melilite-bearing', which is not true for many carbonate-rich or feldspathoid-bearing ultramafic lamprophyres, we suggest the widely used collective term 'ultramafic lamprophyre' as a group name for these genetically related rock types.

In this study, we introduce a simplified version of Rock's (1986) classification of ultramafic lamprophyres. This scheme is illustrated in Table 1. Alnöite is used to describe all melilite-bearing ultramafic lamprophyres. Melilite-free ultramafic lamprophyres are split into aillikite and damtjernite. Ouachitites and polzenites are subtle, more felsic (nepheline-bearing) variants of damtjernite and alnöite, respectively, and as such are dropped to simplify matters. Brief definitions of the three UML end-members are described as follows.

Alnöites are melilite-bearing UML, characterized by olivine, phlogopite and clinopyroxene macrocrysts and/or phenocrysts, and groundmass melilite, clinopyroxene, phlogopite, spinel, ilmenite, perovskite, Ti-rich garnet, apatite and minor primary carbonate. Monticellite may occur in rare instances.

Aillikites are carbonate-rich UML, characterized by olivine and phlogopite macrocrysts and/or phenocrysts, and groundmass primary carbonate, phlogopite, spinel, ilmenite, rutile, perovskite, Ti-rich garnet and apatite. Mela-aillikites are more melanocratic (colour index >90%) as a result of the presence of clinopyroxene and/or richteritic amphibole in the groundmass (at the expense of carbonate). Monticellite may occur in rare instances.

Damtjernites are feldspathoid- and/or alkali feldspar-bearing UML, characterized by olivine, phlogopite and clinopyroxene macrocrysts and/or phenocrysts, and groundmass phlogopite/biotite, clinopyroxene, spinel, ilmenite, rutile, perovskite, Ti-rich garnet, titanite, apatite and primary carbonate, with essential minor nepheline and/or alkali feldspar.

INTEGRATING ULTRAMAFIC LAMPROPHYRES INTO THE IUGS CLASSIFICATION

Strict application of the modified classification system requires following the flow chart in Fig. 1, which is mainly adopted from Le Maitre (2002). Our revision to the IUGS sequential system is highlighted in bold and the quotation marks refer to sections in Le Maitre (2002):

1. If the rock is considered to be of pyroclastic origin, go to the section on 'Pyroclastic Rocks and Tephra, p. 7'.
2. If the rock contains >50 modal % of primary carbonate, go to the section on 'Carbonatites, p. 10'.
3. **If the rock is ultramafic with M > 90% (as defined in the section on 'Principles, p. 4'), inequigranular textured and contains olivine and phlogopite macrocrysts and/or phenocrysts, use the following:**
   (a) **if it does not contain primary carbonate, check to see if the rock is a lamproite as described in the section on 'Lamproites, p. 16';**
   (b) **if melilite-bearing, it is an alnöite (see Table 1 and Fig. 2);**
   (c) **if nepheline- and/or alkali feldspar-bearing, it is a damtjernite (see Table 1 and Fig. 2);**
   (d) **if it is carbonate-rich and contains melanite/schorlomite- or kimzeyite garnets, it is an aillikite (see Table 1 and Fig. 2);**
   (e) **if carbonate-bearing, the rock may be an aillikite, orangeite (former Group 2 kimberlite) or archetypal kimberlite, and discrimination must rely on differences in mineral composition (see Fig. 2).**
4. If the rock contains >10 modal % of melilite, go to the section on 'Melilite-bearing Rocks, p. 11'. **If the rock is also kalsilite-bearing, go to the section on 'Kalsilite-bearing Rocks, p. 12'.**
5. If the rock contains modal kalsilite, go to the section on 'Kalsilite-bearing Rocks, p. 12'.
6. Check to see if the rock is a kimberlite as described in the section on 'Kimberlites, p. 13'.
7. Check to see if the rock is a lamproite as described in the section on 'Lamproites, p. 16'.

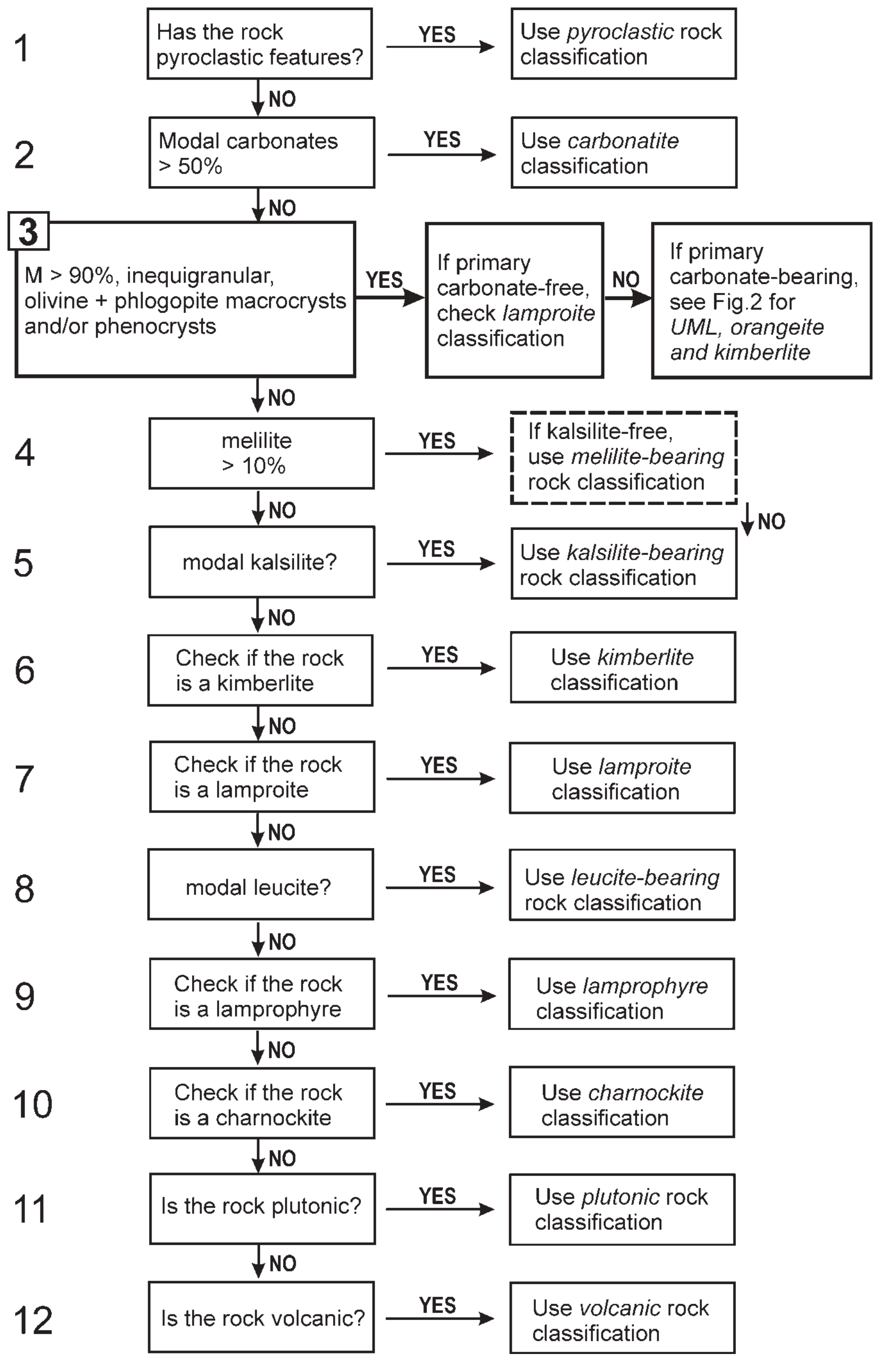

Fig. 1. Flow chart illustrating the sequential system for the classification of igneous rocks following the IUGS scheme devised by Le Maitre (2002). The new 'Step 3' is integrated to distinguish between ultramafic lamprophyres (UML), kimberlite, orangeite and olivine lamproite. (See text for further explanation.) 'M' is defined as mafic and related minerals (i.e. including primary carbonate and apatite).

8. If the rock contains modal leucite, go to the section on 'Leucite-bearing Rocks, p. 18'.
9. Check to see if the rock is a lamprophyre as described in the section on 'Lamprophyres, p. 19'.
10. Check to see if the rock is a charnockite as described in the section on 'Charnockites, p. 20'.
11. If the rock is plutonic as defined in the section on 'Principles, p. 3', go to the section on 'Plutonic Rocks, p. 21'.
12. If the rock is volcanic as defined in the section on 'Principles, p. 3', go to the section on 'Volcanic Rocks, p. 30'.

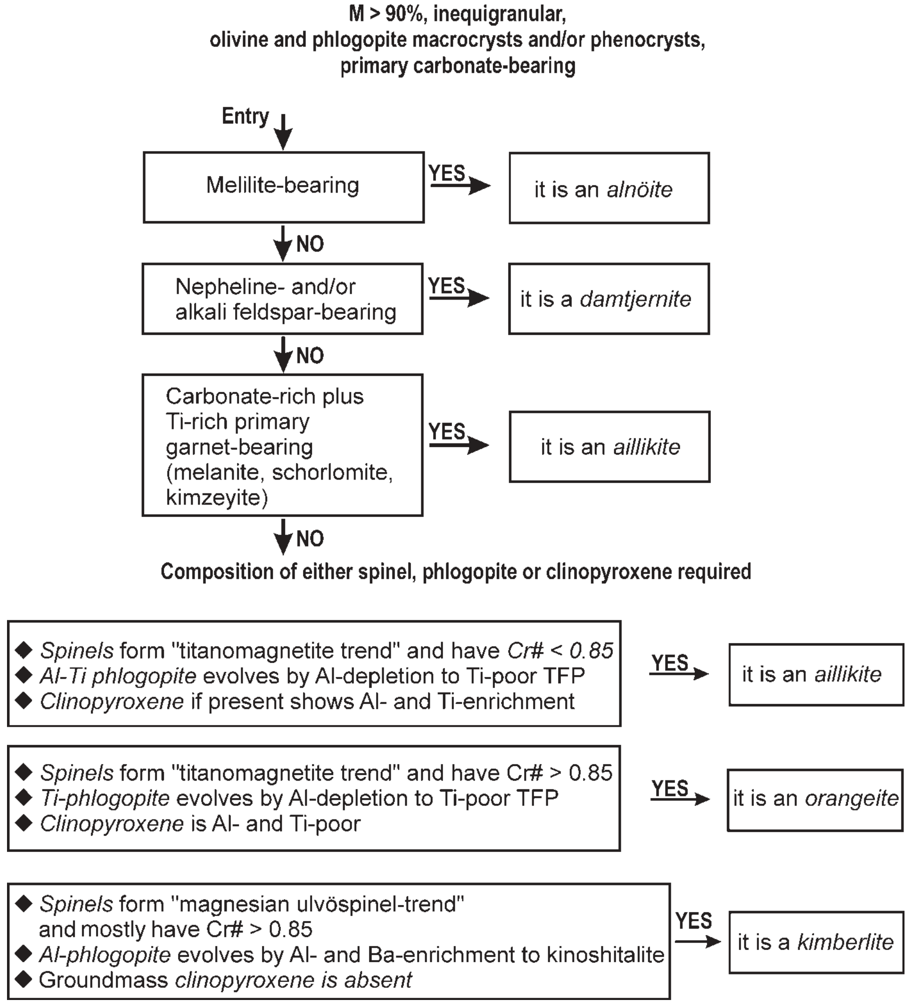

Fig. 2. Flow chart illustrating how to distinguish between the three UML end-members (alnöite, damtjernite, aillikite), orangeite and kimberlite. Discrimination criteria that rely on mineral composition after Mitchell (1986, 1995) and Tappe *et al.* (2004, and in preparation). Cr# (Cr-number) = atomic Cr/(Cr + Al); TFP, tetraferriphlogopite.

APPLICATION OF THE REVISION

Our new Step 3 considers ultramafic (melanocratic to holomelanocratic) inequigranular rocks with olivine and phlogopite macrocrysts and/or phenocrysts. At this step, ultramafic lamprophyres, orangeites and the majority of kimberlites and olivine lamproites are directed to a more appropriate classification scheme. Lamproites are sifted out by the absence of primary carbonate and directed to the existing lamproite classification. The remaining rocks are evaluated in a separate flow chart (Fig. 2). Most ultramafic lamprophyres are identified and sifted out by the presence of groundmass melilite, nepheline, alkali feldspar or Ti- and/or Zr-rich primary garnets. The remaining carbonate-bearing rocks may be aillikite, orangeite or archetypal kimberlite, and discrimination must rely on mineral compositional differences (see also Mitchell, 1986, 1995), as follows.

Kimberlite spinels show variations in atomic Ti/(Ti + Cr + Al) at a fixed high Mg-number [magnesian ulvöspinel trend of Mitchell (1986)]. Phlogopites in kimberlite show Ba and Al enrichment leading to kinoshitalite. Spinels in orangeite and aillikite show similar variation in atomic Ti/(Ti + Cr + Al) with decreasing Mg-number [titanomagnetite trend of Mitchell (1986)], but Cr/(Cr + Al) is higher in orangeite (>0·85) than in aillikite spinels (<0·85; Tappe *et al.*, in preparation). In contrast to kimberlite, phlogopite in orangeite and aillikite is Ti-rich but Ba-poor and evolves by Al depletion to tetraferriphlogopite. Groundmass clinopyroxene is absent from kimberlite, occurs as nearly pure diopside in orangeite, but if present in aillikite or mela-aillikite, it shows Al and Ti enrichment.

It should be noted that it is important to examine a suite of samples, as individual samples may not be representative of the whole rock series. Additionally, it should be noted that some kimberlites and almost all leucite lamproites pass Step 3 and are picked up at the original steps in the IUGS scheme (now Steps 6 and 7). We now consider two test cases where the criteria in Step 3 (Fig. 1) and Fig. 2 allow for a more rigorous classification.

West Greenland

Many carbonate-rich ultramafic alkaline dykes from western Greenland have long been regarded as kimberlites (e.g. Emeleus & Andrews, 1975; Scott, 1981; Thy *et al.*, 1987; Larsen & Rønsbo, 1993). They are characterized by an inequigranular texture and contain both abundant olivine and phlogopite as macrocrysts and phenocrysts. These rocks are directed at Step 3 in Fig. 1 to the flow chart in Fig. 2. Because they do not contain melilite, nepheline, alkali feldspar or Ti-rich primary garnets, one must decide between aillikite, orangeite or kimberlite based on mineral compositions. The spinels are compositionally diverse, but evolve at comparably high Fe/Mg ratios towards titanomagnetite/magnetite. The magnesian ulvöspinel component is low (<15 wt % and 12 wt % MgO for Sarfartoq and Nigerdlikasik–Pyramidefjeld spinels, respectively) and Al is enriched [Cr/(Cr + Al) < 0·85]. The mica compositions are Ba-poor and trend from aluminous titanian phlogopite toward either aluminous magnesian biotite or to Ti- and Al-depleted tetraferriphlogopite. The western Greenland ultramafic dyke occurrences also contain groundmass clinopyroxenes enriched in Al_2O_3 and TiO_2 (up to 10 and 5 wt %, respectively; Mitchell *et al.*, 1999). These criteria eliminate kimberlites and orangeites and clearly identify these rocks as ultramafic lamprophyres, namely the carbonate-rich variety aillikite. This is in agreement with Mitchell *et al.* (1999), who considered that these rocks are not kimberlite but rather ultramafic lamprophyres.

Aillik Bay, Labrador

At the type locality of aillikites at Aillik Bay in Labrador (Kranck, 1939; Foley, 1984; Malpas *et al.*, 1986; Rock, 1986), a variety of Late Neoproterozoic lamprophyric dykes occur that can now all be classified as ultramafic lamprophyres. Many dykes have olivine and aluminous titanian phlogopite phenocrysts and their groundmass is dominated by primary carbonates including rare Ti-rich garnets. Others have olivine, Ti–Al-enriched diopside and aluminous titanian phlogopite phenocrysts, and contain minor alkali feldspar, nepheline and primary carbonate in the groundmass (Tappe *et al.*, in preparation). Using the new classification, the first type is aillikite, whereas the second classifies as damtjernite. These damtjernites include more evolved types with more nepheline and alkali feldspar [the 'sannaites' of Foley (1984)], thus violating the M = 90% screen of Step 3 in Fig. 1. However, they are clearly genetically related to the damtjernites and so we recommend referring to them as 'evolved damtjernites' and not sannaite (see below).

COMMENTS

The introduction of the ultramafic lamprophyre group at an early stage in the IUGS classification scheme does not compromise the existing lamprophyre classification in 'Section 2.9, p. 19' (Le Maitre, 2002) in any way. 'Section 2.9' considers those lamprophyres termed calc-alkaline and alkaline lamprophyres by Rock (1987, 1991), and is herein retained entirely as Step 9 in Fig. 1. This further illustrates the point that the ultramafic lamprophyres were simply omitted in the current IUGS scheme (Le Maitre, 2002), and that there is no genetic relationship between UML and the remainder of lamprophyres.

The prefix 'mela-' can be added to ultramafic lamprophyre rock names to indicate a colour index >90% as suggested by Rock (1986) and applied by Tappe *et al.* (2004) for the first time to aillikites. This is an important qualifier, especially for aillikites, to indicate the gradation into carbonate-poor varieties, which by definition have <10 vol. % modal carbonate. It therefore has a meaning essentially equivalent to 'carbonate-poor aillikite' and allows the correct identification of the petrogenetic affinity of the magma series for degassed varieties. It does not, however, indicate which mafic mineral is common; this can also be done by the use of mineral qualifiers as in the section on lamproites [Section 2.7, p. 17 of Le Maitre (2002)]—for example, 'clinopyroxene mela-aillikite' or 'richterite clinopyroxene mela-aillikite'.

The reintroduction of the term 'damtjernite' for nepheline- and/or alkali feldspar-bearing ultramafic lamprophyres follows the description of dykes associated with the Fen Complex in southern Norway. Although earlier usage of the term damtjernite has been inconsistent [even in spelling: damtjernite vs damkjernite (Griffin & Taylor, 1975; Rock, 1986, 1987, 1991; Dahlgren, 1994; Le Maitre, 2002); a problem that stems from Brøgger (1921)], a more recent compilation of the dykes in the Fen province indicates that the majority have feldspathoids and/or alkali feldspar in the groundmass [the 'F-damtjernites' of Dahlgren (1994)]. Dahlgren's (1994) 'C-damtjernites' are nepheline- and alkali feldspar-free with 25–50 vol. % modal carbonate and therefore correspond to aillikites. This confirms the co-occurrence of distinct ultramafic lamprophyre types together with carbonatites within a single province, with prime examples being the Fen and Aillik Bay areas.

The new definition of damtjernite as an ultramafic lamprophyre with feldspathoids and/or alkali feldspar in the groundmass could potentially cause confusion with other lamprophyre types belonging to the calc-alkaline and alkaline groups. At Aillik Bay, the coexistence of aillikites and sannaites has been described (Foley, 1984; Malpas *et al*., 1986), implying the existence of both ultramafic and alkaline lamprophyre magmas. However, recent work has shown that damtjernites also occur which are petrogenetically linked to both the aillikites and these 'sannaites', forming a strong mineral compositional and geochemical continuum. Age determinations confirm the genetic relationship (Tappe *et al*., in preparation). In this case, ultramafic lamprophyres grade into more evolved rocks that have more than 10 vol. % felsic minerals, but are clearly related by fractionation. Hence, mineralogical definitions based on rigid boundaries of percentage modal minerals introduce arbitrary delimiters that risk being carried over into petrogenetic arguments. We therefore suggest that the term sannaite should be reserved for rocks that not only have the mineralogical characteristics described by the IUGS classification (Le Maitre, 2002, p. 19), but also pass an extra chemical screen ($SiO_2 > 41$ wt %). This greatly restricts the chemical variation amongst rocks hitherto called sannaites (Rock, 1991, p. 82), making it more likely that those remaining as sannaites are related to a specific alkaline lamprophyre magma type. Hence, the former Aillik Bay sannaites are more appropriately referred to as 'evolved damtjernites', similar to the usage by Mitchell (1995), who describes 'evolved orangeites'. This reiterates the message that genetic considerations cannot be left out of classification schemes (Foley *et al*., 1987; Mitchell, 1994*b*, 1995) and removes the confusion of a petrogenetic relation between ultramafic and alkaline lamprophyre groups, which is no longer justified on petrogenetic grounds. A strict application of this genetic concept obviates the need for the former UML types 'polzenite' and 'ouachitite', which are, according to our extensive literature survey, equivalent to evolved alnöites and evolved damtjernites, respectively.

It should be noted that if one were to recover only the evolved damtjernites or evolved orangeites at a locality, then they would not be recognized at Step 3 in the new classification. This re-emphasizes the importance of considering geochemical and, more importantly, mineral compositional data from larger sample suites wherever available.

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