The Canadian Mineralogist
Vol. 36, pp. 895-903 (1998)

MELILITOLITES: A NEW SCHEME OF CLASSIFICATION

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Abstract

A new scheme of classification is proposed for melilite-bearing plutonic rocks with more than 10% melilite and less than 50% primary carbonate phases, based on the absolute modal abundances of the dominant minerals. Melilitolite is retained as a "general" root-name for all such rocks. Previous definitions of terms used in the classification of these rocks, including afrikandite, kugdite, okaite, turjaite and uncompahgrite, are modified in order to provide "specific" root-names for melilitolites. A new rock-name, "ultramelilitolite", is proposed as a specific root-name for samples with more than 65% melilite. The use of multiple root-names and the problems associated with the use of mineral modifiers in rock nomenclature are discussed.

Keywords: melilitolite, afrikandite, kugdite, okaite, turjaite, uncompahgrite, "ultramelilitolite", modifier, root-name.

Sommaire

Nous présentons ici un nouveau schéma de classification visant les roches plutoniques contenant plus de 10% de mélilite et moins de 50% de phases carbonatées primaires, et fondé sur la teneur des minéraux dominants en termes absolus. Nous retenons le terme "mélilitolite" comme racine du nom de telles roches. Les définitions utilisées antérieurement dans le classification de ces roches, par exemple, afrikandite, kugdite, okaïte, turjaïte et uncompahgrite, sont ici modifiées afin d'en arriver à des noms de base spécifiques dans ce schéma. Un nouveau nom, "ultramélilitolite", est proposé pour les échantillons contenant plus de 65% de mélilite. Nous discutons l'utilisation de noms de base multiples et les problèmes associés à l'utilisation de noms de minéraux comme qualificatifs dans la nomenclature de ces roches.

(Traduit par la Rédaction)

Mots-clés: mélilitolite, afrikandite, kugdite, okaïte, turjaïte, uncompahgrite, "ultramélilitolite", qualificatifs, noms de base.

Introduction

Although melilite-bearing igneous rocks are comparatively rare on a worldwide scale, these unusual rocks play an important role in assessing the petrogenetic significance of mantle-derived, SiO_2-poor magmas. The current IUGS classification scheme for melilite-bearing intrusive rocks proposed by Streckeisen (1979) and Le Maitre (1989), and recently affirmed by Woolley *et al.* (1996), defines both intrusive and extrusive melilite-bearing rocks solely on the basis of three mineral components: melilite, olivine and pyroxene. Unfortunately, these minerals do not adequately reflect the mineral assemblages present in worldwide, plutonic, melilite-bearing rocks.

A classification scheme called the Petrographic Code was formulated by Mikhailov *et al.* (1995) in an attempt to classify all magmatic and metamorphic rocks. Included in this scheme was a section on melilite-bearing intrusive rocks, based on a classification scheme first proposed by Egorov (1969). This scheme uses (and in some cases redefines) nomenclature taken from the international literature. Although the classification scheme by Mikhailov *et al.* (1995) is one of the most realistic attempts to classify melilite-bearing intrusive rocks thus far, it has two drawbacks: (i) it strays too far from the original definitions of the terms used in the nomenclature, and (ii) it does not follow current IUGS guidelines on rock nomenclature. In a detailed classification of undersaturated alkaline rocks, Mitchell (1996) included a section on extrusive and intrusive melilite-bearing rocks which provided a compromise between the schemes of Woolley *et al.* (1996) and Mikhailov *et al.* (1995), but did not sufficiently reflect natural mineral assemblages. The present paper sum-

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marizes previous work on the description and classification of worldwide intrusive melilite-bearing rocks, and provides a new, comprehensive scheme of classification based on their modal mineralogy, which respects both old terminology and modern guidelines regarding the nomenclature of igneous rocks.

Summary of Previous Work

Early attempts to name intrusive melilite-bearing rocks were made in the first half of the twentieth century. Larsen & Hunter (1914) used the term "uncompahgrite" to define a melilite–pyroxene rock from Iron Hill, Colorado. Larsen (1942) subsequently described an average uncompahgrite from Iron Hill as containing 68% melilite, 15% clinopyroxene, 10% magnetite, 3% perovskite, 2% mica, 1% apatite and minor calcite. However, the modal abundances of uncompahgrites at Iron Hill vary widely. Melilite can make up from 50 to 100% of the total, and nepheline and garnet also can be present (Larsen 1942). Further detailed petrological studies of the uncompahgrites and related rocks at Iron Hill were carried out by Temple & Grogan (1965) and Nash (1972).

Intrusive melilite-bearing rocks are abundant in Russia, particularly in the Kola Peninsula and the Maimecha–Kotui Province in Siberia. Ramsay (1921) and Kranck (1928) defined the term "turjaite" to describe the abundant nepheline-bearing melilitolites from the Turiy Peninsula in the Kola Peninsula. The type-locality turjaites from Turiy contain melilite (20–65%), nepheline or cancrinite or both (10–35%), mica (3–35%), magnetite (3–30%), perovskite (<5%), with minor apatite and garnet and rare calcite and clinopyroxene (Kranck 1928, Bell *et al.* 1996). The term "okaite" was defined by Stansfield (1923) for the haüyne-bearing equivalent of turjaite, described from the Oka Complex in western Quebec. Samples of okaite and related melilite-bearing rocks from Oka typically contain melilite (30–90%), nepheline (<40%), haüyne (<40%), clinopyroxene (<10%), with minor apatite, calcite, magnetite, mica and perovskite (Eby 1973, Treiman & Essene 1985, Gold *et al.* 1986).

Afrikandite, from the Afrikanda complex in the Kola Peninsula, was first defined by Chirvinskii *et al.* (1940) as an intrusive rock containing clinopyroxene, magnetite, melilite, mica, olivine and perovskite. A later definition of afrikandite by Sørensen (1974) as a melilite – perovskite – magnetite rock was used by Nielsen (1980) to classify ring-dyke rocks from the Gardiner intrusion in Greenland, which also contain mica and apatite in substantial quantities. Other rocks from Gardiner were classified as turjaite and uncompahgrite. The Rangwa complex in Kenya was described by Le Bas (1977) as containing turjaite (40–59% melilite, 1–3% nepheline and cancrinite, 2–5% clinopyroxene, 3–15% perovskite, 5–45% mica, 1–15% magnetite and 3–10% apatite), with rarer uncompahgrite (<17% clinopyroxene and <2% olivine), and afrikandite (15% perovskite and 16% magnetite).

Olivine-bearing melilite rocks from the Kugda Massif within the Maimecha–Kotui Province in Siberia were termed "kugdite" by Egorov (1969). Most melilite-bearing rocks from the other Maimecha–Kotui massifs have been classified as kugdite, okaite, turjaite and uncompahgrite, using the scheme of Egorov (1969). The Maimecha–Kotui province includes the Guli massif, the largest alkaline complex in the world (1500 km^2), which also contains melilitolite and kugdite (Yegorov 1989). Kovdorite, also described as an olivine turjaite, was found in the Kovdor Massif by Zlatkind (1945). Detailed studies of the Kovdor rocks were subsequently carried out by Kupletsky (1948), who devised an early three-component scheme of classification for the samples. Kukharenko *et al.* (1965) described melilite-bearing samples from Kovdor, including kovdorites and turjaites, as containing significant quantities of olivine (<19%) and monticellite (<20%), as well as nepheline-, clinopyroxene- and mica-bearing varieties. Arzamastsev (1994) described the dominant mineralogy of the turjaites from Kovdor as melilite (25–50%), nepheline (15–30%), mica (20–25%) and clinopyroxene (5–25%). An unusual melilitolite sill at Pian de Celle, Italy, was described by Stoppa *et al.* (1997). It contains ~12% calcite and 25% leucite, and was given the name "calcite leucite melilitolite".

Classification of Melilitolites

Rationale

Many melilite-bearing intrusive rocks are dominated by the presence of one (or two) other minerals, apart from melilite. Table 1 demonstrates the three principal melilite-bearing mineral assemblages: (A) silicates (divided into mafic and felsic groups), (B) oxides, and (C) carbonates. Most melilite-bearing rocks fall into category A, but categories B and C are represented in several intrusions, and any proposed scheme of nomenclature needs to take these assemblages into consideration.

TABLE 1. MINERAL ASSEMBLAGES IN MELILITOLITES AND DEFINITION OF SPECIFIC ROOT-NAMES

Group	Dominant mineralogy		Defining mineral (>10%)	Specific root-name
A	silicate	mafic	melilite (>65%)	"ultramelilitolite"
			pyroxene	uncompahgrite
			olivine	kugdite
		felsic	nepheline	turjaite
			hauyne	okaite
B	oxide		perovskite	afrikandite
C	carbonate (primary)		*[carbonate > 50%*	*carbonatite]*
			carbonate < 50%	*e.g.* calcite-melilitolite*

If any sample contains more than 10% of more than one of the defining minerals, then the most abundant defining mineral will provide the specific root-name. Modifiers may be used to denote more than 10% of particular minerals, and are listed in order of increasing abundance.
* No specific root-name is provided for samples containing more than 10% and less than 50% primary carbonate phases.

The scheme proposed in the present paper is based on the modal mineralogy of a worldwide spectrum of intrusive melilite-bearing samples, as shown in Table 2, and provides a concise and descriptive terminology for their classification. The proposed scheme attempts to: i) follow the current IUGS guidelines on the naming of igneous rocks, ii) clearly define previous melilite-bearing rock names with respect to each other, and iii) respect the original definitions of the previous rock names, as far as possible.

TABLE 2. MODAL MINERALOGY OF MELILITOLITES WORLDWIDE, AND NEW CLASSIFICATION

Massif	Literature name	Amp	Ap	Cal	Ccn	Grt	Hyn	Lct	Mgt	Mel	Mi	Mtc	Ne	Ol	Prv	Cpx	*M'*	Prefix	Specific root-name
Rangwa [1]	turjaite		10						1	40	45		1		3	tr	99	apatite–mica	melilitolite
	turjaite		3						8	53	13		3		15	5	97		afrikandite
	turjaite		4						15	59	5		2		13	2	98	magnetite	afrikandite
	uncompahgrite								8	63	4			2	6	17	100		uncompahgrite
	uncompahgrite								16	59	tr			tr	15	1	100	magnetite	afrikandite
Iron Hill [2]	uncompahgrite		1	tr		<5			10	50-	2		<5	3	15		<100		uncompahgrite
										100								pyroxene	"ultramelilitolite"
Oka [3]	okaite		<5	<5			<40		<5	30-	<5		<40		<5	<10		nepheline	okaite
										90								haüyne	turjaite
	nepheline okaite			<5			20		<5	40	<5		40				40	haüyne	turjaite
	haüyne–pyroxene okaite		<5	<5			40			30	<5					10	60	pyroxene	okaite
— [4]	okaite*		2-	15-					5-	30-	1-				1-		100	calcite	melilitolite
			5	50					10	70	5				5				
	nepheline melilitolite		tr	3					5	30	5	50			5		50		turjaite
										50									
	nepheline okaite		1	3					5	30-	10		30-		1		50-		turjaite
										50			50				70		
— [5]	okaite		2						6	65	16				4		100	mica	"ultramelilitolite"
	okaite		2	7					5	69	8				6		100		"ultramelilitolite"
Pian di Celle [6]	calcite–leucite melilitolite		2	12				25	4	28	9	0.5	7	1.5		5	68	calcite–leucite	melilitolite
Turiy [7]	calcite melilitolite*			28		1			10	55	2	1			2	tr	100	calcite	melilitolite
	turjaite			tr		3			5	40	12		35		5		65		
	turjaite																		
	turjaite		1			2			3	46	22		23		3		77	mica	turjaite
	turjaite		4	1					30	20	12		28		5		72	magnetite	turjaite
— [8]	turjaite		4	4	16	4			3	30	35				tr	4	84	cancrinite–mica	melilitolite
	melilitolite		tr	1		2			7	65	6	tr	10		5	tr	90	nepheline	"ultramelilitolite"
Kovdor [9]	turjaite	<5		<5		<5			<5	25-	20-		15-		<5	5-	70-	pyroxene	uncompahgrite
										50	25		30			25	85	nepheline	turjaite
— [10]	melilitolite								1	90	4				<1	5	100		"ultramelilitolite"
	melilitolite								1	89	4				<1	5	100		"ultramelilitolite"
	monticellite melilitolite	<1							11	73	<1	3		4	<1	8	100		"ultramelilitolite"
	monticellite melilitolite								5	72		10		3	<1	10	100	monticellite–pyroxene	"ultramelilitolite"
	monticellite melilitolite								5	69		20		2	<1	4	100	monticellite	"ultramelilitolite"
	kugdite	1							1	62	4	7		19	<1	7	100		kugdite
	uncompahgrite								1	70	2				<1	27	100	pyroxene	"ultramelilitolite"
	uncompahgrite								10	36	2	1		2	<1	48	100		uncompahgrite
	uncompahgrite	1							3	29	2				<1	67	100		uncompahgrite
	phlogopite turjaite								14	62	7		15	2	1		85		turjaite
	phlogopite turjaite								10	59	18		14		<1	3	86	mica	turjaite
	phlogopite turjaite								10	44	7		26		<1	13	74	pyroxene	turjaite
	phlogopite turjaite								6	38	26		27		<1	3	73	mica	turjaite
	turjaite								7	59	1		22		<1	11	78	pyroxene	turjaite
	turjaite								5	48			31		<1	15	69	pyroxene	turjaite
	turjaite								8	45			27		1	19	73	pyroxene	turjaite
	turjaite								2	40			22		<1	37	78	nepheline	uncompahgrite
	turjaite								6	13	1		30		<1	51	70	nepheline	uncompahgrite
Afrikanda [11]	afrikandite								5	10				75	10		100	perovskite	kugdite

TABLE 2 (cont'd). MODAL MINERALOGY OF MELILITOLITES WORLDWIDE, AND NEW CLASSIFICATION

Massif	Literature name	Amp	Ap	Cal	Ccn	Grt	Hyn	Lct	Mgt	Mel	Mi	Mtc	Ne	Ol	Prv	Cpx	*M'*	Prefix	Specific root-name
Maimecha – Kotui province [12]																			
Odehincha	uncompahgrite					2				68						30	100	pyroxene	"ultramelilitolite"
Kugda	uncompahgrite								13	76	1				0.3	10	100	pyroxene	"ultramelilitolite"
Kugda	olivine uncompahgrite								9	74	0.5			10		7	100	olivine	"ultramelilitolite"
Kugda	nepheline uncompahgrite								16	59	4	3	1	3	4	9	99	magnetite	melilitolite
Bihit-Zapad	nepheline uncompahgrite								9	74			4	5		7	96		"ultramelilitolite"
Bihit-Zapad	turjaite								10	64	0.3		10	2		15	90	nepheline	uncompahgrite
Kara-Meny	turjaite								3	77	4		9	1		7	91		"ultramelilitolite"
Nemakeet	turjaite								10	62	14		9			5	91		melilitolite
Odehincha	turjaite		3			8			5	66			10		3	5	90	nepheline	"ultramelilitolite"
Atrdyak	turjaite								15	32	0.5		20	1		25	80	nepheline–magnetite	uncompahgrite
Changit	porphyritic turjaite								15	25		6	15	5		35	85	nepheline–magnetite	uncompahgrite
Bihit-Zapad	olivine turjaite								12	58	1		14	7	1	6	86		turjaite
Kara-Meny	olivine turjaite								8-	30-	5-		25-	5-		10-	65-	pyroxene	turjaite
									10	35	10		35	10		15	75		
Romaneecha	olivine turjaite								12	37	3	14	10	8		16	90	olivine–monticellite	uncompahgrite
Nemakeet	olivine turjaite								5	21	10		20	10		34	80	olivine–nepheline	uncompahgrite
Kara-Meny	olivine turjaite								5	31	5		28	20		12	72	pyroxene–olivine	turjaite
Chara	nepheline turjaite								8	35	2	5	30			20	70	pyroxene	turjaite
Odehincha	pyroxene okaite					3			3	56	5		25			7	75		turjaite
Kara-Meny	okaite								10	51	1		38	1			62		turjaite
Bihit-Vostochny	olivine okaite		0.3	0.3					8	48	6		33	3	1	1	67		turjaite
Kara-Meny	okaite								5	30			50	10	5		50	olivine	turjaite
Nemakeet	okaite					21			1	37	11		29		1		71	garnet	turjaite
Kugda	kugdite								12	70	0.5	0.5		14	0.5	2	100	olivine	"ultramelilitolite"
Kugda	kugdite								12	41	13		1	34			99		kugdite
Kugda	nepheline kugdite								9	48	13		7	20		3	93		kugdite
Gulinsky	pyroxene kugdite								4	30		15		30	1	1	100	monticellite	kugdite
Gulinsky	melilitolite								13	77	5			2		3	100		"ultramelilitolite"
Gulinsky	olivine melilitolite								17	75	1			7		0.2	100	magnetite	"ultramelilitolite"
Kugda	nepheline melilitolite								25	61	2		5		2	4	95	magnetite	melilitolite
Kugda	nepheline melilitolite								25	72	0.4	0.6		1	1	0.2	100	magnetite	"ultramelilitolite"
Gardiner [13]		1	2						12	83					1	1	100		"ultramelilitolite"
		2	1						10	84						2	100		"ultramelilitolite"
									10	83					5	2	100		"ultramelilitolite"
		2-	4-		0.5-				6-	75-	0.5				2-	2-	100		"ultramelilitolite"
		3	5		1				8	83	1				5	4			
			1.5						7.5	78	1.5				6.5	5	100		"ultramelilitolite"
			13						18	54	5.5				6	3.5	100	apatite–magnetite	melilitolite
			20						21	45	9				4.5		100	apatite–magnetite	melilitolite
		2	10						12	63	0.5				12	1.5	100	apatite	afrikandite
			<1	15	tr	2				82	<1					<1	100	calcite	"ultramelilitolite"
			1						8	77	10				3		100		"ultramelilitolite"
									15	72					3	10	100	pyroxene	"ultramelilitolite"
		2	<1						15	60					18	4	100		afrikandite
		1	<1						7	63	4				5	20	100		uncompahgrite
			<1						6	68	<1				6	15	100	pyroxene	"ultramelilitolite"
			1						5	30	10				5	50	100		uncompahgrite
			1						15	75	2				5	1	100		"ultramelilitolite"
		6	20						15	50					7		100	apatite	melilitolite
			8						4	45	40				3		100	phlogopite	melilitolite
			2						5	15	1				2	75	100		uncompahgrite

* also melilite carbonatites with >50% calcite.

References: [1] Le Bas (1977), [2] Larsen (1942), [3] Gold *et al.* (1986), [4] Treiman & Essene (1985), [5] Eby (1973), [6] Stoppa *et al.* (1997), [7] Dunworth (1997), [8] Bell et al. (1996), [9] Arzamastsev (1994), [10] N.S. Rudachevsky, unpubl. data, [11] E.A. Dunworth, unpubl. data, [12] Egorov (1969), [13] T. Nielsen (pers. commun., 1997). The symbols used are those of Kretz (1983), except that Mgt is chosen for magnetite. In addition, Amp represents amphibole, and Mi represents mica.

Root names

1. Melilitolite is affirmed as a *general root-name* for all plutonic rocks containing >10% modal melilite and <50% modal primary carbonate (Woolley *et al.* 1996), as shown in Figure 1. Any sample containing <10% melilite is not

a melilitolite and should be defined on the basis of the rest of its modal mineralogy with "melilite-bearing-" used as a prefix (Le Maitre 1989). Samples of this nature fall into the shaded area in Figure 1.

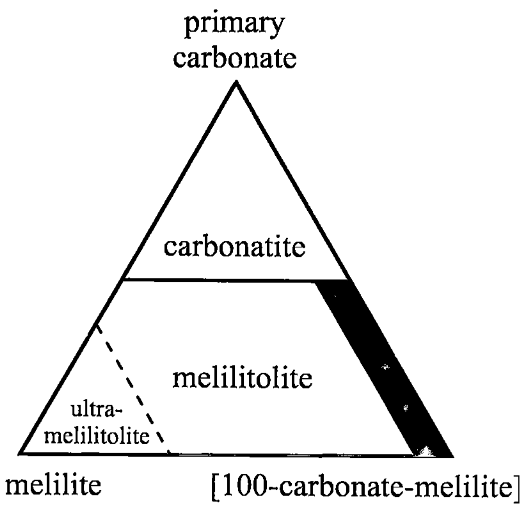

FIG. 1. Classification of rocks containing primary carbonate, melilite and other minerals, based on modal mineralogy. The division between melilitolite and carbonatite occurs at 50% carbonate, following the flow-chart classification for all igneous rocks, outlined in Woolley *et al.* (1996). The creation of the specific root-name "ultramelilitolite" within the melilitolite field occurs at 65% melililite. The shaded area represents rocks with less than 10% melilite, which are not considered to be melilitolites.

2. If more detailed nomenclature is required, and in order to define terms used in previous studies with respect to each other, the following use of *specific root-names* is also suggested. Samples that contain greater than 10% modal abundance of any of the five "defining minerals" olivine, pyroxene, perovskite, nepheline and haüyne, may use the specific root-name associated with that mineral, as listed in Table 1. Any sample that contains in excess of 10% of more than one of the "defining minerals" may derive a specific root-name from the most abundant "defining mineral", and any less abundant "defining mineral(s)" may be used as a modifier(s), as shown in Figure 2.

3. We propose that any plutonic sample with melilite in excess of 65% should be given the specific root-name "ultramelilitolite". This aspect of the classification scheme is explained in further detail in a later section and is shown in Figures 1 and 2.

Modifiers

Modifiers are normally used to denote high quantities of a particular mineral in a sample. We suggested that any mineral with more than 10% absolute modal abundance in a melilitolite should have the mineral name added as a modifier to the root name; where more than one modifier is required, the modifiers are listed in order of increasing mineral abundance. However, the "defining mineral" used to define a specific root-name, as described above, should not be used as an additional modifier. For example, the scheme precludes the use of "nepheline turjaite".

It is also suggested that mica and magnetite should be used as modifiers only where they reach more than 15% absolute modal abundance, given that these minerals are relatively abundant in many samples of melilitolite, as seen in Table 2.

Note

It should be emphasized that the terms of rock nomenclature derived by using general and specific root-names are equivalent. For example, "nepheline pyroxene melilitolite" is equivalent to "nepheline uncompahgrite". Examples of names derived using the proposals above are listed in Table 2.

ROCK NOMENCLATURE

Rationale

The choice of minerals used to define the specific root-names listed in Table 1 was made on the following grounds:

a) In order to limit the number of root-names in the classification scheme, we have redefined melilitolite rock-names that already exist in the literature wherever possible. Previous names such as afrikandite, kugdite, okaite, turjaite and uncompahgrite have now been defined on the basis of modal mineralogy.

b) Melilitolites can be broadly divided into three main groups, on the basis of dominance of silicate, oxide and carbonate minerals, as shown in Table 1, and the nomenclature chosen reflects these natural divisions, while taking modal mineralogy and the worldwide abundance of each group into account.

c) The definitions of the terms kugdite and uncompahgrite in this scheme are very similar to those used by both Le Maitre (1989) and Mikhailov *et al.* (1995). However, the terms turjaite, okaite and afrikandite were listed as "not recommended usage" by Le Maitre (1989), whereas turjaite and okaite were redefined by Mikhailov *et al.* (1995) in the Petrographic Code, as described below, but afrikandite was not included.

The original definition of okaite (Stansfield 1923) listed haüyne as an essential mineral, instead of, or as well as, nepheline. We have chosen to respect this definition in the new classification scheme, while recognizing that it has previously been used to describe "melilite–nepheline" assemblages in the classification schemes of Egorov (1969) and Mikhailov *et al.* (1995). Similarly, turjaite was originally defined by Ramsay (1921) as a rock containing melilite + nepheline + phlogopite. The classification scheme proposed in this paper has used the presence of nepheline to define the use of the term turjaite, while acknowledging that the presence of phlogopite also is important in these rocks. The definitions of Egorov (1969) and Mikhailov *et al.* (1995) list nepheline + pyroxene as essential components in turjaite, but given the limited occurrence of pyroxene in the type-locality turjaites of the Turiy Massif, this definition has been rejected. The original definition of turjaite (Ramsey 1921) listed nepheline as one of the essential minerals. In the system nepheline – calcite – H_2O, Watkinson & Wyllie (1971) showed that a reaction of nepheline and calcite produced cancrinite under hydrous conditions, and it has been postulated by Bell *et al.* (1996) that cancrinite also can form as a primary product of the crystallization of a Ca-rich silicate magma such as turjaite, instead of nepheline.

The use of the term afrikandite to define the melilite–oxide assemblage (B) in Table 1 follows the definition of afrikandite by Sørensen (1974) as a "melililite – perovskite – magnetite" rock. The type-locality "afrikandite" from the Afrikanda massif is, in fact, a melilite-bearing olivinite containing ~10% melilite, 15% perovskite + magnetite, and 75% olivine. The term "afrikandite" is no longer used in the Russian literature given the definition of Sørensen (1974), along with the

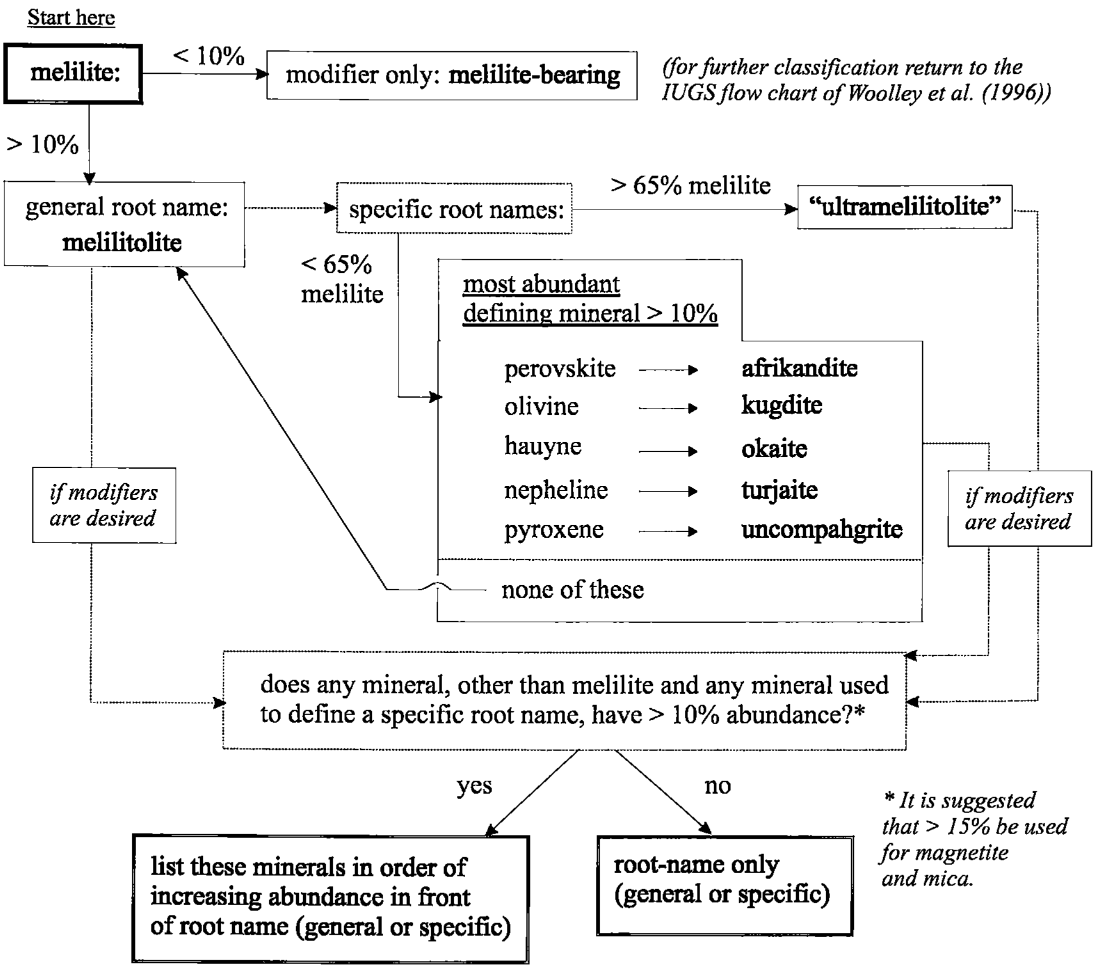

FIG. 2. Flow-chart classification for plutonic rocks that contain melilite. It should be noted that the use of specific root-names is optional, and that terms of nomenclature derived using general and specific root-names for any given sample are equivalent.

fact that the type-locality material contains significant quantities of perovskite + magnetite, we have chosen to retain this term to describe melilite–oxide assemblages.

"Ultramelilitolite"

A term to specifically describe melilite-rich intrusive rocks, based on the *absolute* abundance of melilite, has been lacking up until now. In the olivine – clinopyroxene – orthopyroxene scheme of classification of ultramafic rocks (Le Maitre 1989), the term pyroxenite is used to describe rocks whose mafic mineralogy is dominated by pyroxene. Similarly, in the previous olivine – pyroxene – melilite scheme of classification of intrusive melilite-bearing rocks (Le Maitre 1989), the term melilitolite was used both as a term to describe rocks with [melilite/(melilite + olivine + pyroxene)] > 90% *and* as a general root-name to describe any intrusive rock with melilite > 10%. Such dual usage is inadvisable and misleading for purposes of rock nomenclature and classification. In our new proposed scheme, we prefer to use the term "melilitolite" as a general root-name to describe intrusive samples with greater than 10% melilite (and less than 50% primary carbonate). For those melilitolites that contain a high modal abundance of melilite, a new specific root-name is required. Thus, the term "ultramelilitolite" is suggested here as a specific root-name for plutonic rocks with melilite in excess of 65% modal abundance. Examples of "ultramelilitolite" are listed in Table 2.

Discussion

The new scheme of classification proposed in this paper has been evaluated using the worldwide modal abundance data listed in Table 2. From the information provided in this table, it can be seen that a variety of melilitolites are represented within individual massifs, and that the new terminology provides concise and clear descriptions for almost all the samples.

There are a number of points to note regarding the relationship between the classification scheme proposed here, and the current IUGS classification of igneous rocks. Firstly, Figure 1, based on an early part of the IUGS flow chart for the classification of igneous rocks outlined in Woolley *et al.* (1996), provides a diagrammatical representation of the sequential classification of carbonatites and melilitolites. Some melilitolites can contain significant quantities of primary or secondary carbonate phases, but the presence of primary carbonate is the sole criterion for defining the top apex of Figure 1. Secondary carbonate phases may be detected using petrographic techniques, cathodoluminesence spectroscopy or geochemical relationships.

Secondly, another aspect of the earlier IUGS classification of melilitolites (Le Maitre 1989) that has not yet been discussed is the use of the mafic index M'. The use of M' in the classification of melilitolites, as suggested by Woolley *et al.* (1996) and Le Maitre (1989), should be discontinued, as M' should only be used to classify samples that fall within the QAPF diagram. This also implies that paragraph B.8.2 of Le Maitre (1989), where it is suggested that rocks containing more than 10% melilite and with M' less than 90 should be named "melilite nephelinite" (or, presumably, "melilite ijolite"), is incorrect.

Thirdly, the suggested use of the terms "general root-name" and "specific root-name" throughout this paper has implications for the classification of other igneous rocks, where similar situations frequently arise. For example, in the classification of ultramafic rocks, the term peridotite would become a general root-name, whereas lherzolite, wehrlite and harzburgite would become specific root-names. Similarly, in the classification of more SiO_2-rich rocks, trachyandesite (general root-name) can be divided into benmoreite and latite (specific root-names), and there are many other examples. It is important to note that the names derived from general or specific root-names should be considered equivalent in rank, and that specific root-names are not "sub-root-names".

We believe that the melilitolite classification scheme outlined above is to be preferred to the previous IUGS classification scheme for melilitolites (Le Maitre 1989, Woolley *et al.* 1996) on the following grounds:

i) The mineral assemblages present in worldwide melilitolites are inadequately described using the olivine – pyroxene – melilite triangular plot of Le Maitre (1989), given the wide variation in the modal mineralogy of natural melilitolites, as outlined in Tables 1 and 2;

ii) All names in the proposed scheme are based on the absolute abundance of all minerals present, which we believe to be more informative than ratioed proportions needed in order to use triangular plots. In a classification scheme where only 10% of a single mineral (melilite) is essential, nomenclature is required that reflects the rest of the modal minerals;

iii) There is an inconsistency in the use of modifiers with the methods proposed by Le Maitre (1989). The purpose of modifiers is to emphasize the presence of high modal abundances of certain minerals. Modifiers such as those used by Le Maitre (1989) in their olivine – pyroxene – melilite triangular plot (*e.g.*, "olivine–pyroxene melilitolite") are solely defined on the basis of their *relative* abundance with respect to the other two minerals, and not in relation to their absolute abundance in the sample. The subsequent use of additional modifiers, based on the *absolute* abundance of a mineral within a sample (*e.g.*, >10%), introduces complications when simultaneously using modifiers defined using different criteria. The classification proposed here uses six definitive minerals (melilite, olivine, pyroxene, perovskite, haüyne and nepheline) to classify specific root-names (Table 1), and all modifying prefixes used in front of the general or specific root-names refer *only* to absolute modal abundance.

The classification scheme for intrusive melilitolites proposed in this paper no longer corresponds to the mineral assemblage used to classify their extrusive equivalents, as proposed by Le Maitre (1989). The mineral assemblage melilite – olivine – pyroxene – nepheline is common in melilite-bearing *extrusive* igneous rocks; therefore, we contend that the olivine – pyroxene – melilite (melilitite) triangle of Le Maitre (1989) is suitable for classification of extrusive rocks with more than 10% melilite. The dissimilarities in modal mineralogy between extrusive and intrusive melilite-bearing samples provide sufficient justification to use different schemes of classification to describe them.

Conclusions

This revised and extended classification of melilite-bearing intrusive rocks provides a comprehensive scheme of classification, which has been lacking up until now. A clear distinction has been made between "general" and "specific" root-names. The term melilitolite continues to be used as a "general" root-name for plutonic rocks containing more than 10% modal melilite and < 50% carbonate minerals. The proposed scheme of classification has defined older terms such as afrikandite, kugdite, okaite, turjaite, uncompahgrite, that have been in "unofficial" and uncertain usage for many years, as "specific" root-names, which, along with clearly defined modifiers, provide a classification scheme that is concise and descriptive for melilite-bearing plutonic rocks. "Ultramelilitolite" has been proposed as a new "specific" root-name for samples with more than 65% melilite. The scheme proposed here provides a convenient and useful way to classify most melilite-bearing intrusive rocks.

Acknowledgements

We thank Marjorie Wilson for initially introducing the first author to melilite-bearing rocks; Andrei Bulakh and Valeriy Ivanikov introduced both authors to the field relationships of melilite-bearing plutonic rocks. Andrei Bulakh, Anton Chakhmouradian, Natalya Krasnova, Troels Nielsen, Hatten Yoder Jr., Alan Woolley and Mike Le Bas provided very constructive comments on previous versions of this manuscript. The comments of the latter two reviewers reflect their own opinions on the proposed scheme, and do not reflect the official opinions of the IUGS Subcommision on the Nomenclature of Igneous Rocks. Troels Nielsen provided the previously unpublished data on modal mineralogy of the Gardiner Complex shown in Table 2. Thanks are also due to the numerous people who provided a fascinating variety of suggestions for the new specific root-name. This work was partly supported by NSERC grant A7813 to K. Bell.

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Received April 25, 1997, revised manuscript accepted December 15, 1997.