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Some notes on the IUGS classification of lamprophyric rocks

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Abstract

The lamprophyric rocks are uncommon volatile-rich melanocratic porphyritic rocks which contain only mafic phenocrysts. The felsic minerals are confined in the groundmass. They occur as dikes, sills and diatremes. The lamprophyric rocks are sometimes associated with diamond deposits. This review article discusses the ongoing debate in igneous petrology regarding the classification of lamprophyric rocks, specifically the Lamprophyre clan vs Lamprophyre facies problem. The background of this debate is rooted in conflicting interpretations of the classification of these rocks, with some researchers grouping them into a super-group called the "Lamprophyre clan" while others emphasize the distinction between the different types of these rocks (Lamprophyre facies). The aim of this study is to provide a comprehensive analysis of relevant literature and propose a more inclusive petrological classification system for lamprophyric rocks by considering the geological setting, petrography, texture, mineralogy, whole-rock geochemistry and isotopic analysis of the various kimberlites, orangeites, lamproites, para-lamproites, calc-alkaline, alkaline and ultramafic lamprophyres. Lastly, the diamond potential is also taken into account. The implications of this study are significant for the international geological community. It proposes the adoption by the IUGS TGIR of both the Lamprophyre clan (as updated by Kamvisis & Phani, 2022, i.e. genetically interrelated rocks) and Lamprophyre facies (as suggested by Mitchell, 1994, i.e. rocks that formed under volatile-rich conditions) concepts to achieve a more widespread consensus among igneous petrologists. Both terms can be correct but they represent different perspectives in the study of these exotic rocks.

Keywords: IUGS, classification, kimberlite, lamproite, lamprophyre

1. Introduction

The term "lamprophyre" was first introduced into petrology by the German geologist Wilhelm von Gümbel in 1874 for rocks from the Bohemian massif. It originates from the Greek words "lampros" and "porphyre" and means a glistening porphyry. The lamprophyric rocks are volatile-rich mesocratic to holomelanocratic porphyritic igneous rocks which contain phenocrysts of mafic minerals like mica, amphibole, pyroxene and olivine whereas the light-colored constituents (feldspars, foids, carbonate) are confined in the groundmass. They are generally hypabyssal, occuring as dikes, sills and diatremes, although volcanic flows do exist.

The lamprophyric rocks are occasionally associated with economic diamond deposits. They have been the center of a long-lasting debate among scholars.

2. Discussion

The Lamprophyre clan vs Lamprophyre facies debate was initiated when the late Nicholas Rock published his voluminous book on lamprophyric rocks in 1991 (Rock, 1991) just one year before his tragic death. In his book, he included kimberlites, lamproites, calc-alkaline, alkaline and ultramafic lamprophyres into one super-group called the “Lamprophyre clan”. On the contrary, the conclusions of the IUGS Subcommission on Igneous Rocks (Le Maitre et al., 2002) were based mainly on an older article by Woolley et al. (1996). However, this article clearly states that the recommendations are presented for discussion and should not be regarded as the definitive statement on the topic. In 2022 the IUGS Task Group on Igneous Rocks (TGIR) published a report which included the classification of lamprophyric rocks as one of the key issues for academic discussion (see §13, 14, 15 in Lustrino et al., 2022). In § 14 of this report, the TGIR supported the Lamprophyre facies concept (Mitchell 1994), defining therefore lamprophyres as rocks formed by late-stage retention of H_2O and CO_2 in the parental magmas either by a long differentiation process or by prolonged crystallization at high pressures. The Lamprophyre clan concept, on the other hand, has recently been updated through extensive bibliographic research and a sequential genetic diagram with rock interrelations has been created for this purpose by Kamvisis & Phani (2022). Similar diagrams have been constructed by Barbara Scott-Smith (see Fig. 4 in Scott-Smith 1995 and Fig. 1 in Scott-Smith 2017). She particularly mentions that the less common and more extreme varieties of each rock type may fall outside that encompassed by the definition, and may show petrographic gradations or overlaps with the adjacent rock types (Scott-Smith 1995). After a careful review of relevant literature, we suggest that the following points should additionally (to the concluding remarks of Kamvisis & Phani, 2022) be taken into consideration when classifying lamprophyric rocks:

- The archetypal kimberlites show similar genetic features to orangeites. They are derived from a common evolving source in the convecting mantle (Sarkar et al., 2023).
- The transitional kimberlites are not rocks unique to the Kaapvaal craton of South Africa but they are also found in the Arkhangelsk region, NW Russia (Beard et al., 2000) and Guaniamo, Venezuela (Kaminsky et al., 2004).
- Although orangeites and peri-cratonic lamproites are somehow distinct in their mineralogy (Tappe et al., 2022) and textures (Fig. 1), they are also related (Kjarsgaard et al., 2022). This relation is best evident in the dikes of the Dronning Maud Land, Antarctica (Romu et al., 2008). The MgO content of the dykes (9.2–15.7 wt%) is similar to that of the average lamproite and some orangeites. The concentration of Zr (279–1515 ppm) and Nb (92-206 ppm) show affinities towards olivine lamproites and orangeites, whereas the Nb/La and Ce/Sr ratios (0.44–1.01, 0.13–0.22 respectively) are more similar to orangeites. Nd-Sr data indicates radiogenic Nd typical of lamproites and orangeites.
- The anorogenic lamproites are not exclusively found in cratons or mobile belts surrounding cratons. They also occur in tectonically active areas like Bucak in Turkey along with orogenic lamproites (Prelevic et al., 2008). These lamproites exhibit unradiogenic $^{87}Sr/^{86}Sr$ (0.72–0.74), $^{207}Pb/^{204}Pb$ (11.5–13.6), and radiogenic $^{143}Nd/^{144}Nd$ (0.511–0.512) and $^{206}Pb/^{204}Pb$ (18.8–19.2). They have a smooth incompatible trace element pattern with low LILE/HFSE ratios and high concentrations of Nb (>80ppm) and Ti (>1%).
- The orogenic lamproites may contain microcline instead of groundmass sanidine (Krmíček & Chalapathi Rao, 2022). The same is true for the extremely potassic (>10% K_2O) minette variety sizunite from France (Le Maitre et al., 2002).
- The para-lamproites petrologically connect subduction-related low-Ti lamproites and shoshonitic lamprophyres (i.e. minettes, Table 1 and Fig. 2). They are lamprophyric rocks with many lamproitic characteristics (e.g. $Al_2O_3<12$, $TiO_2>1$, $Fe_2O_3<10$, Mg#>70, CaO<10, $K_2O>3$ (Mitchell 2020), $K_2O/Na_2O>2$ (Prelevic et al., 2007; Mitchell, 2020), MgO>5, MgO>CaO, Cr>500ppm, Ni>300ppm, Cr>Ni (Vladykin, 2008)) that do not pass all IUGS screens for lamproites (Le Maitre et al., 2002). These mainly phlogopite-sanidine rocks, which lack Na-leucophases (like liquidus plagioclase, nepheline, and sodalite) have been characterized by igneous petrologists either as minettes or evolved lamproites since both have phlogopite phenocrysts in a sanidine groundmass (see Table 2 in Mitchell, 1995). In this context, it was suggested that phlogopitic rocks could be considered as examples of lamprophyric facies lamproites (Mitchell, 2007). Para-lamproites are commonly associated with shoshonitic rocks like in NW Vietnam (Tran et al., 2016) and the Mediterranean (Casalini et al., 2022). This can be explained by the fact that an increasingly K-character with increasing depth of subduction-generated igneous activity could eventually create lamproitic melts (Mitchell & Bergman, 1991). One characteristic example is the Limnos island phlogopite-rich para-lamproite in Greece (Kamvisis & Vasyukova, 2021) (Fig. 3). The para-lamproite follows the deep Kondias-Kotsinas fault and it is associated with the shoshonitic volcanism of Limnos (Gläser et al., 2022). About 70-80% of the Mediterranean lamproites do not cover the IUGS lamproite criteria (Lustrino et al., 2016) and could actually be para-lamproites.
- The para-lamproite variety cocite was defined by the IUGS as a melanocratic lamprophyre (Le Maitre et al., 2002). On the contrary, Vietnamese, Russian and Canadian igneous petrologists (Tran et al., 2016, Polyakov et al., 1995, Mitchell, 2005) have considered cocites as low-Ti lamproites. Statistical analysis by Tran et al. (2016) places them with

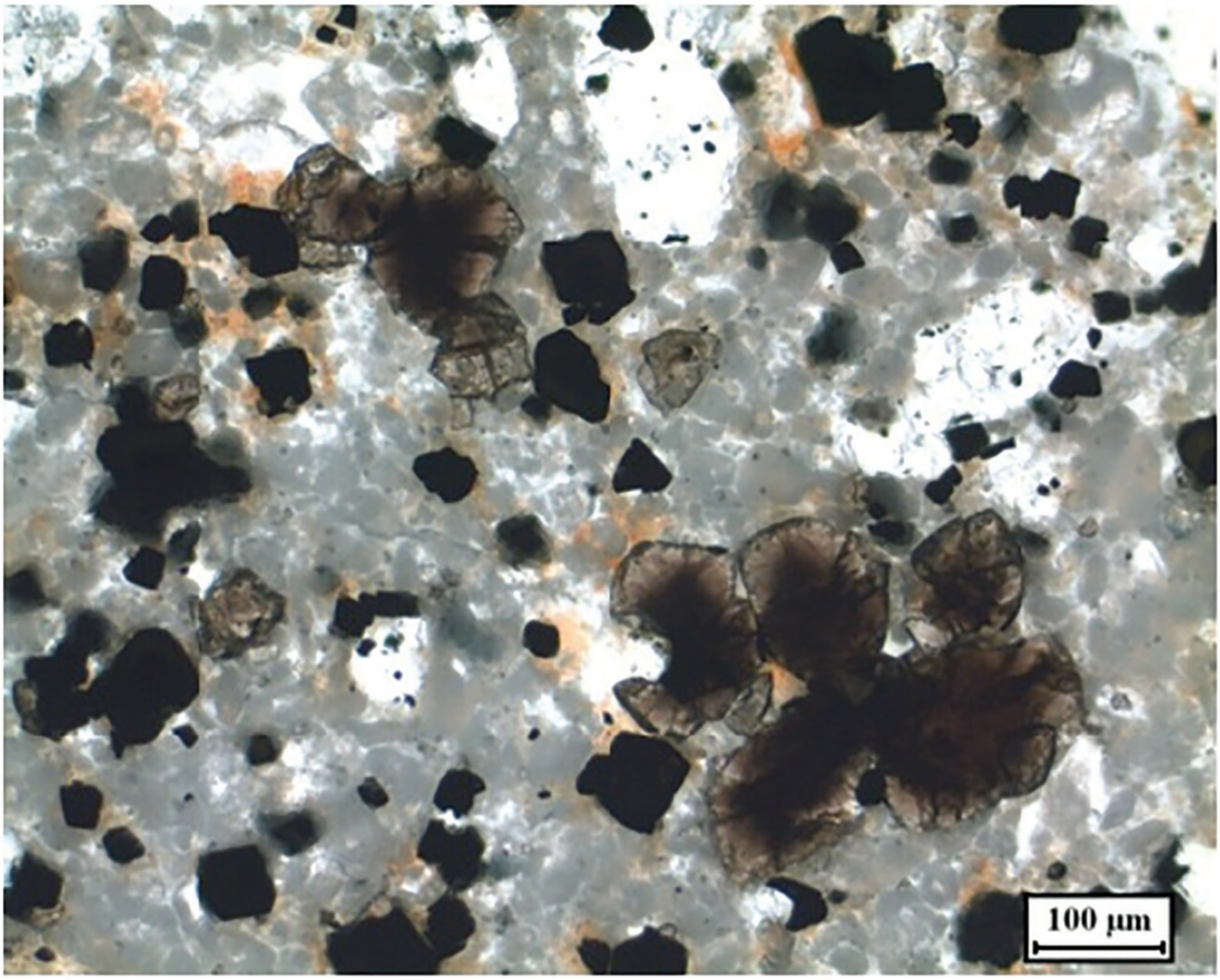

Figure 1. A photomicrograph with characteristic cauliflower-shaped dark translucent perovskite and orange tetraferriphlogopite in a serpentinised olivine matrix in PPL from the Balkamthota Vanka micaceous kimberlite (orangeite) in India (Phani and Raju, 2017).

Table 1. Representative compositions of para-lamproites from around the world. Mt. Bundey in Australia (Sheppard and Taylor, 1992), W. Churchill province in Canada (Peterson et al., 2002), Qinghai Xizang plateau in China (Mei et al., 1989), Bohemian massif in the Czech Republic (Krmíček et al., 2020), Limnos island in Greece (Kamvisis and Vasyukova, 2021), Aldan shield in Russia (Izokh et al., 2024), Pendennis and Jersey island in the U.K. (Hall, 1982; Wagner and Velde, 1985) and Coc Pia area in Vietnam (Tran et al., 2016).

Country→	Australia	Australia	Canada	Canada	China	China	CzechR.	CzechR.
sample→	113393	113395	P97-92	P97-T138B	Me209	Li-26	PK-28	PK-41
SiO_2	46.01	46.04	48.83	51.14	47.87	48.54	48.4	51.3
TiO_2	1.9	1.8	1.32	1.11	0.83	1	1.04	1.08
Al_2O_3	10.27	9.98	10.32	10.33	10.88	11.16	11.4	11.6
Fe_2O_3	9.84	9.84	7.09	7.73	4.01	4.92	7.07	6.02
FeO	na	na	na	na	5.07	4.17	na	na
MnO	0.14	0.14	0.11	0.14	0.09	0.18	0.11	0.1
MgO	9.84	10.71	10.91	9.87	11.4	9.6	10	10.4
CaO	7.41	7.53	8.74	8.03	7.79	8.41	5.56	5.64
SrO	0.25	0.31	0.14	0.09	na	na	0.08	0.07
BaO	0.52	0.46	0.89	0.43	na	na	0.21	0.52
Na_2O	2.22	1.76	1.6	1.46	2.22	1.54	1.85	0.96
K_2O	5.99	6.71	6.42	4.13	4.57	5.71	6.18	7.75
P_2O_5	2.33	2.5	1.79	1.55	0.85	1.13	0.89	1.33
CO_2	0.5	0.76	na	na	0.19	0.02	na	na
H_2O^+	na	na	na	na	3.54	2.12	na	na
LOI	2.67	2.83	na	na	na	na	6.7	2.7
Total	98.62	99.84	na	na	100.11	98.5	99.2	98.8

(*Continued*)

Table 1. Continued

Country→	Greece	Greece	Russia	Russia	U.K.	U.K.	Vietnam	Vietnam
sample→	GL28	GL27	I55-2-12	005-15	Actual	35AX	P-81	T-1725
SiO_2	47.48	48.23	49.76	50.11	50.69	51.58	50.33	51.23
TiO_2	1.56	1.6	0.69	0.67	1.58	1.08	0.57	0.63
Al_2O_3	10.87	11.23	10.83	10.84	9.71	10.83	11.07	10.75
Fe_2O_3	6.99	7.01	8.3	8.21	3.06	4.96	7.5	6.95
FeO	na	na	na	na	3.37	1.87	na	na
MnO	0.1	0.08	0.13	0.14	0.13	0.13	0.13	0.14
MgO	10.97	9.9	9.9	9.9	6.07	8.86	12.61	11.79
CaO	6.05	5.89	7.1	7.19	5.28	5.84	7.92	6.93
SrO	0.06	0.06	na	0.31	0.24	na	0.12	0.15
BaO	0.1	0.1	0.2	0.23	0.63	na	0.17	0.21
Na_2O	1.86	2.17	1.26	1.26	0.47	2.1	0.83	2.09
K_2O	4.53	4.93	6.97	7.51	9.22	7.7	6.66	4.99
P_2O_5	0.98	1.02	0.65	0.64	1.73	1.41	0.54	0.51
CO_2	na	na	na	na	6.91	na	na	na
H_2O^+	na	na	na	na	0.82	2.15	na	na
LOI	8.1	7.4	3.67	1.92	na	na	1.42	3.83
Total	99.39	99.38	99.75	99.23	100.27	99.99	99.58	99.84

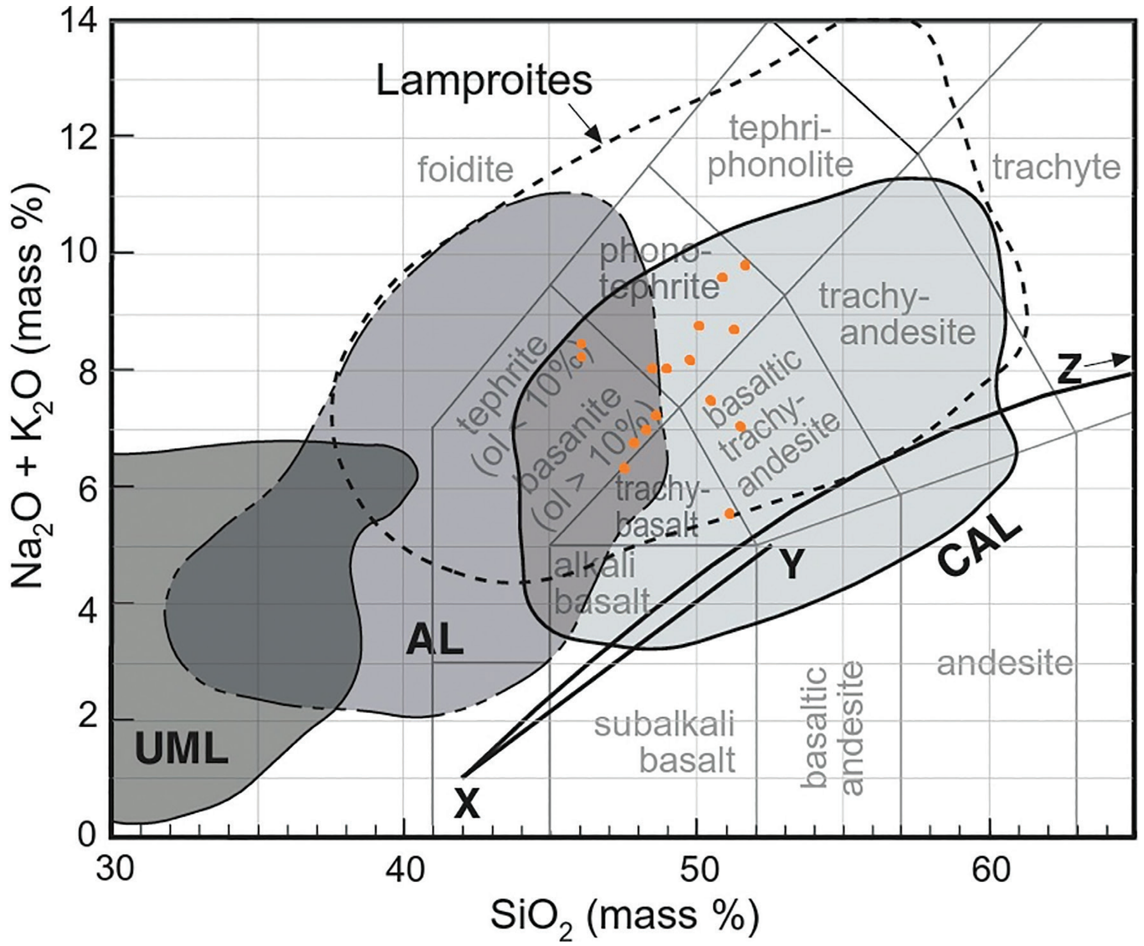

Figure 2. TAS diagram adjusted for lamprophyres and lamproites (Gill and Fitton, 2022). UML are ultramafic lamprophyres, AL alkaline lamprophyres, CAL calc-alkaline lamprophyres and LL lamproites. Orange dots are the para-lamproites of Table 1. The dots project on the area where lamproites and calc-alkaline lamprophyres overlap. Access date 13/5/2024. *Igneous Rocks and Processes: A Practical Guide*, Second Edition. Robin Gill and Godfrey Fitton. © 2023 John Wiley & Sons Ltd. Published 2023 by John Wiley & Sons Ltd. Companion website: www.wiley.com/go/gill/igneous2.

lamproites (e.g. similar Mg#). However, cocites lack typomorphic K-richterite and characteristic Ti and Zr-rich oxides like priderite, wadeite and perovskite, which are found in classic lamproites (Polyakov et al., 1995). Also, in plots of εNd versus $^{87}Sr/^{86}Sr$ (0.707) the Vietnamese cocites fall closely to the minette field

Figure 3. A photomicrograph with phlogopite microphenocrysts in PPL from the Limnos island para-lamproite sample GL28. The rock also contains phenocrysts of serpentinized forsteritic olivine and diopside, and magnesiochromite grains in a groundmass which additionally includes sanidine.

Figure 4. The isolated Thumb minette neck in New Mexico, USA (photo by John 2016). The minette magma originated from a depth of 190km as the analysis of garnet peridotite and other xenoliths showed (Smith et al., 1991). Access date 13/5/2024.

rather than close to lamproites (Tran et al., 2016). This points to an intermediate character between Mediterranean-type lamproites and minettes.

- An interesting occurrence of the para-lamproite-minette connection is found at the Tobuk complex in the Ryabinovyi plutonic massif of Aldan, Siberia (Izokh et al., 2024). Here, phlogopitic minette dikes are co-magmatic with a cocite-like low-Ti lamproite diatreme. This gradation has been explained by the crystallization and gravitational differentiation of magma in a single chamber with the addition of silicate-carbonate immiscibility. No hybridization or crustal contamination has taken place in the formation of the Tobuk minettes.
- Primitive minette magmas (i.e. not crustally contaminated or crystal-fractionated) generally obey, according to Rock (1991), the following criteria for Mg# and mantle-compatible elements: Mg#>65, Sc>15ppm, Cr>200ppm, Co>25ppm and Ni >90ppm. It is, therefore, obvious that most minettes

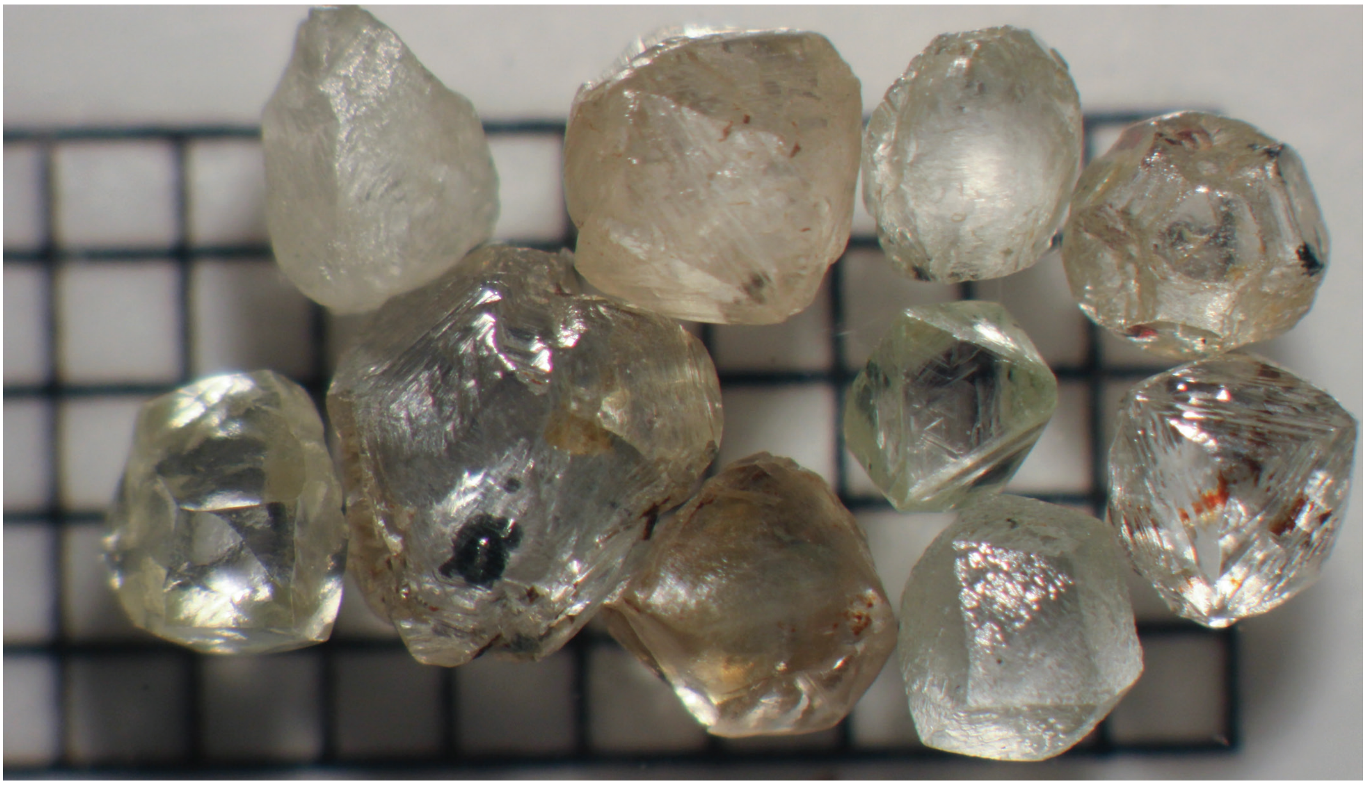

Figure 5. Ten Appalachian diamonds from the state of North Carolina, USA appearing on a 1mm grid (photo by Chris Tacker from the North Carolina Museum of Natural Sciences 2014). Access date 13/5/2024.

and alkali minettes (or lampyrites = minettes with Mediterranean lamproite affinity; Krmíček et al., 2020) are not just late offshoots of granitoid plutons, since this can be hard to reconcile with their primitive melt chemistry and mineralogy. The Navajo minettes, for example, occur far away from any pluton (Fig. 4). Finally, note that the minette magmas possess mantle isotopic values for εNd (-10 up to +10) in contrast to the crustal values of granitoids.

- The calc-alkaline minettes could actually grade petrographically into kersantites, vogesites and spessartites (Mitchell, 2007).
- Up-to-date bibliography has considered kimberlites and aillikites akin (e.g. Nosova et al., 2018, Giuliani et al., 2021, Pilbeam et al., 2024). In regard to Sr-Nd-Hf isotopic compositions, the global data compilation points to a similarity between kimberlites and ultramafic lamprophyres (like aillikites), suggesting a genesis from broadly similar sources in the convecting mantle (Dalton et al., 2024). In the Kola peninsula of NW Russia, in particular, they appear to originate from identical melt sources. The different degrees of magma ascent rate in the crust are contributing parameters to explain the petrographic, mineralogical and geochemical variation between fast kimberlites and slower aillikites (Kopylova, 2022).
- The holomelanocratic mela-aillikites are distinct variants of aillikites with clinopyroxene and/or groundmass richterite and <10% primary carbonate (Tappe et al., 2005).
- The alnöites (Rosenbusch 1887) do not always contain primary carbonate (see Table 1 in Tappe et al., 2005). The Nata melilite-bearing lamprophyre in Cyprus (Chan et al., 2008), which is associated with continental rifting, is one such case.
- The polzenites and allied rocks (luhites, modlibovites, vesecites) should be included in the Lamprophyre clan along with other ultramafic lamprophyres. In spite of the fact that they generally evolve from alnöitic melts, the polzenites could also be quite distinct (with the absence of clinopyroxene and presence of haüyne, see Ulrych et al., 2014).
- The alkaline lamprophyre sannaite has been lately omitted from the lamprophyre nomenclature literature since it is very similar to damtjernite (Krmíček & Chalapathi Rao, 2022). It should be noted that the presence of primary carbonate is not necessary in damtjernites (see Table 1 in Tappe et al., 2005).
- Camptonites (including the glassy eustratites) and monchiquites crystallize under more volatile-rich conditions, at much higher pressures and for a longer time interval than common alkali olivine basalts. The diamondiferous Wandagee monchiquites in W. Australia (Rock, 1991), for example, formed much deeper than any alkali olivine basalt.
- In regard to diamond exploration, lamprophyres in Canada (Lefebvre et al., 2005) and Guyana (Smith et al., 2012; Shirey et al., 2013), para-lamproites in China (Woolley, 2019; Xiang et al., 2020), and transitional rocks between kimberlites and aillikites in Greenland (Hutchison & Frei, 2009) and India (Smith et al., 2013) are known to be diamondiferous. Also, there are many unconventional macrodiamond occurrences like Borneo, the Urals, California, New South Wales, Burma, Thailand (Davies

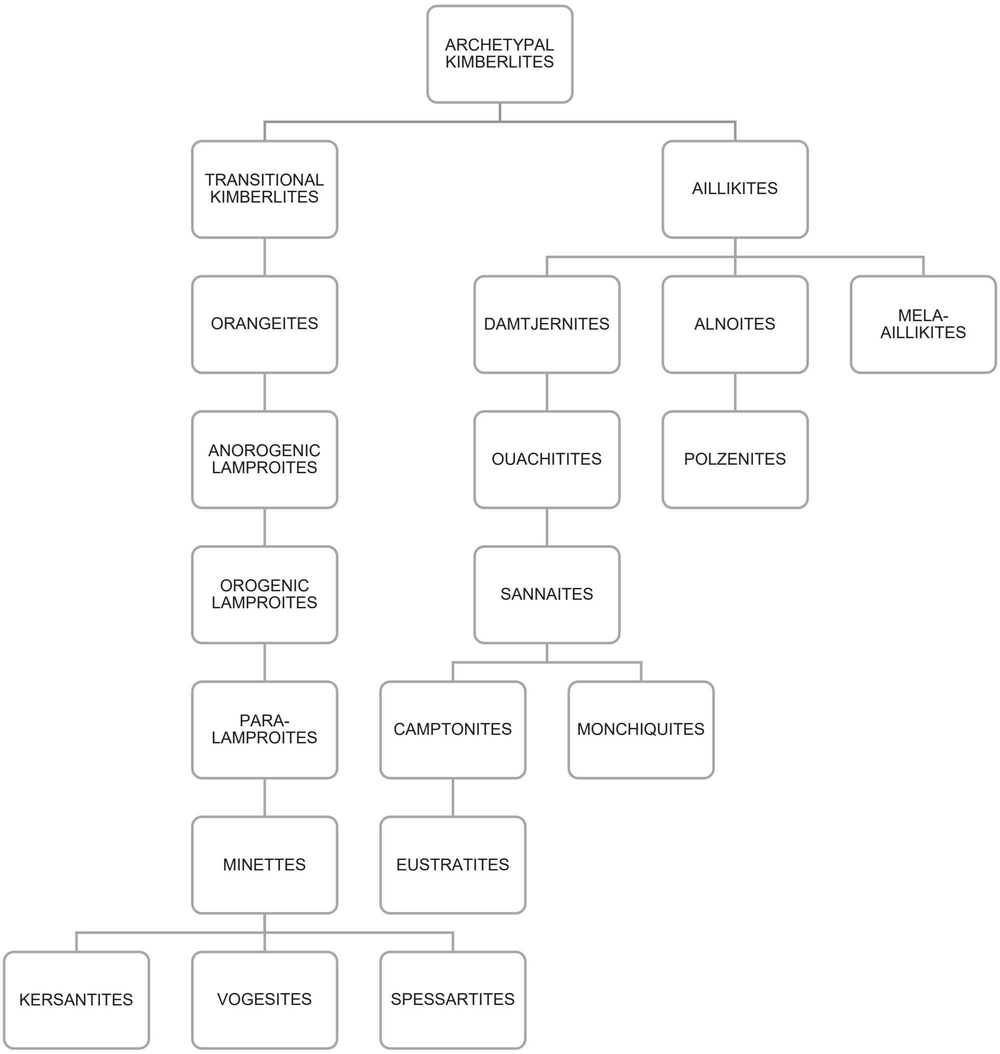

Figure 6. A simplified genetic diagram presenting the interrelations among lamprophyric rocks as shown by Kamvisis and Phani (2022) and this article.

et al., 2002), N. Ireland, Victoria (Birch & Barron, 1997), Tasmania (Bottrill, 1998), the Appalachians (Hausel, 1998) (Fig. 5), Northern Algeria (Godard et al., 2014) and Sumatra (Van Gorsel, 2018). No kimberlites, orangeites and peri-cratonic olivine lamproites have been discovered in these areas, bypassing, therefore, Clifford's rule. Their primary diamond sources could possibly be fast ascending lamprophyres (minimum speed 1m/sec). Note that most minettes last equilibrate at 60-190km depth (see O'Neill & Wyman, 2006), and in the case of a subduction geotectonic environment, they may "fall" well within the diamond stability field at 100km (Griffin et al., 2000).

3. Final remarks

It has been observed that many researchers have used the clan and facies terminologies synonymously while others have used them distinctly (e.g. Chalapathi Rao et al., 2020; Dai et al., 2021). The question is whether an igneous petrologist should best use the term Lamprophyre clan (*sensu* Kamvisis & Phani, 2022, i.e. as genetically interrelated rocks, Fig. 6) or the Lamprophyre facies (*sensu* Mitchell, 1994 i.e. as rocks forming under volatile-rich conditions). The answer to this dilemma is either. Both terms can be correct, but they represent different perspectives in the study of these rocks. Therefore, we propose that both concepts are adopted by the TGIR of IUGS to reach the most widespread consensus among the international geological community.

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Statement about the conflicts of interest

There are no conflicts of interest.

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