Origin of lamprophyres associated with myrmekite-bearing granitic rocks

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ABSTRACT

Some lamprophyres have a deep mantle origin. Others have a crustal origin associated with myrmekite-bearing granitic rocks (gneisses or plutons) formed by metasomatic processes, and these granitic rocks have resulted from the chemical replacements of micro-fractured, former, relatively-mafic, solidified, igneous plutons or gneisses where flowage and breakage occurs below melt conditions. Examinations of many places suggest that escaping hot hydrous fluids carry K, Mg, and Ca away from the newly produced granitic rocks to make some kinds of lamprophyres that are rich in these elements and poor in silica because much silica remains behind in quartz in the granitic rocks.

Introduction

Some lamprophyres have a deep mantle source in plumes or pipes that are rich in Mg and commonly contain phlogopite and diamonds (Scott Smith, 2008; Mitchell, 2021). They also contain chrome-diopside, olivine, and pyrope-rich garnet. Some are associated with carbonatites (Gwalani et al., 2016; Coulson et al., 2003). It is also true that mantle metasomatism does occur in mantle peridotites, changing their compositions below island arcs as water is driven out of ocean lithosphere during subduction (Ionov et al., 2002). But this article does not discuss this kind of mantle metasomatism or mantle sources of lamprophyres. What is discussed is (a) the fact that other kinds of lamprophyres are found associated with myrmekite-bearing granitic rocks and (b) the fact that their origins have been puzzling.

The term "lamprophyre", from "*lampros*" and "*porphyros*" (glistening porphyry), 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. Rosenbusch (1897) broadened the term lamprophyre to include a wide variety of hypabyssal rocks containing ferromagnesian phenocrysts. Eventually a lamprophyre group was proposed that became a repository for any difficult to characterize mafic phenocryst-rich rock. Unfortunately, the practice of type locality nomenclature led to the introduction of a "*legion of obscure rock types named after equally obscure European villages*" (Rock, 1990, p. 1), and this grouping has been interpreted to imply genetic relationships where none actually exists.

Rock (1986, 1990) proposed a “lamprophyre clan” that is a group of rocks that superficially look the same, are commonly associated in the field and have a number of petrological characteristics in common; e.g., richness in volatiles, porphyritic texture, occurrence as minor intrusions. A lamprophyric character commonly implies the presence of mica, amphibole, or pyroxene phenocrysts set in glassy or felsic matrix. They have a common trait of crystallization under volatile-rich conditions.

Because of the diverse mineral assemblages which may crystallize from these magmas, Mitchell (1992) proposed an extended definition that highlights the principal characteristics of the group. This states that:

"Lamprophyres are rocks which are characterized by the presence of euhedral- to-subhedral phenocrysts of mica and/or amphibole together with lesser clinopyroxene and/or melilite set in a groundmass which may consist (either singly or in various combinations) of plagioclase, alkali feldspar, feldspathoids, carbonate, monticellite, melilite, mica, amphibole, pyroxene perovskite, Fe-Ti oxides and glass."

Mitchell (1992) proposed that the genesis of lamprophyres indicated (a) high depth of melting, which yields more mafic magmas, (b) low degrees of partial melting, which yields magmas rich in the alkalis (particularly potassium), (c) the presence of lithophile element enrichment, (d) high Ni and Cr, (e) high K and Na concentrations and (f) where silica undersaturation is common, some form of volatile enrichment to provide Mg-rich biotite (phlogopite) and Mg-rich amphibole (pargasite), and (g) high ratios of (MgO/FeO + MgO).

On that basis, Mitchell (1992) considered them to be ***late offshoots of plutons***, although he felt that such offshoots were ***difficult to reconcile*** with their primitive melt chemistry and mineralogy. This difficulty is justified when Collins (1988) reported a common association of granitic plutons with the presence of lamprophyre dikes (e.g., Grantham. 1926; Backland, 1932; Wiseman, 1932; Kaitaro, 1953; Haller, 1953, 1971; Oftedahl, 1957; Zweifel, 1959; Moore and Hopson, 1961;

Johnson, 1961; Joplin, 1966; Jahn, 1973; Rock, 1977; Chen and Moore, 1979; Wikstrom and others, 1980; Cater, 1982; Spišiak et al., 2018; Dai et al, 2021).

Alternative explanation

Because of the characteristics of lamprophyres, an alternative explanation for their origins is possible. These characteristics include the facts that (a) lamprophyres have phenocrysts of phlogopite and/or pargasite (Mg-rich ferromagnesian silicates), (b) were crystallized in fluids rich in water (not melts), (c) are commonly K-rich, and (d) occur associated with myrmekite-bearing granitic rocks where (1) deformation of rising solidified plutons or (2) stretching of these rocks in both plutons and gneisses has caused micro-fracturing to allow hot hydrous fluids to move through these rocks and modify their chemical and mineralogical compositions at temperatures below melt conditions and extract Ca and Mg. That is, these elements have to go somewhere, and some kinds of lamprophyres provide a possible likely site where they go.

Examples

(1) The Duncan Hill pluton

The association of lamprophyre dikes with granitic rocks was found in a study of the Duncan Hill pluton west of Chelan, Washington (Collins, 1988). This pluton is a tadpole-shaped diapir that is rotated 90 degrees so that its composition can be observed from its narrow tail at the bottom (diorite, with a strong cataclastic texture) that grades upward into granodiorite, then quartz monzonite, and finally into granite and granophyre at the bulbous top (Cater, 1982) (**Figure 1**).

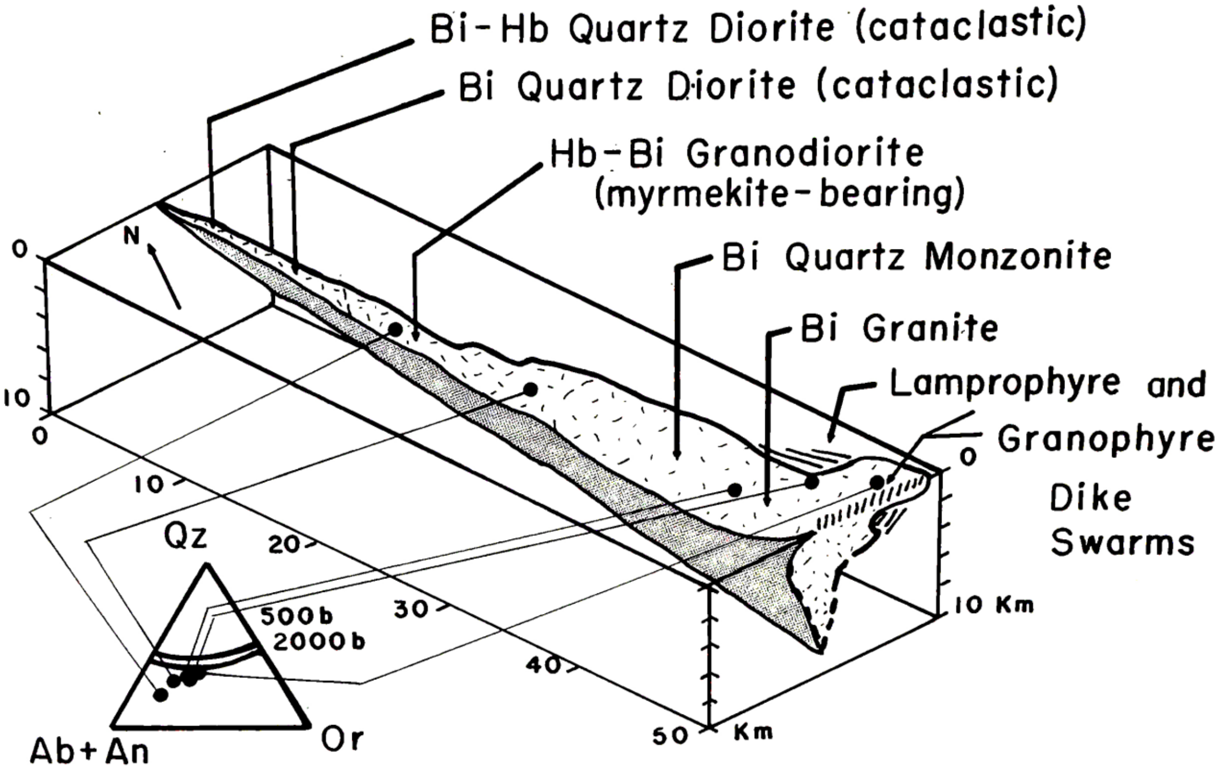

Figure 1. Three-dimensional section through the Duncan Hill pluton near Chelan, Washington. Tilt of pluton is about ten degrees. (C. A. Hopson, 1982, personal communication). Section and triangular, quartz-plagioclase-orthoclase diagram are modified after unpublished figure (C. A Hopson, 1982; written communication), and from geologic map (Cater, 1982). Arcs on triangular diagram indicate water pressures of 500 bars and 2000 bars. Lamprophyres and aplite dikes in figure are schematically drawn to indicate their locations but not their relative abundances or depths in which they extend.

In the granodiorite, ***myrmekite occurs***. The granite at the top eventually reached melting temperatures so it crystallized from magma because it has miarolitic cavities. But extending adjacent to and near the top of the Duncan Hill pluton are lamprophyre dikes (pawdite, kersantite, spessartite, and augite minette). Therefore, these dikes likely represent the displaced elements from the granodiorite where deformation and hot fluids allowed metasomatic myrmekite to be formed.

(2) Other areas and K-metasomatism at Temecula, California

Studies of multiple areas containing myrmekite-bearing granitic rocks are summarized in Collins and Collins (2012). Collins and Collins (2002a) found that a diorite near Temecula, California, was micro-fractured so that hot hydrous fluids could (a) bring in K that replaced primary plagioclase feldspar with K-feldspar, (b) that where incomplete replacement occurred, myrmekite was formed, and (c) Mg and Ca left the system while Fe was left behind in magnetite and Na was left behind in recrystallized more-sodic plagioclase; see **Table 1** in the **Appendix**. Moreover, silica is not extracted by these fluids but remains behind to replace some of the primary ferromagnesian silicates with quartz so that the extracted fluids carrying Ca, Mg, and K that move out of the systems are silica deficient and feldspathoids may be formed instead of feldspars in lamprophyres, but in some places, feldspars are formed.

All studies in Collins and Collins (2012) show this same pattern of K introduced into rocks as Mg and Ca leave them, and these studies include where myrmekite is found in more than 50 localities in granitic rocks in Arizona, Nevada, California, New York, Massachusetts, Connecticut, Rhode Island, New Jersey, Washington, Wisconsin, Wyoming, Canada, Australia, Scotland, Ireland, France, Greece, Norway, China, and Iran. The chemical studies of the Temecula rocks in Collins (1988; **Table 1**, **Appendix**) show this relative movement of elements – K coming in and Mg and Ca leaving the system and probably excess K going out of the system with Mg and Ca to form overlying lamprophyres. Having these elements go to lamprophyres is logical because they have to go somewhere, and lamprophyres are places that have concentrations of these elements. Of course, more Mg and Ca have left some replaced and recrystallized rocks that are more mafic and calcic, as occur in the Gold Butte area (described below), than have left other replaced and recrystallized rocks that are less mafic and calcic, as occur in the Temecula area.

(3) Gold Butte area, Nevada

Another study by Collins (1997; 1998a) of the Gold Butte area in Nevada, provides a further example where this same relative movement of elements is apparent. In this area Fryxell et al. (1992) thought that garnet, garnet-sillimanite, and garnet-sillimanite-cordierite gneisses were formed by metamorphism of Al-rich shales (pelites). The study (Collins, 1997) shows that former layers of diorite and gabbro have been strongly deformed and micro-fractured so that hydrous fluids could move through these rocks and convert them into these aluminous gneisses (**Figure 2**).

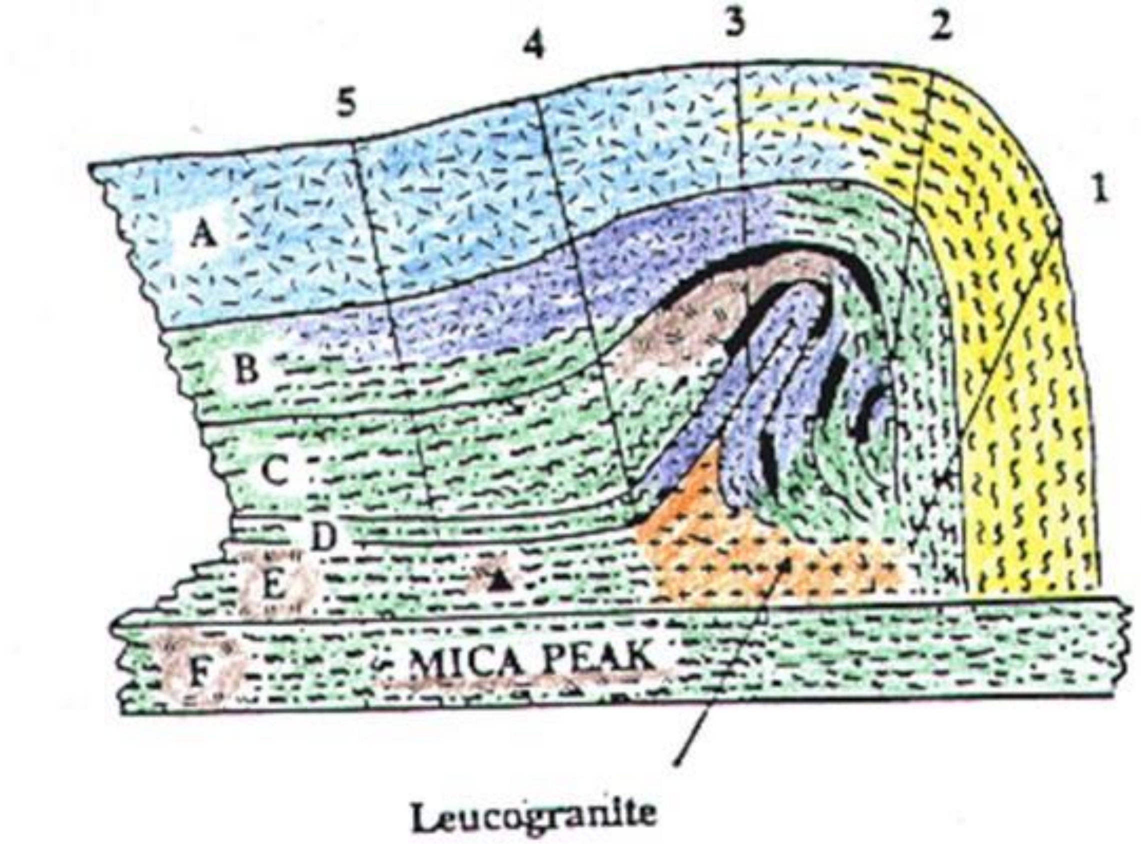

Figure 2. An interpretive diagram, showing relative positions of units A-F in the Gold Butte anticline. A = felsic diorite; B = mafic diorite; C and D = mafic diorite, gabbro, mafic gabbro, and ultramafic rocks (black areas indicate two layers rich in mafic silicates); E and F = mafic diorite, gabbro, and mafic gabbro. Purple areas represent deformed igneous rocks. Right side (vertical areas in yellow and green) show places that are converted into garnet-, garnet-sillimanite-, and garnet-sillimanite-cordierite-gneisses. Orange area is leucogranite.

Where K accompanied this movement, myrmekite was formed and much Mg and Ca were removed from these rocks as revealed by using the isocon diagram of analysis of Grant (1986), and Al was enriched in the garnet-, garnet-sillimanite-, and garnet-sillimanite-cordierite gneisses as well as K, Rb, Na, and Ba (**Figure 3**).

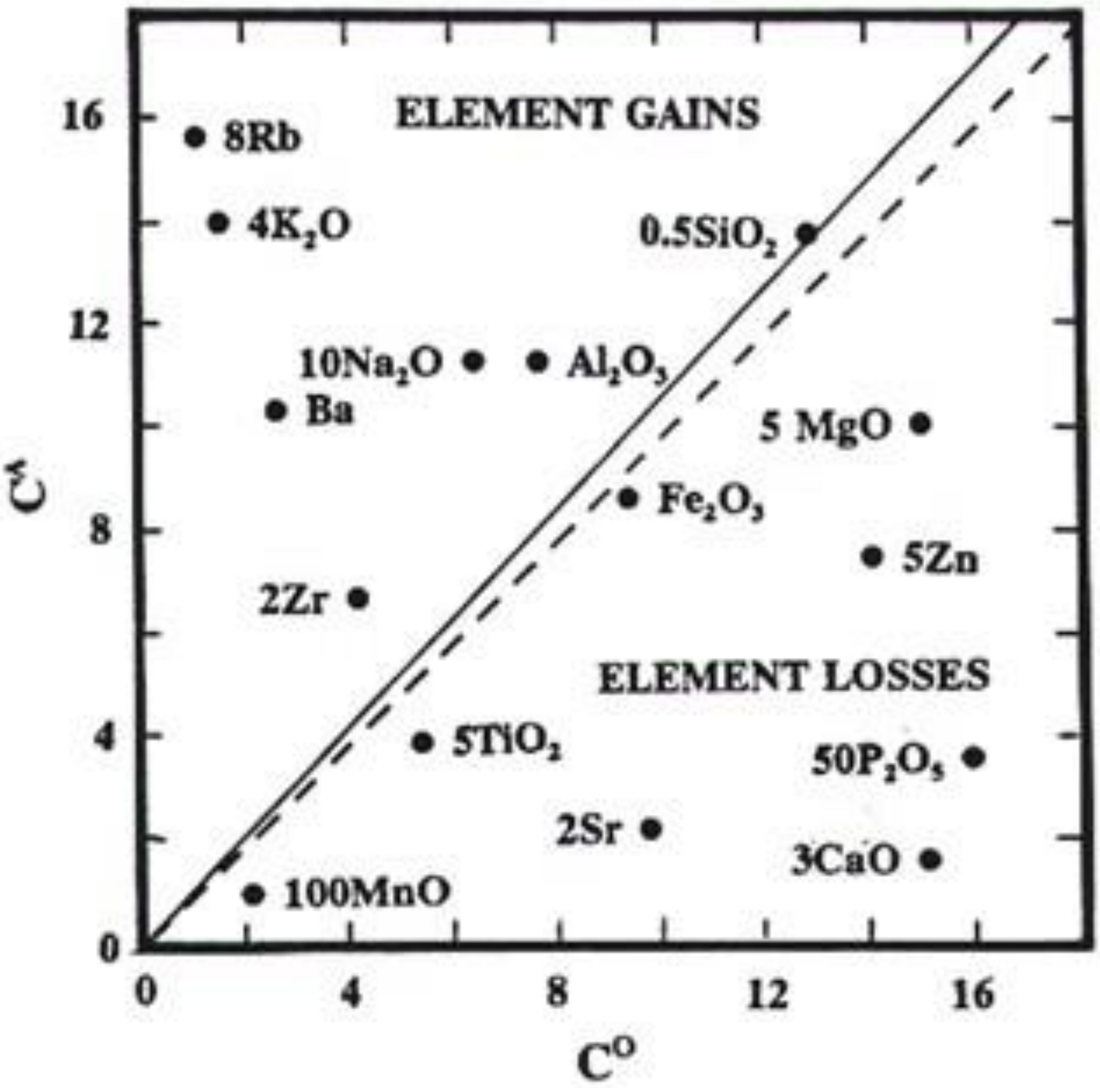

Figure 3. Original element concentrations C^O in mafic gabbro protoliths in comparison to altered element concentrations C^A in replaced rocks that are now garnet-sillimanite-cordierite gneisses (after Grant, 1986). Major oxide abundances are in wt%; trace elements are in ppm. Some values are proportionally scaled. Solid line = constant volume reference frame; short-dashed line = constant mass reference frame.

The Ba enrichment in the Gold Butte replaced and recrystallized rocks, as shown in the isocon diagram (**Figure 3**), occurs because the Ba ion has a large radius like the K ion and fits into the same sized hole in the lattice of recrystallized biotite or K-feldspar. This same Ba enrichment was also observed in tiny celsian crystals inside recrystallized myrmekite-bearing K-feldspars (microcline) in the Temecula rocks (Collins and Collins, 2012) and in myrmekite-bearing, Ba-zoned, orthoclase megacrysts in the Papoose Flat Pluton in eastern California (Collins and Collins, 2002b).

The Na enrichment occurred because it was concentrated in the sodic plagioclase An 22-27 in the residual leucogranite (**Figure 2**).

The Al enrichment in the garnet-, garnet-sillimanite-, and garnet-sillimanite-cordierite gneisses occurs because the plagioclase feldspars have high Al contents in the mafic diorites with compositions of An 35-45 and in gabbros with compositions of An 45-87 but which are An 22-27 in the leucogranite where the volumes of the more sodic plagioclase are much less than the volumes of more calcic plagioclase in the diorites and gabbros. That is, the Al in the diorites and gabbros has gone into garnet and sillimanite as Ca from the replaced and recrystallized plagioclase crystals has left the system in large quantities (**Figure 3**), and the difference in volumes of plagioclase crystals that were once present in the diorites and gabbros but are now in the volumes that were left behind in the leucogranite (**Figures 2** and **4**) gives an estimate of the volumes of lamprophyres that were created by the escaping fluids.

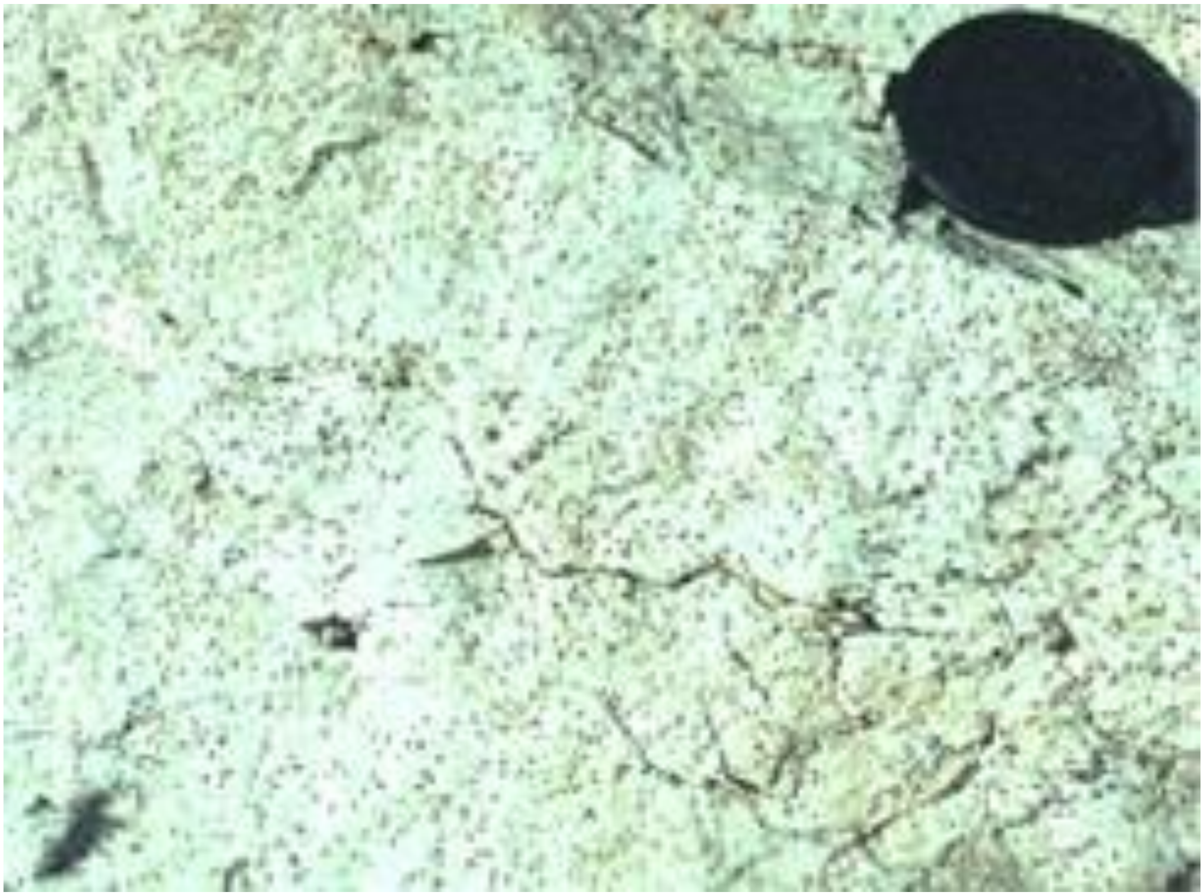

Figure 4. Gold Butte leucogranite consisting of tiny garnet crystals in a matrix of sodic plagioclase, quartz, and trace K-feldspar. (Camera lens cap for scale)

Note that the volume of leucogranite (**Figures 2** and **4**) exists in the tightest part of the anticline. That is, this leucogranite did not come in from a deep granitic magma source to fill an opening in a low-pressure site. Instead, it is an extreme high-pressure site. The extreme compression to form this anticline caused stretching, deformation, and chemical destruction of plagioclase feldspar and ferromagnesium silicate crystals in the mafic diorite and gabbro layers in the right limb and produced an inner core of the anticline that is isoclinal (**Figure 2**). This enormous amount of compression produced the garnet gneisses as well as causing a huge volume loss of Ca, Mg, Fe, Al, and K that escaped the system and created a residue that is the leucogranite (**Figures 2** and **4**). The escaped fluids with these elements would have produced lamprophyres that once overlayed this area that now have been eroded away.

(4) Myrmekite-bearing granites in Japan

A large loss of Ca from myrmekite-bearing granites was also observed in the Komaki District of southwestern Japan (Takagi et al., 2007). Near these granites are metasomatic quartz-bearing anorthosites (Collins and Collins, 2012), which suggests that not only can extracted Ca go into lamprophyres, it also can go into metasomatic anorthosites.

(5) Dartmoor Granite, England

A similar situation to the Gold Butte area is a lamprophyre lava field near the Dartmoor Granite in England (Floyd, et al., 1938); personal communication, David Tyler). Other lamprophyres occur in the same area of Permian age in southwestern England (Dupois et al., 2015). This granite is magmatic, contains abundant tourmaline, and lacks myrmekite (Brammall and Harwood, 1923), but its becoming magmatic may be like what occurred in the Duncan Hill pluton where melting temperatures were later reached.

(6) Gneisses and granites in France

Also, in France numerous examples of myrmekite-bearing gneisses are reported in quadrangle map descriptions (Floc’h et al.,1986; Chèvremont et al., and1996; Briand et al., 1978) and in myrmekite-bearing granites (Charles et al. 2009 [The Montagne Noire migmatitic dome] and Choulet et al. 2012 [Autun granite]. These metasomatically modified gneisses and granites are associated with two gigantic gneissic nappes, one on top of the other, and they overlie the above-mentioned, high-grade, mica-gneisses and granite basement in the Central Massif. These nappes have been further folded and form very gentle broad anticlines and synclines. Subsequent to the formation of the nappes, stretching of the crust occurred that resulted in the collapse of a collisional orogen that formed intramontane basins. Bordering the Autun basin, leucogranites and gneisses were mylontinized and deformed (Vanderhaeghe et al., 2020).

In some places that were ductilely deformed in a NE direction, hot hydrous fluids moved through them to introduce K so that myrmekite was formed, and these same fluids extracted Ca and Mg that migrated upwards with excess K to produce overlying lamprophyre dikes (Choulet et al. 2012). An example of the lamprophyre dike (**Figure 5)** occurs in the Piégut-Pluviers main quarry (coarse facies of the Piégut-Pluviers granodiorite; **Figure 6**). On the basis of the above description of the geology, the Central Massif area is clearly not where mantle plumes are making the lamprophyres.

Figure 5. Lamprophyre sample from the Piégut-Pluviers main quarry from the Piégut-Pluviers granodiorite (common facies) in the Central Massif, France. (Courtesy of Rudolph Pohl)

Figure 6. Lamprophyre dike in coarse-grained facies of the Piégut-Pluviers granodiorite. (Courtesy of Rudolph Pohl)

(7) Other gneiss localities

Myrmekite is also found in granitic gneisses in the Appalachian Mountains in eastern United States where stretching and deformation occurs in the limbs of anticlines (Collins, 1988), in migmatitic gneisses adjacent to and in a rising granitic pluton near Cooma, Australia (Collins, 1998b), and in gneissic charnockites in India (Allen et al., 1985; Ravinda Kumar et al., 1985).

Conclusion

On that basis of the above observations, some lamprophyres are not formed from hydrous melts that come from deep in the mantle in plumes and pipes but are formed locally above crustal rocks that were brittle-deformed and micro-fractured that allowed abundant hot hydrous fluids to move through the relatively calcic and mafic rocks and caused their chemical and mineralogical modifications to leave behind myrmekite-bearing granitic rocks while transferring Mg, Ca, and K to overlying lamprophyres.

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References

Allen, P., Condie, K. C., and Narayana, B. L., 1985, The geochemistry of prograde and retrograde charnockite-gneiss reactions, Geochimica et Cosmochimica Acta, v. 49, p. 323-336.

Backland, H. G., 1932, Das Alter des ‘metamorphen Komplexes’ von Franz Josef Fjord in Ostgronland: Meddelser om Gronland, v. 87, no.4, p. 1-119.

Briand, B., Chenevoy, M., Jean Chamayou, J., and Georges Guyonnaud, G., 1978, Notice explicative de la feuille Châlus (XIX-32). Carte géologique de la France 1/50000. BRGM, Orleans.
Brammall, A. and Harwood, H. F., 1923, The Dartmoor granite – Its mineralogy, structure, and petrology, Mineralogical Magazine, v. 20, issue 101, p. 39-53.

Cater, F. W., 1982, Intrusive rocks of the Holden and Lucerne Quadrangles, Washington: U. S. Geological Survey Professional Paper 1220, 108 p.

Charles, N., Faure, M., and Chen, Y., 2009, The Montagne Noire migmatitic dome emplacement (French Massif Central) new insights from petrofabric and AMS studies, Journal of Structural Geology, v. 31, n. 11, p. 1423-1440.

Chen, J. H. and Moore, J. G., 1979, Late Jurassic Independence dike swarm in eastern California: Geology, v. 7, p. 129-133.

Chevremont, P., et al., 1996, Notice explicative de la feuille Rochechouart (687), Carte géologique de la France 1/50000. BRGM, Orleans. ISBN 2-7159-1687-6.

Choulet, F., Faure, M., Fabbri, O., 2012, Relationships between magmatism and extension along the Autun-La Serre fault system in the Variscan Belt of the eastern French Massif Central, International Journal of Earth Sciences, v.

Collins, L. G., 1988, Hydrothermal Differentiation and Myrmekite - A Clue To Many Geological Puzzles: Theophrastus Publications, Athens, 387 p.

Collins, L. G., 1997, Myrmekite in garnet-sillimanite-cordierite gneisses and Al-Ti-Zr trends, Gold Butte, Nevada: electronic journal Myrmekite, ISSN 1323-5757, 19 p. This article can be accessed at this link. Nr11Gold.pdf (csun.edu)

Collins, L. G., 1998a, Metasomatic aluminous gneisses at Gold Butte, Nevada, U.S.A.; A clue to strongly peraluminous granites?: Theophrastus Contributions, v. 2, p. 33-46.

Collins, L. G., 1998b, 27. METASOMATIC ORIGIN OF THE COOMA COMPLEX IN SOUTHEASTERN AUSTRALIA: electronic journal Myrmekite, ISSN 1223-5757, 16 p. This article can be accessed at this lin. Nr27Cooma.pdf (csun.edu)

Collins, L. G. and Collins, B. J., 2002a, Myrmekite formation at Temecula, California, revisited: A photomicrographic essay illustrating replacement textures: electronic journal Myrmekite, ISSN 1323-5757, 46 p. This article can be accessed at this link. Nr43Temecula.pdf (csun.edu)

Collins, L. G. and Collins, B. J., 2002b, K-metasomatism and the origin of Ba- and inclusion-zoned orthoclase megacrysts in the Papoose Flat pluton, Inyo Mountains, California, USA, electronic journal Myrmekite, ISSN 1323-5757, 19 p. This article can be accessed at this link. Nr44Papoose.pdf (csun.edu)

ISSN 1526-5757 44. K-metasomatism and the origin of Ba- and inclusionzoned orthoclase megacrysts in the Papoose Flat pluton, Inyo Mountains, California, USA Lorence G. Collins and Barbara J. Collins July 31, 2002 email:lorencecollins@gmail.co

Collins, L. G. and Collins, B. J., 2012, K-, Na-, and Ca-metasomatism – characteristics of replacement textures associated with feldspars and ferromagnesian silicates and the formation of coexisting rim, wartlike, or ghost myrmekite: electronic journal Myrmekite, ISSN 1323-5757, 19 p.   This article can be accessed at this link. Nr56v.pdf (csun.edu)

Coulson, I. M., Goodenough, K. M., Pearce, J. G., and Leng, M. J., 2003, Carbonatites and lamprophyres of the Gardar Province – a ‘window’ to the sub-Gardar mantle?, Mineralogical Magazine, v. 67, i. 5, p. 855-872.

Dai, H. K., Oliveira, B., Zheng, J.-P., Griffin, W. L., Afonso, J. C., Xiong, Q., & O'Reilly, S. Y. (2021). Melting dynamics of Late Cretaceous lamprophyres in central Asia suggest a mechanism to explain many continental intraplate basaltic suite magmatic provinces. Journal of Geophysical Research: Solid Earth, v. 126.

Dupuis, N. E., Braid, J. A., Murphy, J. B., 1, Shail, R. K., Archibald, D. A., and Nance, R. D., 2015, 40Ar/39Ar phlogopite geochronology of lamprophyre dykes in Cornwall, UK: new age constraints on Early Permian post-collisional magmatism in the Rhenohercyian Zone, SW

England, Journal of the Geological Society, v. 172, p. 566-575.

Everhart, D. I., 1951, Geology of the Cuyamaca Peak Quadrangle, San Diego County, California; in California Division of Mines and Geology Bulletin 159, 51-115.

Floc'h, J. P., Platel, J. P., and Recoing, M., 1986, Notice explicative de la feuille Montbron (710). Carte géologique de la France 1/50000. BRGM, Orléans.

Fryxell, J. E., Salton, G. G., Selverstone, J., and Werniche, B., 1992, Gold Butte crustal section, South Virgin Mountains, Nevada: Tectonics, v. 11, p. 1099- 1120.

Gwalani, L. G., Jaques, A. L., Downes, P. J., and Rao, N. V. Chalapathi, 2016, Kimberlites, lamproites, carbonatites and associated alkaline rocks: a tribute to the work of Rex T Prider, Mineralogy and Petrology, v. 110, i. 2-3, p. 149-153.

Grant, J. A., 1986, The isocon diagram - a simple solution to Gresens' equation for metasomatic alteration: Economic Geology, v. 81, p. 1976-1982.

Grantham, D.R., 1928, The petrology of the Shap granit: Proceedings of the Geologists Association, v. 39, p. 299-223.

Haller, J., 1953, Geologie und Petrographie von West-Andrees Land und Ost-Fraenkels Land (Nordost-gronland): Meddelser om Gronland, v113, no. 5, 1-196.

Haller, J., 1971, Geology of the East Greenland Caledonides: New York, Interscience Publishers, 413 p.

Ionov, D. A., Bodinier, J. L., Mukasa, S. B., and Zanetti, A., 2002, Mechanisms and Sources of Mantle Metasomatism: Major and Trace Element Compositions of Peridotite Xenoliths from Spitsbergen in the Context of Numerical Modelling, Journal of Petrology, v. 43, i. 12, p. 2219-2259.

Jahn, B., 1973, A petrogenetic model for the igneous complex in the Spanish Peaks region, Colorado: Contributions to Mineralogy and Petrology, v. 41, p. 241-258.

Johnson, R. B, 1968, Geology of the igneous rocks of the Spanish Peaks region, Colorado: U. S. Geological Survey Professional Paper 594-G, p. 1-47.

Joplin, G. A., 1966, On lamprophyres: Journal and Proceedings, Royal Society of New South Wales, v. 99, p. 37-44.

Kaitaro, S., 1953, Geologic structure of the late Precambrian intrusives in the Ava area, Aland Islands: Bulletin de la Commission Geologique de Finland No. 162, 71 p.

Larsen, E. S., Jr., 1948, Batholith and associated rocks of Corona, Elsinore, and San Luis Rey quadrangles, southern California, Geological Society of America Memoir 29, 182 pp.

Merriam, R., 1946, Igneous and metamorphic rocks of the southwestern part of the Ramona quadrangle, San Diego, California, Geological Society of America Bulletin, v. 57, p. 223-260.

Mitchell, R. H., 1994, The lamprophyre facies: Mineralogy and Petrology, v. 51(2), p. 137-146.

Mitchell, R. H., 2021, Potassic Alkaline Rocks: Leucitites, Lamproites, and Kimberlites, Encyclopedia of Geology (Second Edition), p. 215-239.

Oftedahl, C., 1957, Studies of the igneous rock complex of the Oslo region. XV. Origin of the composite dikes: Skrifter utgitt av Det Norske Videnskaps-Akademi i Oslo, Arbok ; I Avhandlingar, Matermatisk-naturvinskapelig Klasse, No. 2, 17 p.

Ravinda Kumar, G. R., Srikantappa, C., and Hansen, E., 1985, Charnockite formation in Ponmudu in southern India, Nature, v. 313, p. 207-209.

Rock, N. S., 1977, The nature and origin of lamprophyres: some definitions, distinctions, and derivations: Earth-Science Reviews, v. 13(2), p. 123-169.

Rock, N. M. S., 1986, The nature and origin of ultramafic lamprophyres: alnöites and allied rocks: Journal of Petrology, v. 27(1), p. 155-196.

Rock, N. M., 1987, The nature and origin of lamprophyres: an overview: Geological Society, London, Special Publications, v. 30(1), p. 191-226.

Rosenbusch, H., 1897, The lamprophyre facies: Mikroscopishe Physiographie.

Scott Smith, B. H., 2008. Canadian kimberlites: Geological characteristics relevant to emplacement, Journal of

Volcanology and Geothermal Research, v. 174, i. 1-3, p. 9-19.

Spišiak, J., Vetráková, L., Chew, D., Ferenc, Š., Mikuš, T., Šimonová, V., and Bačík, P., 2018, Petrology and dating of the Permian lamprophyres from the Malá Fatra Mts. (Western Carpathians, Slovakia), *Geologica Carpathica*, v. 69, n. 5, p. 453–466.

Takagi, T., Naito, K., Collins, L. G., and Iizumi, S., 2007, plagioclase-quartz rocks of the Komaki District, southwestern Japan, Canadian Mineralogist, v. 45, p. 559-580.

Vanderhaeghe, O., Laurent, O., Gardien, V., Moyen, J., Gébelin, A., Chelle-Michou, C., Couzinié, S., Villaros, A., and Bellanger, M., 2020, Flow of partially molten crust controlling construction, growth and collapse of the Variscan orogenic belt: the geologic record of the French Massif Central, Earth Sciences Bulletin, v. 191, n. 25, p. 1-56.

Wikstrom, A., Aaro, S., and Lagmansson, M., 1980, The Graversforand and Stavsjo granites: Sveriges Geologiska Undersokning, Series C, NR 773, Avhandlingar och Uppsalter, Arsbok 74, 46 p.

Wiseman, J. D. H., 1932, A contribution to the petrology of the metamorphic rocks, East Greenland: Quarterly Journal of the Geological Society of London, v. 88, p. 312-348.

Zweifel, H., 1959, Geologie und Petrographie von Natherets Land (Nordost-gronland): Meddelser om Gronland, v. 160, no. 3, p. 1-94.