Memoirs of the College of Science, University of Kyoto, Series B,
Vol. XXVIII, No. 2 Geology and Mineralogy, Article 2, 1961

A Structural and Genetical Study of the Lamprophyre of Mt. Hiei, Kyoto, Japan

By

Hajime Yoshizawa and Kyoichi Ishizaka

(Received May 10, 1961)

Abstract

The lamprophyre of Mt. Hiei is injected into the granite and its surrounding hornfels of the Palaeozoic Era. The injection period of the lamprophyre is considered to be later than that of the satellites of the granite, that is, aplites and porphyries, etc.. The lamprophyre fills either fissures due to tensional stress or joints of the granite, the latter showing peculiar shapes. The lamprophyre, for the most part, spessartite and camptonite, is generally andesitic or doleritic in texture and in mineral assemblage and, moreover, contains many minerals with hyperfusible components.

As to the origin of the lamprophyre, the following view is presented: In a past geological period when the present land-surface part was brought to a subvolcanic horizon from a deeper zone due to the co-operation of surface erosion and landwarping, the contaminated basic volcanic magma was injected there and built up subvolcanic dykes, giving rise to lamprophyre. Enrichment of volatiles in magma may have originated from magmatic contamination of sialic materials.

Introduction

Since first described and classified by C. W. Gümbel in 1874, lamprophyre has been studied in various parts of the world by numerous students, and different views as to its genesis have been proposed.

Having had in 1960 an opportunity to re-examine the lamprophyre of Mt. Hiei[1], the writers will describe the outline of the results which they have gained, with special reference to the genesis of this rock. Researches both in the field and in the laboratory were made by the senior writer (H.Y.) with the junior writer (K.I.) having helped him in a certain stage of research.

I. Geological setttings of the lamprophyre of Mt. Hiei

The lamprophyres of Mt. Hiei occur, as a whole, on a rather small scale and only a small number of occurrence have been observed so far.

In the studied region, lamprophyre occurs dominantly in the granite pluton, but occasionally in the surrounding hornfels area, too.

Like other dykes such as quartz- and granite-porphyry and quartz- porphyrite, the strike of the lamprophyre dykes, generally, varies from N 30° E to N 30° W, but occasionally the same dykes persistently keep nearly E—W trends. Compared with other larger dykes of quartz- and granite-porphyry, etc., which maintain throughout their occurrences the definite trends, the lamprophyre dykes change their strikes and dips more complicatedly, as stated later.

The dykes, generally, are a few meters in length and a few decimeters in thickness.

Because of lack of good exposure in this area, it is frequently difficult to observe the mode of occurrence of the lamproyhyre in detail. In cases, which are rather rare, when good exposures are found, the lamprophyre shows very interesting features thus.

a) On the exposure in the road-cut of the Mt. Hiei Drive Way, near the top of Mt. Hiei, lamprophyre traverses aplite dykes somewhat irregularly curved (Fig. 1). The lamprophyre fills joints of the granite, and its strike and dip follow those of the joints of the granite; this lamprophyre extends from one joint of the granite to another, intersecting each other at large angles.

A similar example can be seen on an exposure in the road-cut, NNE 1 km apart from the top of Mt. Tsubosaka (Fig. 2).

b) On the exposure of the cut along the lane, located north 300 m from the " Kitashirakawa Health Center ", lamprophyre shows a strange mode of occurrence, i.e., the rock fills an open fissure formed by two intersecting joints in the granite (Fig. 3).

c) On another exposure of a lane, nearly 600 m apart from the Shugakuin-rikyu, there is seen a lamprophyre dyke filling a fissure of the granite (Fig. 4). It was observed that both sides of the fissure went through a differential movement and that the fissure had already existed before the injection of lamprophyre.

d) A group of lamprophyre dykes are seen on the slope of Kirarasaka, east of Shugakuin, etc., which fill echelon-like fissures of the granite (Fig. 5).

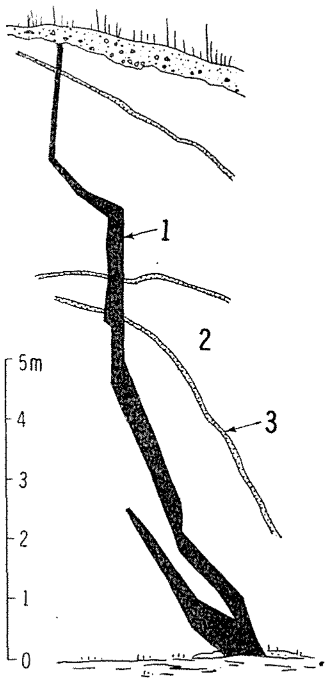


Fig. 1

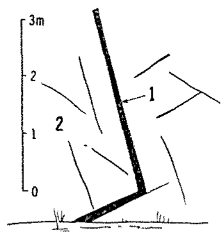


Fig. 2

Fig. 1~Fig. 5
1 . . . lamprophyre
2 . . . granite
3 . . . aplite

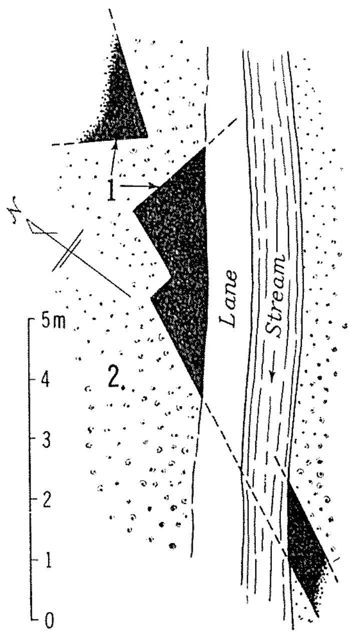


Fig. 3

(bird's eye view)

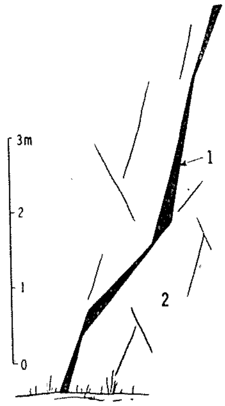


Fig. 4

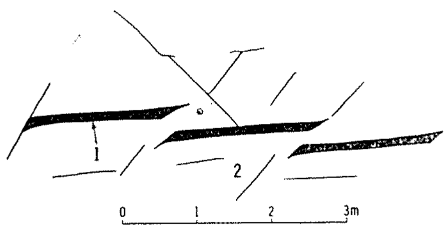


Fig. 5

Throughout all the examples illustrated above, no marked geological disturbance seems to have worked upon each dyke after its formation; the original forms of lamprophyre having been preserved until the present time.

In extremely rare cases, slight hydrothermal alteration is observed in part of country rock adjacent to the dyke. But, in general, the contact bordering the dykes and country rocks is distinct; on the boundary between them, no transitional zone was observed which might indicate any strong reaction which would have happened between them.

In short, it is obvious that lamprophyre is formed from the magma which filled open fissures and joints of the granite. Field observation suggests that the lamprophyre magma had low viscosity (i.e., high fluidity) and did not inject into fissures violently, but flowed along them without marked reaction on country rocks. Some of those fissures may be no other than joints of the granite, but some may have been produced by tensional stress acted on the granite. Furthermore, as borders of the open fissures filled by magma are fresh and angular, and erosion of fissure walls is scarcely noticed, there may not be a long time interval between the formation of fissures and the injection of lamprophyre magma.

Various kinds of strange mode of occurrence of lamprophyres were, also, reported in Finland,[2] Norway,[3] etc..

In contrast with the lamprophyres, dykes of aplite, pegmatite, quartz-porphyry and porphyrite, in Mt. Hiei, have reaction zone, though narrow, between them and country rocks, and the walls are more uneven than those of lamprophyre.

The lamprophyre, moreover, penetrates into the aplites not only on the exposure above mentioned, but also on the exposures of the road-cut east of the Shugakuin-rikyu, of the mountain path behind the Ginkakuji Temple and of the road near the Gobessho limestone.* But in this area, no exposure has yet been found whose lamprophyre is cut or traversed by aplite. Therefore, it is reasonable to assume that the lamprophyres in this area were formed later than the aplites.

As to the relation between the lamprophyre and the other dykes of acid rocks such as quartz-porphyry, quartz-porphyrite, granite-porphyry, etc., except aplite, it is uncertain which dyke group is of later formation of the two, since there is no exposure on which these two kinds of dykes contact with each other. Judging, however, from the difference in mode of occurrence above mentioned between these two kinds of dykes and from the texture of lamprophyre, which will be stated later, it is supposed that these acidic dykes were formed in a hypabyssal horizon, while lamprophyre was formed in a subvolcanic horizon and in the later stage when the surface erosion proceeded up to a higher degree, i.e., lamprophyre is considered to have injected into fissures of the granite after the present surface reached to a subvolcanic horizon. Therefore, it is difficult to regard the lamprophyre as a kind of satellites of the granite from the view point of their geological features.**

Such an opinion that the lamprophyre of Mt. Hiei may be xenoliths or replacement dykes in the granite, though it once prevailed among some students, will be denied from these facts stated above. The following data will, also, support the writers' opinion.

a) The lamprophyre consists of very fine minerals throughout all the rocks, so in most of them, development of a more fine-grained chilled margin is, generally, hardly noticiable by the naked eye, but it is rarely seen that in some exposures it develops distinctly in the part where lamprophyre contacts with country rock. For example, this chilled margin is observed on the

* These data are due to the oral communication from Mr. W. Nakajima.

** Judging from their geological properties, in Mt. Hiei, the granite-porphyry and quartz-porphyry and -porphyrite, except the aplite, may not be satellites of the granite, as well as the lamprophyre: These porphyritic rocks may have injected into the granite in a deeper horizon and in an earlier period in contrast to the lamprophyre, and the geological difference between these two kinds of rocks, i.e., the porphyritic rocks and the lamprophyre, can be recognized, as stated above.

exposure of the road-cut of the drive way, east of the Tanotani Pass. The difference between in the inner part and in the outer one is that the former has monoclinic pyroxene and plagioclase as phenocrysts, and that brown hornblende appears in groundmass, while the latter lacks these phenocrysts, i.e., the outer part is quite similar to the innerpart from which the phenocrysts are taken away. Therefore, this dyke is, so to say, a composite dyke[4] formed by injecting magma.

b) Two kinds of blocks were found which are obviously considered to be xenoliths in the granite. One is a block, which, a few centimeters in diameter, consists of fine recrystallized aggregate of biotite, quartz, feldspar, etc.. This may be probably of sedimentary origin. Another is a granular rock block which consists of plagioclase, hornblende and a small amount of quartz. In the plagioclase, there remains irregular-shaped basic part as the inner core. This amphibolite-like xenolith may be of basic rock origin and is similar to the so-called basic xenolith which is frequently met in metamorphic zones of Japan, for example, in the Ryoke Zone. This amphibolitic xenolith may, in a sense, be regarded as lamprophyre of metasomatic origin, but it is quite different from the rocks now under consideration in this paper.

II. Microscopic observation of lamprophyre

The lamprophyre is divided into the following groups from their textural properties observed under the microscope.

a) lamprophyre which resembles pyroxene-andesite

b) lamprophyre which resembles dolerite

c) lamprophyre the same as a) or b) but apparently suffered strong hydrothermal alteration

a) This kind of lamprophyre has andesitic texture. Augitic pyroxene, plagioclase and occasionally brown – pale green hornblende, also, are seen as phenocrysts. In groundmass, rarely, monoclinic pyroxene appears; in many cases, groundmass consists of brown — pale green hornblende, plagioclase, etc.. Alkali feldspar, quartz, etc., fill the interstices of these minerals above mentioned (Pl. I).

The plagioclase in phenocryst is An 70–55, and occasionally thin albitic rim develops around it. The plagioclase in groundmass is An 50–29. The optic properties of brown hornblende are as follows:

$C \wedge Z = 15-16°$, $n_{1(110)} = 1.670-1.680$ (± 0.003)
$n_{2(110)} = 1.690-1.695$ (± 0.003)

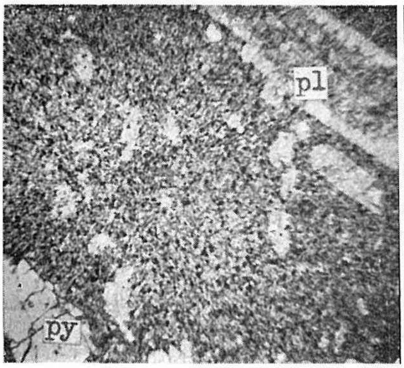
X...pale brownish yellow Y...brown Z...reddish brown

This seems to be barkevikitic hornblende. The optic properties of pale green hornblende are as follows:

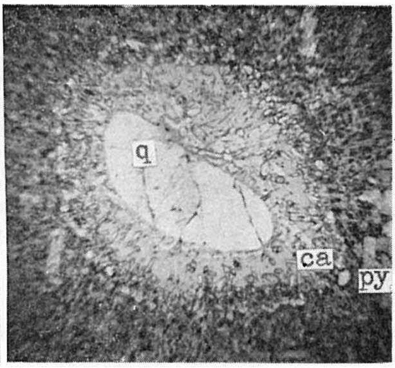
$C \wedge Z = 18-20°$, $n_{1(110)} = 1.655-1.660$ (± 0.003)
$n_{2(110)} = 1.665-1.670$ (± 0.003)

X...pale yellow Y...pale green Z...pale green

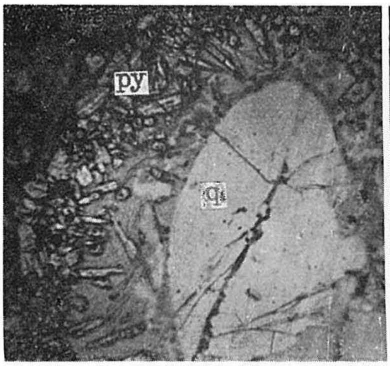
Pl. I



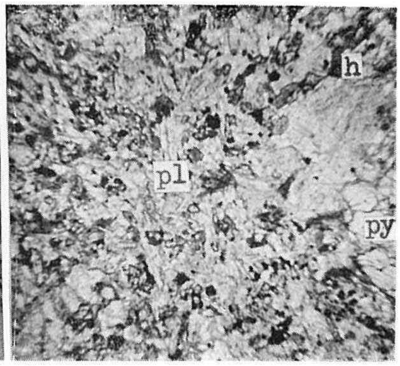
No. 1



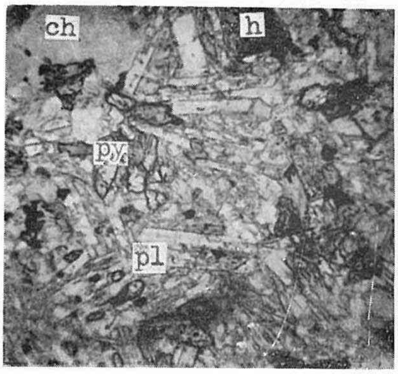
No. 2



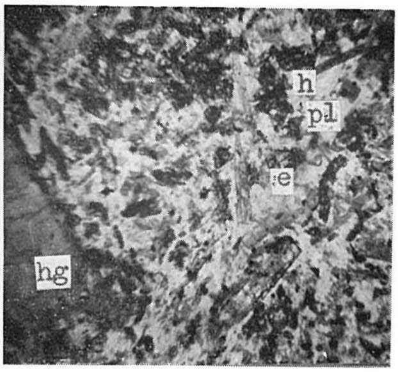
No. 3



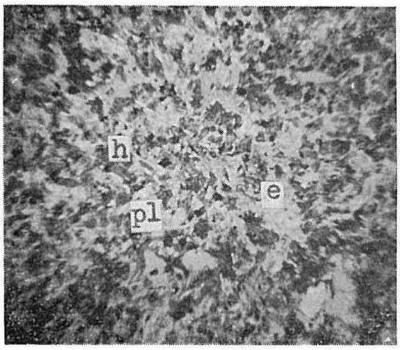
No. 4



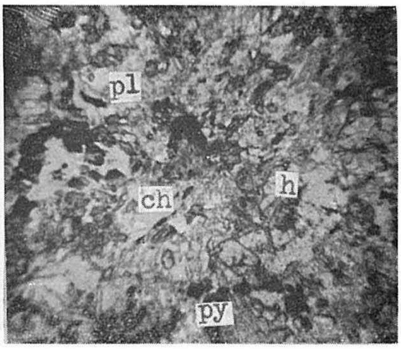
No. 5



No. 6



No. 7



No. 8

Pl. 1	Microphotographs of the lamprophyres of Mt. Hiei.
No. 1	Lamprophyre showing andesitic texture. ×25
No. 2	Quartz xenolith in the lamprophyre (in No. 1). ×25
No. 3	A part of the quartz xenolith (same to No. 2). ×70
No. 4	Lamprophyre showing intermediate texture between andesitic and doleritic one. ×25
No. 5	Lamprophyre showing doleritic texture. ×25
No. 6	Lamprophyre, apparently suffered hydrothermal alteration. ×25
No. 7	Outer part (chilled margin) of lamprophyre. ×25
No. 8	Inner part of the same lamprophyre. ×25

All photographs in upper nicol opened.

q .... quartz	pl ... plagioclase	h .... brown hornblende
hg ... green hornblende		py ... diopsidic pyroxene
ch ... chlorite	ca ... calcite	e .... epidote

Accessory minerals are ilmenite and sphene, but biotite is rarely seen, and besides these, apatite, zoisite, epidote, chlorite, etc., are noticed. Irregular-shaped grains of quartz or its vein is present.

In these lamprophyric rocks, granite xenoliths are rarely observed which are recognizable with the naked eye. And sometimes there are observed quartz xenocrysts under the microscope. Quartz xenocryst, contained in the kind of rock which has monoclinic pyroxene as phenocryst and brown hornblende in groundmass, has the following reaction rim around it (Pl. 1). There are corroded and irregular-shaped quartz in its innermost interior, and plagioclase kelyphite (An30ca.) encloses this. On the outer part of these plagioclase crystals, there develops the yellowish part without double refraction or with very weak refraction. In this part, small prismatic hornblende and irregular-shaped calcite are present. The observation with high magnifying lens seems to indicate that this yellowish part consists of aggregation of minute-grained crystals. The index of refraction of this is higher than that of the kelyphitic plagioclase and lower than that of hornblende. This part may possibly be a chloritic mineral. On the most exterior part of these, there is aggregation of fine-grained monoclinic pyroxene bearing thin rim of hornblende. Occasionally it is observed that the yellowish-white part or chloritic part connects with the groundmass of the lamprophyres across the outer pyroxene zone above stated. Judging from these observations, the quartz grains, which entered in the magma in its intratelluric stage, went through magmatic corrosion and reacted on the magma to crystallize kelyphitic plagioclase around themselves. Furthermore, monoclinic pyroxene crystallized around this. After that reaction, amphibolitization and crystallization of chlorite and calcite were followed.

Except the presence of hornblende in groundmass and the development of hydrothermal minerals, there are not so many differences between this kind of lamprophyre and normal pyroxene andesite from the view-point of its texture and mineral assemblage.

b) This kind of lamprophyre (group (b)) is superfine-grained and has monoclinic pyroxene, plagioclase and brown hornblende as phenocrysts. Groundmass consists of plagioclase, amphibolized augitic pyroxene and the brown — pale green hornblende which intergrows ophitically with plagioclase (Pl. I).

This group resembles the group (a) both in its mineral assemblage and in the kind of minerals, but differs in texture from that one. It goes without saying that hydrothermally altered minerals develop in this rock as well as in the group (a). This rock (b) resembles dolerite or diabase in its texture.

c) With decrease in augite, hornblende and plagioclase which developed in the groups (a) and (b), very fine — fine crystal grains of actinolitic hornblende, sodic plagioclase (An_{15-20}), epidote, zoisite, chlorite and pale brown mica began to crystallize, and distribution of each mineral becomes more heterogeneous. The following alteration, for example, of the plagioclase phenocryst is observed. This alteration, of course, happens, also, among the rocks in the groups (a) and (b), even though not intensely. Small prismatic crystals of brown hornblende are scattered in the interior of the plagioclase (An content of this crystal is difficult to determine because of strong alteration). In the exterior part of the plagioclase, hornblende disappears, and minute flakes of sericite develop. The very fine network vein of zeolite (?) develops remarkably along and across the cleavage planes of original plagioclase through the whole mass. Besides these, flaky chlorite develops both in the interior and exterior parts. It is considered that in this plagioclase, hornblende crystallized first by metasomatism, and then was followed by crystallization of sericite, chlorite and finally of zeolite.

The texture, in this group, is no longer andesitic or doleritic, but turns into the one which underwent strong hydrothermal alteration. There are frequently observed the rocks which bolong to intermediate species between the group (a) or (b) and the group (c) (Pl. 1).

Judging from the above stated petrography, it can be s id that the lamprophyre of Mt. Hiei mainly consists of spessartite—camptonite and rarely minettic lamprophyre.

It may be reasonable to assume that these lamprophyres were injected in a subvolcanic horizon and that they were originated from basic contaminated volcanic magma which contained abundant volatile components, judging from their textures and mineral assemblages akin to volcanic ones.

III. Historical review on the genesis of lamprophyre

As stated previously, the lamprophyres have once been regarded as differentiates from granitic magma, and then as xenoliths or replacement dykes in the granite.

On the origin of lamprophyric rocks, generally, many hypotheses have been proposed. According to these, lamprophyre is either

1) a metasomatized rock[5)6)] by metamorphism,
2) a basic rock refused or reacted by injecting magma,
3) a product of refusion[7)8)] of part of minerals crystallized from granite magma, viz., that of hornblende and biotite by sinking down to the bottom of the magma basin, or
4) a differentiate[3)4)9)10)] of granite and other kind of magmas.

The writers have no hesitation in recognizing the existence of lamprophyre of different origin as these. For instance, it is clear that some of the so-called basic xenoliths seen in metamorphic zones, and amphibolitic one, previously stated, in Hiei-zan granite belong to the group 1) and 2). The rocks under consideration, however, do not belong to the group 1) and 2) clearly, juding from their geological settings and petrological features. So here it is reasonable that the discussion should be made only on the group 3) and 4).

a) According to the hypothesis that lamprophyre is a differentiate[11)] from granite magma, granite magma is separated into the leucocratic magma from which aplite was formed, and the melanocratic magma from which lamprophyre was formed. These two kinds of rocks are in complementary in nature i.e., an example of diaschisthic dyke rocks. The result of experiments has shown that the liquid immiscibility does not occur in a silicate system such as now in question. Therefore, this hypothesis seems to be untenable.

b) Some students,[12] however, consider that lamprophyre is formed by accumulation of minerals which crystallized in an earlier stage of granitic evolution. This assumes that[13][14] hornblende and biotite which crystallized in granitic magma sink down and remelt, forming lamprophyre. Geological evidences support hardly that such phenomena had taken place actually.

c) Some of the investigations[10][15][16] have laid more emphasis on the role of volatiles in magma. In lamprophyre, develop hydrous minerals or minerals with volatile components such as hornblende, biotite, epidote, tourmaline, apatite, calcite, etc.. It is assumed that the volatiles in lamprophyre magma lower crystallization temperature of minerals, stimulating a large quantity of hornblende and biotite instead of pyroxene to crystallize. Furthermore, it is proposed that lamprophyre is originated from magma which is rich in volatile components supplied by hydrothermal solution rich in alkalies, and that this magma ascended in hydrothermal phase.[10]

d) There are different opinions concerning the time interval between the emplacement of granite and the injection of lamprophyre.

Some[3][9][10][17][21][23] assume existence of lamprophyre magmas which are not originated from granite magma. Moreover, they consider that lamprophyre is comagmatic with co-existing diabase. An example is the occurrence of camptonites, in Skaergaad,[17] associated with diabase in Tertiary system.

Similar consideration on diabase — lamprophyre association on the south coast of Norway[3] was described in detail. In this case, also, it is considered that these dykes as well as those in Skaergaad have no genetic relation with granite.

In Arizona,[18] camptonite injects into fanglomerate of the Quaternary age, having no genetic relation with granite.

In Helsinki[10] and other places, also, similar phenomena are reported.

e) The fact that lamprophyres occur abundantly in granite has been considered to be due to mechanical — structural relation of granite by some students.[2][3][19][20]

f) Volatiles abundant in basic magma from which lamprophyre is originated may owe their origin to assimilation of sialic materials.[9][20][21]

IV. Concerning the genesis of the lamprophyre of Mt. Hiei

Based on their geological and petrological evidences stated above by the writers, the petrogenesis of the Hiei lamprophyre may be described as follows:

a) The lamprophyre of Mt. Hiei is not satellite of the granite.

b) In the geological age, i.e., when erosion reached to the level less high than the present land-surface, the contaminated basic magma which assimilated granite and other sialic materials, (for example, the magma belonging to the hypersthene rock series[22]), ascended and injected along fissures of tensional origin and joints of the granite. This injection took place in a subvolcanic horizon.

c) This lamprophyre magma was remarkably abundant in volatiles which greatly influenced its crystallization causing appearance of minerals with volatile contents throughout its magmatic and deuteric stage. It goes without saying that the volatile contents lower the crystallization temperature of minerals.

The origin of these volatiles may be due to contamination of sialic materials. The lamprophyre magma may represent some part in contaminated basic magma where volatiles concentrated, for instance, top part of magma.

d) A detailed study of the fissure and joint system of the Hiei granite and the hornfels has not yet been carried out. Further research in this respect may make a great contribution to the igneous geology of lamprophyre and offer a key to solve the question why lamprophyre occurs so abundantly in granite.

Acknowledgments

Thanks of the writers go to Prof. S. Matsushita who offered to them an opportunity of re-examination of the petrological geology of Mt. Hiei and gave them advices on their study.

This investigation was partly supported by the financial aid of the Kyoto Press Office.

References

1) T. Hiki: The geological guide in and around Kyoto. Jour. Geol. Soc. Jap., 24, 249–256, 1917, etc..

2) S. Kaitaro: On some offset structures in dilation dykes. Bull. Comm. Geol. Finland, 157, 67–74, 1952, cf. H. Carstens: Comagmatic lamprophyre and diabase on the south coarst of Norway. Beitr. Min. u. Petrog., 6, 299–319, 1959.

3) H. Carstens: Comagmatic lamprophyres and diabase on the south coarst of Norway. Beit. Min. u. Petrog., 6, 299–319, 1959.

4) H. Kuno: Composite lava flows and dikes found in North Izu, Japan. Jour. Geol. Soc. Jap., 167–172, 1950.

5) E. Goodspeed: Dilation and replacement dyke. Jour. Geol., 48, 175–195, 1940.

6) " : Replacement and rheomorphic dykes. Jour. Geol., 60, 353–363, 1952.

7) S. Kozu and Sh. Watanabe: Studies of minerals and rocks occurring in the Yagoshi Mine and in its environs (V). Jour. Jap. Assoc. Min. Petrol. and Econ. Geol., 26, 171–200, 1941 (in Japanese).

8) K. Hirayama: The so-called spessartite and granophyre in the neighbourhood of

Shiratorihonmachi, Pref. Kagawa. Rep. Geol. Surv. Jap., 140, 1951 (in Japanese).
G. Kawano and K. Kishida: Dyke swarms of spessartite and granophyre through granite at Shiratori, Pref. Kagawa. Jour. Jap. Assoc. Min. Petrol and Econ. Geol., 23, 165–177, 1940 (in Japanese).
9) F. J. Turner and J. Verhoogen: Igneous and metamorphic petrology. 1951.
10) P. Eskola: Ein Lamprophyrgang in Helsinki und die Lamprophyrprobleme. Tsch. Min. u. Petr. Mitt., 4, 329–337, 1954, etc.
11) H. Rosenbusch und A. Osann: Elemente der Gesteinslehre. 1923.
12) G. W. Tyrrel: The principles of petrology. 1926.
13) P. Niggli und P. Beger: Gesteins- und Mineralprovinzen. 1923.
14) N. L. Bowen: The evolution of igneous rocks. 1928.
15) F. H. Hatch, A. K. Wells and M. K. Wells: The petrology of the igneous rocks. 10ed. 1949.
16) H. G. Smith: The lamprophyre problem. Geol. Mag., 83, 1946.
17) E. A. Vincent: Hornblende-Lamprophyre dykes of basaltic parentage from the Skaergaaden area, East Greenland. Q.J.G.S., 109, 21–49, 1953.
18) I. Campbell and E. T. Schenk: Camptonite dykes near Boulder Dam, Arizona. Amer. Mineral., 35, 671–692, 1950.
19) S. Kaitaro: Geologic structure of the pre-Cambrian intrusives in the Åland Island. Bull. Comm. Geol. Finland, 162, 1951.
cf., P. Eskola: Ein lamprophyrgang in Helsinki und die Lamprophyrprobleme. Tsch. Min. u. Petrol. Mitt., 4, 1954.
20) E. Bederke: Zum Problem der lamprophyrprobleme. Nachr. Akad. Wiss., Göttingen, Math-phys. Kl., 1947.
cf., P. Eskola: Tschem. Min. u. Petrog. Mitt., 4, 1954.
21) T. F. W. Barth: Theoretical petrology. 1952.
22) H. Kuno: Petrology of Hakone volcano and the adjacent areas, Japan. Bull. Geol. Soc. Amer., 61, 957–1020, 1950.
23) N. Murakami: Cretaceous and Tertiary igneous activity in Western Chûgoku, Japan. Science Rep. Yamaguchi Univ., 11, 21–126, 1960 (in Japanese).