ISSN 0742-0463, Journal of Volcanology and Seismology, 2011, Vol. 5, No. 5, pp. 335–340. © Pleiades Publishing, Ltd., 2011.
Original Russian Text © V.V. Anan'ev, O.B. Selyangin, 2011, published in Vulkanologiya i Seismologiya, 2011, No. 5, pp. 42–48.

Rhonite in Molten Inclusions from the Olivine of Allivalite Nodules from Malyi Semyachik Volcano and Basalts of Klyuchevskoi Volcano, Kamchatka

V. V. Anan'ev[a] and O. B. Selyangin[b]

[a] *Institute of Volcanology and Seismology, Far East Division, Russian Academy of Sciences, Petropavlovsk-Kamchatskii, Bul. Piipa 9, 683006 Russia*

e-mail: avv@kscnet.ru

[b] *Geotechnological Research Center, Far East Division, Russian Academy of Sciences, Petropavlovsk-Kamchatskii, Severo-vostochnoe shosse, 30, 683002 Russia*

Received September 13, 2010

Abstract—A microprobe study of olivine found in allivalite nodules from lavas discharged by Malyi Semyachik Volcano and of olivine phenocrysts from basalts discharged by Klyuchevskoi Volcano revealed the presence of rhonite as a daughter mineral, for the first time ever. Rhonite was found in small (10–50 μm) grains that are xenomorphic in intergrowths with other minerals and have regular crystallographic outlines in contact with glass. We also found high-alumina clinopyroxene, chromium-free spinel, and hornblende. Residual glass is distinguished by its higher concentrations of SiO_2, Al_2O_3, alkalies, and by lower concentrations of FeO, MgO, and CaO. The chemical composition of the rhonite we studied is characterized by limited variations of the major components and fits the formula $(Si,Al)_6(Ti,Al,Fe^{+3},Fe^{+2},Mn,Mg)_6(Ca,Na)_2O_{20}$ well. The data points in the composition of the rhonites we have studied lie in the overall field of much more variable compositions to be found in the field. Unlike the previous findings in alkaline and subalkaline rocks, the rhonite we describe in the present report was found in rocks of the tholeiitic and calc-alkaline series.

DOI: 10.1134/S0742046311050022

INTRODUCTION

A microprobe study of olivine from allivalite nodules found in lavas of Malyi Semyachik Volcano and of olivine phenocrysts from basalts discharged by Klyuchevskoi Volcano revealed rhonite as a daughter mineral.

Rhonite is a silicate, a mineral of the enigmatite group, its name derives from the Rhoen massif in Germany. It is in the triclinic system and is characterized by the general formula $X_2Y_6Z_6O_{20}$, where X = Na, K, Ca; Y = Ti, ^{VI}Al, $^{VI}Fe^{+3}$, Fe^{+2}, Mn, Mg; Z = Si, ^{IV}Al, $^{IV}Fe^{+3}$. Rhonite is found as a rare earth in the form of subphenocrysts and microlites in alkali basalts, teschenites, limburgites, tephrites, and phonolites, as well as replacing amphibole xenocrysts and as an interstitial phase in rhonite xenoliths. The mineral associations that are typical of it contain titanaugite, kaersutite, diopside, forsterite, spinel, perovskite, magnesioferrite, and titanomagnetite [*Mineral* ..., 2001]. Rhonite was described as a daughter mineral in melt inclusions found in olivines of basanites in the North Minusinsk Basin and in southern Israel [Timina et al., 2006; Sharygin, 2002], in pyroxenes from lunar soil brought by the Luna 24 mission [Treiman, 2008], and in pyroxenes in the Haute Loire massif, France [Babkine et al., 1964]. The most complete reviews of rhonite can be found in [Johnston, Stout, 1985; Sharygin et al., 2007].

We discovered rhonite when studying melt microinclusions in olivines from olivine–anorthite (Ol–An) inclusions (allivalites) in a continuously differentiated flow (from basalt to andesite) discharged by Malyi Semyachik Volcano [Selyangin, 1979] and in basalts discharged by the Predskazannyi Vent on Klyuchevskoi Volcano [Khrenov et al., 1985]. The Ol–An inclusions consist of coarse-grained aggregates of olivine (Fo_{75-80}) and anorthite (An_{90-95}) with some stratification and transitions to eucrite. The grains of olivine are as large as 5 mm, while those of anorthite are up to 10 mm in size. The interstitial space frequently contains some amount of residual melt, which is usually crystallized to reach the stage of a fine-grained, porous, dolerite-like aggregate [Selyangin, 1979]. The rhonite-bearing olivines in the high-alumina basalts discharged by the Predskazannyi Vent have the composition Fo_{84-86}, are as large as 2.5 cm across, and are probably xenocrysts [Khrenov et al., 1985] or were produced by disintegration of lava-affine deep-seated cumulates.

The melt inclusions are ellipsoidal or irregular in shape, are from a few microns to 0.2–0.3 mm across, and usually have undergone partial crystallization. The daughter minerals include high-alumina clinopyroxene, spinel, amphibole, and rhonite. The glass in these inclusions is frequently penetrated by very thin

Table 1. Mean rhonite compositions

Sample #	LS16	LS20	LS26-28	KL119-3	KL119-5
Number of analyses	3	6	17	2	2
SiO_2	25.51	25.45	25.78	29.06	26.35
TiO_2	5.17	4.82	6.05	3.80	3.19
Al_2O_3	18.87	18.94	18.54	18.67	17.77
Fe_2O_3	13.27	12.53	9.64	8.94	17.20
FeO	13.29	14.02	14.88	17.09	9.53
MnO	0.18	0.18	0.18	0.17	0.18
MgO,	11.49	11.36	11.34	10.81	13.34
CaO	12.56	12.49	12.41	11.82	11.96
Na_2O	0.65	0.45	0.59	0.99	0.75
Total	101.00	100.23	99.42	101.33	100.26
Formula-based amounts per 20 oxygen atoms					
Si	3.4096	3.4299	3.4908	3.8470	3.5157
Ti	0.5198	0.4882	0.6159	0.3779	0.3196
Al	2.9735	3.0091	2.9595	2.9128	2.7953
Fe^{+3}	1.3352	1.2711	0.9827	0.8902	1.7272
Fe^{+2}	1.4850	1.5797	1.6850	1.8918	1.0640
Mn	0.0204	0.0204	0.0205	0.0183	0.0208
Mg	2.2895	2.2813	2.2892	2.1327	2.6541
Ca	1.7993	1.8041	1.8007	1.6765	1.7101
Na	0.1676	0.1163	0.1556	0.2528	0.1932
Mg#	0.61	0.59	0.58	0.53	0.71
Total	14.0000	14.0000	14.0000	14.0000	14.0000

Table 2. Theoretical rhonite formulas

Sample #	Formula
LS16	$(Si,^{IV}Al)_6(Ti,^{VI}Al,Fe^{+3},Fe^{+2},Mn,Mg)_{6.03}(Ca,Na)_{1.97}O_{20}$
LS20	$(Si,^{IV}Al)_6(Ti,^{VI}Al,Fe^{+3},Fe^{+2},Mn,Mg)_{6.08}(Ca,Na)_{1.92}O_{20}$
LS26-28	$(Si,^{IV}Al)_6(Ti,^{VI}Al,Fe^{+3},Fe^{+2},Mn,Mg)_{6.04}(Ca,Na)_{1.96}O_{20}$
KL119-3	$(Si,^{IV}Al)_6(Ti,^{VI}Al,Fe^{+3},Fe^{+2},Mn,Mg)_{6.07}(Ca,Na)_{1.93}O_{20}$
KL119-5	$(Si,^{IV}Al)_6(Ti,^{VI}Al,Fe^{+3},Fe^{+2},Mn,Mg)_{6.10}(Ca,Na)_{1.90}O_{20}$

dendrites of minerals and contains bubbles of a gas phase.

Rhonite is found as fine grains (10–50 μm) that are xenomorphic in intergrowths with other minerals and that have regular crystallographic outlines at contacts with glass (Fig. 1). Although we have examined many melt inclusions, rhonite was found in few of these.

RESULTS

The chemical composition of the rhonite we have studied (Table 1) shows limited variations $(Si,Al)_6(Ti,Al,Fe^{+3},Fe^{+2},Mn,Mg)_6(Ca,Na)_2O_{20}$, (Table 2). The data points lie in the general field of much more variable compositions of this mineral when it occurs naturally [Johnston and Stout, 1985] (Fig. 2).

Clinopyroxenes were encountered either in small crystals or in the rims at the olivine–melt boundaries. The pyroxenes typically have high alumina concentrations, which occasionally reach 16–17% Al_2O_3, low concentrations of silica (as low as 38%), and higher concentrations of titanium. Earlier studies by one of the present authors [Anan’ev, 1985; Anan’ev and Shnyrev, 1984] classified such high-alumina phases

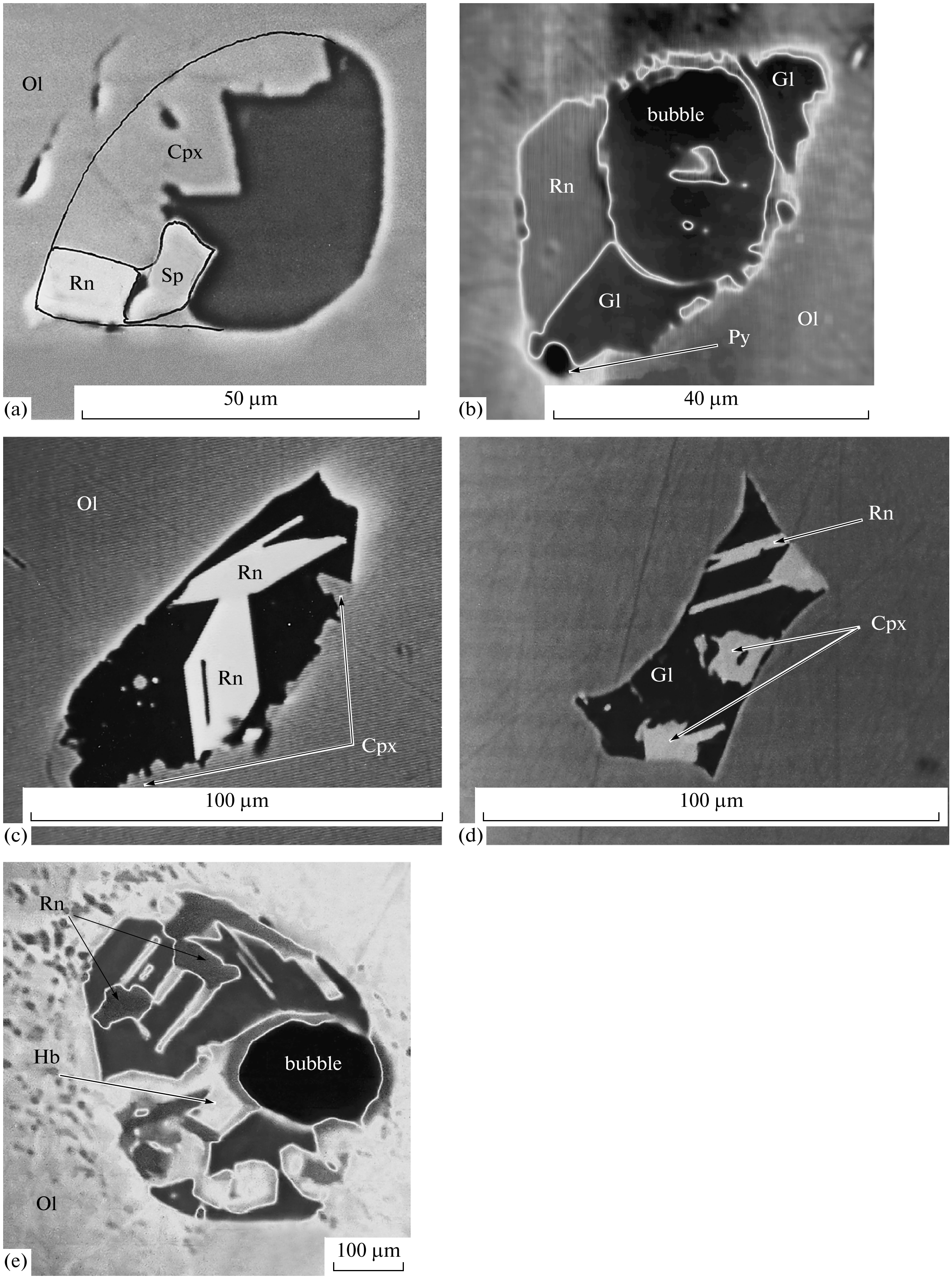

Fig. 1. Microprobe photographs of rhonite-bearing inclusions: (a) sample LS16, (b) sample LS20, (c) sample LS26-28, (d) sample KL119-3, (e) sample KL119-5. Ol stands for olivine, Cpx for clinopyroxene, Hb for hornblende, Sp for spinel, Rn for rhonite, Gl for glass, and Py for pyrite. Images are in backscattered electrons. Images a, b, and c were subjected to additional treatment in order to identify the boundaries of mineral phases.

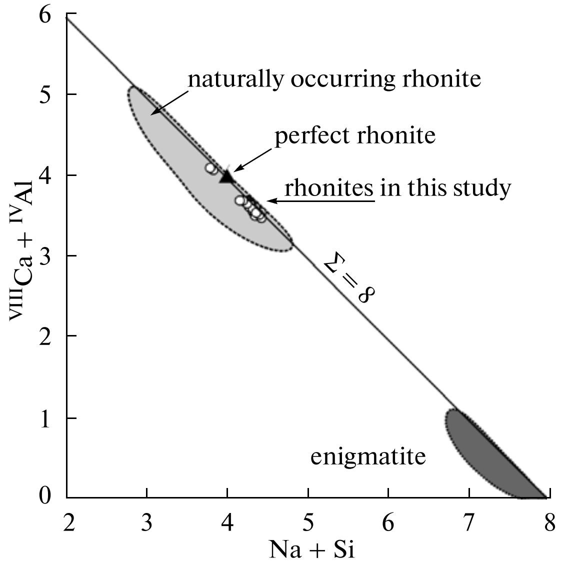

Fig. 2. A plot of Na + Si versus $^{VIII}Ca + ^{IV}Al$ for naturally occurring rhonite and enigmatite after [Johnston and Stout, 1985].

with very low concentrations of SiO_2 (38%) as garnets since they could not be studied optically. Stoichiometry does not distinguish between such pyroxenes and garnets and calculations show almost completely identical compositions of these phases with the garnet formula $Si_6(Ti,Al,Fe^{+3})_4(Mg,Fe^{+2},Ca)_6O_{24}$. However, such pyroxenes were also encountered in melt inclusions that did not contain rhonite, with the overall trend being continuous with Al_2O_3 concentration, going from 3% to 17%, and having complementary variations in the concentration of SiO_2 that are not typical of garnet. Similar pyroxenes were also described elsewhere [Grib and Perepelov, 2008; Plechov et al., 2008; Sharygin, 2002]. In addition, pyroxenes that were as high-alumina as the ones above (12% Al_2O_3) have been described as mineral impregnations in basalts from Auvergne, Eifel, and the Oslo area [Dobretsov et al., 1971], as well as in some alkaline and subalkaline rocks of Kamchatka [Volynets et al., 1990; Savel'ev and Filosofova, 2005].

Spinel is found as a high-alumina chrome-free variety with a comparatively low concentration of trivalent iron. Hornblende has a higher concentration of aluminum and forms both small dendrites that permeate the glass in the inclusions like felt and mature crystals.

The glass in these inclusions is a differentiate of the primary melt that has remained when the daughter minerals crystallized. It has higher concentrations of SiO_2, Al_2O_3, and alkalies and lower concentrations of FeO, MgO, and CaO (Table 3).

It should be noted that nearly all previous finds of rhonite were in alkali rocks. The rhonite described in the present report was found in rocks of the tholeiitic and calc-alkaline series that consist of high-alumina basalts [Khrenov et al., 1985], as well as of high-magnesium basalts and andesites, whose continuous series was formed by fractionation of the allivalite–eucrite association and by mixing with dacite magma at the top of the magma column [Selyangin, 1979, 1987].

DISCUSSION OF RESULTS

Numerous studies of rhonite-bearing mineral associations suggest a stable paragenesis of rhonite and high-alumina clinopyroxene [Timina et al., 2006; Sharygin, 2002; Kogarko et al., 2005; Magonthier and Velde, 1976 and elsewhere], while the other accompanying phases are characterized by more variable compositions and are not always present in these associations. Another stable feature to use to infer the presence of rhonite in a melt microinclusion is that the residual acidic glass should be high in alumina.

On homogenizing, the cryometry of rhonite-bearing melt inclusions in olivine extracted from alkaline rocks [Sharygin, 2002; Sharygin and Timina, 2008] in which gas bubbles contained liquid CO_2 gave the result that the melt inclusions were captured in cores of olivine phenocrysts at T > 1300°C and P > 3–5 kbars. The following sequence of phase generation was identified: ± sulfide globule > Al-spinel (1320–1255°C > rhonite (1260–1180°C) > clinopyroxene (1240–1130°C > apatite > ±amphibole, Fe–Ti-oxides (ilmenite or Ti-magnetite) (>1100°C) > glass (>1100°C). The glass in homogenized inclusions [Sharygin, 2002] is characterized by high concentrations of FeO (14.4–21), MgO (4.5–7.5), CaO (8.5–11), TiO_2 (2.3–4.5), and P_2O_5 (0.7–0.9) and by low concentrations of SiO_2 (43.3–46.9), Al_2O_3 (9–14), and $Na_2O + K_2O$ (2.6–5.5 wt %). The residual glasses in the original (unheated) inclusions are substantially more acidic (in wt %): SiO_2 (60.5–61), TiO_2 (0.2–0.3), Al_2O_3 (23.2–24.5), FeO (0.8–1.8), MgO (0.2–1.5), CaO (0.4–0.7), Na_2O (5.2–6.6), K_2O (4.9–5.8), P_2O_5 (0.3–0.7), and Cl (0.3–0.4). With the exception of a smaller rise in alkalinity, this tendency of melt differentiation was also observed in rhonite-bearing inclusions from olivine in the rocks of normal alkalinity studied here.

Grapes et al. [2003] report that rhonite and accompanying minerals crystallized between 1190 and 1090°C and at pressures <0.5 kbars in basanites discharged by Mount Sidley, western Antarctica. Treiman [2008] conjectures that rhonite may have been produced by the reaction of titanium–oligoclase amphibole with pyroxene:

$$Ca_2(M_4^{+2}Ti)(Al_2Si_6)O_{22}(OH)_2 + M^{+2}SiO_3$$
$$= Ca_2M_5^{+2}Ti(Al_2Si_4)O_{20} + 3SiO_2 + H_2O.$$

Appropriate calibration is supposed to allow that reaction to limit the bounds of possible fugacity of water and associated volatiles.

The early and long (1320–1130°C) liberation of as high-alumina phases as are spinel, rhonite, and clinopyroxene from a melt that has a low alumina con-

Table 3. Compositions of associated daughter minerals

Sample #	LS16			LS26-28		LS20	KL119-3		KL119-5	
Minerals	Cpx	Sp	Gl	Cpx	Cpx	Gl	Cpx	Cpx	Hb	Gl
SiO_2	45.42	0.00	63.64	44.37	43.30	64.44	39.49	39.44	42.35	56.85
TiO_2	1.76	0.44	0.93	1.77	1.84	0.20	2.07	2.57	0.75	0.62
Al_2O_3	10.40	58.13	22.17	13.19	13.52	22.82	15.34	16.91	17.82	23.95
Cr_2O_3	0.02	0.00	0.00	0.02	0.00	0.03	0.00	0.00	0.01	0.01
Fe_2O_3	2.20	8.86	0.00	2.00	2.82	0.00	6.29	5.54	8.23	0.00
FeO	7.40	19.97	2.07	7.34	6.08	1.88	5.22	5.43	0.00	2.06
MnO	0.19	0.19	0.04	0.22	0.16	0.04	0.14	0.19	0.27	0.09
MgO	11.30	14.35	0.54	9.77	9.62	0.40	7.67	7.42	15.93	0.67
CaO	20.66	0.00	3.72	21.60	22.50	4.23	22.42	22.28	10.14	4.98
Na_2O	0.36	0.00	5.15	0.37	0.26	4.26	0.28	0.45	2.36	4.44
K_2O	0.00	0.00	1.54	0.09	0.00	1.20	0.00	0.00	0.20	1.97
H_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.13	0.00
Total	99.72	101.94	99.80	100.74	100.10	99.50	98.92	100.23	100.19	95.64
Formula amounts (Cpx per 6 oxygen atoms, Hb per 23, Sp per 32, and Gl per 8)										
Si	1.7021	0.0000	2.8221	1.6489	1.6200	2.8449	1.5137	1.4886	5.9427	2.6645
Ti	0.0499	0.0701	0.0309	0.0496	0.0517	0.0067	0.0595	0.0731	0.0796	0.0220
Al	0.4600	14.4532	1.1589	0.5775	0.5961	1.1876	0.6932	0.7521	2.9480	1.3230
Cr	0.0005	0.0000	0.0000	0.0006	0.0000	0.0012	0.0000	0.0000	0.0007	0.0005
Fe^{+3}	0.0620	1.4066	0.0000	0.0560	0.0795	0.0000	0.1815	0.1575	0.8691	0.0000
Fe^{+2}	0.2322	3.5231	0.0766	0.2281	0.1902	0.0693	0.1673	0.1713	0.0000	0.0809
Mn	0.0061	0.0337	0.0013	0.0068	0.0052	0.0015	0.0045	0.0060	0.0324	0.0037
Mg	0.6311	4.5134	0.0355	0.5412	0.5366	0.0266	0.4384	0.4177	3.3334	0.0465
Ca	0.8298	0.0000	0.1767	0.8602	0.9018	0.2001	0.9208	0.9008	1.5239	0.2501
Na	0.0264	0.0000	0.4427	0.0266	0.0189	0.3645	0.0211	0.0328	0.6418	0.4035
K	0.0000	0.0000	0.0870	0.0045	0.0000	0.0677	0.0000	0.0002	0.0362	0.1176
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Mg#	0.73	0.56	0.32	0.70	0.74	0.28	0.72	0.71	1.00	0.36
Total	4.0000	24.0001	4.8317	4.0000	4.0000	4.7701	4.0000	4.0001	16.4078	4.9123

Note: Fe_2O_3 in clinopyroxene, hornblende, and spinel was calculated in accordance with the stoichiometry of these minerals, Fe_2O_3 in rhonite was calculated following [Johnston and Stout, 1985]. For hornblende we also calculated the content of water per one molecule H_2O. The analyses were made at the Institute of Volcanology and Seismology using a Camebax microprobe. The accelerating voltage was 20 kV with a current of 20 nA through the sample. Analyst V.V. Anan'ev.

tent, such as that in a homogenized inclusion [Sharygin, 2002], added to its accumulation in the residual melt, seems paradoxical. It is to be supposed that this association of daughter minerals was preceded by crystallization of the host mineral (olivine) on the walls of vesicles and that this provided for a sufficient concentration of Al_2O_3 by the time the rhonite-bearing association began to be liberated. This must have considerably expanded the inclusions during homogenization.

The textural features of rhonite suggest its being an "ephemeral" intermediate phase during crystallization of the spinel–pyroxene sequence [Sharygin and Timina, 2008], although we have failed to find any mention of disintegration structures of rhonite or some reaction relationships of it with other phases. In our opinion, rhonite should be treated as a rare (rarely detected) accessory mineral.

A review of the accessible literature shows wide limits for the parameters of its stability: temperature (1260–1180°C), pressure (4–0.5 kbars), oxygen fugacity (ranging between that relevant to the iron–wuestite buffer in meteorites [Fuchs, 1971] and the fugacity controlled by the nickel–bunsenite equilibrium in the situation of amphibole replacement in xenoliths [Grapes et al., 2003]), concentrations (and apparently the composition) of volatiles, as well as the compositions of the magma melts from which rhonite was liberated (ranging from high- and normal-alkaline (tholeiitic) and from ultramafic to acidic). Therefore, at the present state of our knowledge, we find no critical factor or a set of factors that control the generation of rhonite, although in statistical terms one could highlight such favorable factors as increased alkalinity of the melt and increased pressure.

Theoretically speaking, the evolution of a cooling magma captured by minerals in the form of microinclusions ought to be similar to the evolution of the bulk of magma outside the phenocrysts; this should in the general case (on a qualitative level) be facilitated by the presence of rhonite both in melt inclusions and in the bulk of olivine and olivine-free (olivine being liberated) alkaline rocks. One finds that boiling and crystallization occur in a similar manner for interstitial melts in fragments (nodules) of cumulates that are comagmatic to the volcanics that discharge them. The mineral/melt quantitative relationships in rhonite-bearing inclusions (see Fig. 1) are similar to the degree of crystallinity in these interstices and the groundmass of basic to intermediate normal-alkaline rocks, which are, however, composed of ordinary single- and bipyroxene–plagioclase associations with titanomagnetite (±ilmenite) and acidic low-alumina glass. Whether the absence of free (not daughter) rhonite in these (even though as relicts) is a question of a more careful search or some essential difference between the conditions of evolution for a "conserved" and a free magma melt constitutes an intriguing petrogenetic problem that calls for broader and more detailed investigations using finer geochemical and experimental techniques.

REFERENCES

Anan'ev, V.V., The Origin of Ol–An Segregations in Volcanic Rocks Based on a Study of Spinels and Melt Inclusions, in *Tez. dokladov VI Vsesoyuznogo vulkanologicheskogo soveshchaniya* (Abstracts of reports made at the VI All-Union Volcanological Conference), no. 2, Petropavlovsk-Kamchatskii, 1985, pp. 124–126.

Anan'ev, V.V. and Shnyrev, G.D., Garnet in Molten Inclusions from Olivine of Ol–An Segregations: Ksudach Volcano, Kamchatka, *Dokl. AN SSSR*, 1984, vol. 274, no. 2, pp. 402–406.

Babkine, J., Conquere, F., Vilminot, J.C., and Duong, P.K., Sur un nouveaugiasement de rhonite (Monistrol-d'Allier, Haute Loire), *C. R. Acad. Sci.,* 1964, ser. D 258, pp. 5479–5481.

Dobretsov, N.L., Kochkin, Yu.N., Krivenko, A.P., and Kutolin, V.A., *Porodoobrazuyushchie pirokseny* (Rock-Forming Pyroxenes), Moscow: Nauka, 1971.

Fuchs, L.H., Occurrence of Wollastonite, Rhonite and Andradite in the Allende Meteorite, *Amer. Miner.,* 1971, vol. 56, pp. 2053–2067.

Grapes, R.H. and Wysoczanski, R.J., Hoskin, P.W.O., Rhonite Paragenesis in Pyroxenite Xenoliths, Mount Sidley Volcano, Marie Byrd Land, West Antarctica, *Mineral. Mag.*, 2003, vol. 67, no. 4, pp. 639–651.

Grib, E.N. and Perepelov, A.B., Olivine Basalts at the Karymskii Volcanic Center: Mineralogy, Petrogenesis, and Magma Sources, *Vulkanol. Seismol.*, 2008, no. 4, pp. 14–35 [*Journal of Volcanology and Seismology*, 2008, vol. 2, no. 4, pp. 228–247].

Johnston, A.D. and Stout, J.H., Compositional Variation of Naturally Occurring Rhoenite, *Amer. Miner.*, 1985, vol. 70, pp. 1211–1216.

Khrenov, A.P., Anan'ev, V.V., Baluev, E.Yu., et al., The Petrology of Ejecta from Klyuchevskoi Volcano (Predskazannyi Vent, 1983), *Vulkanol. Seismol.,* 1985, no. 1, pp. 47–70.

Kogarko, L.N., Hellebrand, E., and Ryabchikov, I.D., Trace Element Partitioning between Rhonite and Silicate Melt in Cape Verde Volcanics, *Geokhimiya*, 2005, no. 1, pp. 3–9.

Magonthier, M.C. and Velde, D., Mineralogy and Petrology of Some Tertiary Leucite–Rhonite Basanites from Central France, *Mineral. Mag.*, 1976, vol. 40, no. 316, pp. 817–826.

Mineral Data Publishing, 2001, Version 1.2. http://www.handbookofmineralogy.org/pdfs/rhonite.pdf

Plechov, P.Yu., Shishkina, T.A., Ermakov, V.A., and Portnyagin, M.V., Conditions for the Generation of Allivalites (Olivine–Anorthite Crystalline Inclusions) in Volcanic Rocks of the Kuril–Kamchatka Arc, *Petrologiya*, 2008, vol. 16, no. 3, pp. 275–276.

Savel'ev, D.P. and Filosofova, T.M., Mineralogic Features of Cretaceous Alkali Basalts in the Kamchatskii Mys Peninsula, Eastern Kamchatka, *Vestnik KRAUNTs, Ser. Nauki o Zemle*, 2005, no. 5, pp. 94–102.

Selyangin, O.B., Continuously Differentiated Lava Flows with Inclusions and a Probable Structure of the Magma Differentiation Region under a Volcano, *Byull. Vulkanol. St.*, 1979, no. 57, pp. 39–52.

Selyangin, O.B., *Petrogenezis bazal't-datsitovoi serii v svyazi s evolyutsiei vulkanostruktur* (Petrogenesis of the Basalt–Dacite Series in Connection with the Evolution of Volcanic Features), Moscow: Nauka, 1987.

Sharygin, V.V., Melt Inclusions in Olivine from Mahtesh Ramon Basanite, Southern Israel, *Abstracts of reports at the All-Russia seminar "Geochemistry of Igneous Rocks"*, The "Alkaline Magmatism on Earth–2002". ttp://alkaline2002.narod.ru/abstracts/sharigin.html

Sharygin, V.V., Szaby, Cs., Kythay, K., et al., Rhonite in Silica-Undersaturated Alkali Basalts: Inferences on Silicate Melt Inclusions in Olivine Phenocrysts, in *Alkaline Magmatism, Its Sources and Plumes*, Irkutsk-Napoli, 2007, pp. 157–182.

Sharygin, V.V. and Timina, T.Yu., Rhonite in Alkali Basalts: A Potential Indicator of P–T–fO_2 Conditions (from a Study of Melt Inclusions), *Abstracts of reports at the All-Russia seminar "Geochemistry of Igneous Rocks",* The "Alkaline Magmatism on Earth–2008". http://geo.web.ru/conf/alkaline/2008/sharigin3.htm

Timina, T.Yu., Sharygin, V.V., and Golovin, A.V., Melt Evolution during Crystallization of Basanites in the Tergesh Pipe, North Minusinsk Basin, *Geokhimiya*, 2006, no. 8, pp. 814–833.

Treiman, A.H., Rhonite in Luna 24 Pyroxenes: First Find from the Moon, and Implications for Volatiles in Planetary Magmas, *American Mineral.*, 2008, vol. 93, nos. 2/3, pp. 488–491.

Volynets, O.N., Uspenskii, V.S., Anoshin, G.N., et al., The Evolution of the Geodynamic Magma-Generation Regime during Late Cenozoic Time in Eastern Kamchatka: Geochemical Evidence, *Vulkanol. Seismol.*, 1990, no. 5, pp. 14–27.