LETTER

Rhabdophane-(Y), $\text{YPO}_4 \cdot \text{H}_2\text{O}$, a new mineral in alkali olivine basalt from Hinodematsu, Genkai-cho, Saga Prefecture, Japan

Yasuhiro TAKAI* and Seiichiro UEHARA

*Department of Earth and Planetary Sciences, Faculty of Sciences, Kyushu University,
6-10-1 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan*

**Present affiliation: Enecom Co., Ltd.*

Rhabdophane-(Y), ideal formula $\text{YPO}_4 \cdot \text{H}_2\text{O}$, occurs in a druse of the Higashimatsuura basalt at Hinodematsu, Genkai-cho, Saga Prefecture, Japan. It occurs as short rod-like crystals and forms radial aggregates. Rhabdophane-(Y) is hexagonal, $P6_322$, $a = 6.959(2) \text{ \AA}$, $c = 6.384(2) \text{ \AA}$, $V = 267.7(1) \text{ \AA}^3$, $Z = 3$. It is yellowish white to yellowish brown in color with a silky to dull luster. The density is 4.54 g/cm^3 (calc.). The strongest lines in the X-ray powder diffraction pattern are $[d (I/I_0) hkl]$ 2.821 (100) 102, 3.013 (77) 200, 6.026 (76) 100, 4.385 (47) 101, 3.480 (44) 110, 2.127 (28) 003, and 1.854 (26) 212.

Keywords: Rhabdophane-(Y), Hinodematsu, Higashimatsuura basalt, New mineral

INTRODUCTION

During a mineralogical investigation of rare earth (RE) minerals in the alkali olivine basalt, northern Kyushu, Japan, we identified rod-like RE phosphates, using scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS). The X-ray powder diffraction patterns showed the phosphates to be members of the rhabdophane group of minerals. Rhabdophane-group minerals generally contain the larger RE elements such as La, Ce, and Nd, and the Y-rich form of rhabdophane has yet to be reported.

Rhabdophane-group minerals occur widely in the Higashimatsuura basalt, and they have a wide range of chemical compositions with respect to RE elements. The Y-dominant member of the rhabdophane group of minerals has been found in the Hinodematsu and other basalts, in addition to rhabdophane-(La), rhabdophane-(Ce), and rhabdophane-(Nd). Other RE phosphates such as monazite, xenotime, and churchite have not been found.

The Y-dominant form of rhabdophane-(Ce) has been named rhabdophane-(Y), according to the Levinson rule (Levinson, 1966). The mineral and mineral name have been approved by the International Mineralogical Association,

Commission on New Minerals, Nomenclature and Classification (No. 2011-31). The type specimen is deposited at the Kitakyushu Museum of Natural History and Human History, Kitakyushu, Japan, under the registered number KMNHM000002.

OCCURRENCE

Rhabdophane-(Y) occurs in a small druse in an alkali olivine basalt at Hinodematsu, Genkai-cho, Saga Prefecture, Japan, called the Higashimatsuura basalt. The Higashimatsuura basalt is a Neogene alkali olivine basalt and consists of five stages, based on volcanic activities (Ishibashi, 1971). The most recent stage has yielded three new minerals: kimuraite-(Y) (Nagashima et al., 1986), kozoite-(Nd) (Miyawaki et al., 2000), and kozoite-(La) (Miyawaki et al., 2003). The basalt in Hinodematsu is a second-stage basalt, and this is the first time a RE phosphate has been found in the Higashimatsuura basalt.

Rhabdophane-(Y) occurs in a druse of the basalt and covers the surface of the druse or druse minerals (Fig. 1; Color version of Figure 1 is available online from <http://joi.jlc.jst.go.jp/JST.JSTAGE/jmps/111020j>). Under SEM-EDS, short rod-like crystals (1 μm in diameter, 2–3 μm long), forming radial aggregates, are observed (Fig. 2). The mineral is associated with plagioclase, forsterite, augite, enstatite, magnetite, and ilmenite. Lanthanite-(Nd)

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Y. Takai, takai@kyudai.jp

S. Uehara, uehara@geo.kyushu-u.ac.jp Corresponding author

$[\text{Nd}_2(\text{CO}_3)_3 \cdot 8\text{H}_2\text{O}]$ sometimes occurs in Hinodematsu, but it is not found in association with rhabdophane-(Y) in the same druse.

OPTICAL AND PHYSICAL PROPERTIES

Rhabdophane-(Y) is yellowish white to yellowish brown in color and translucent. The streak is yellowish white. It

Figure 1. Micrograph of rhabdophane-(Y) showing its occurrence mode. Color version of Figure 1 is available online from <http://joi.jlc.jst.go.jp/JST.JSTAGE/jmps/111020j>.

has a silky to dull luster. The calculated density is 4.54 g/cm^3 . Because of the small amount of the mineral available, the other optical and physical properties could not be measured.

CHEMICAL COMPOSITION

Quantitative chemical analysis was carried out using an electron-probe microanalyzer (EPMA; JEOL SUPER-PROBE 733, 15 kV and 10 nA). The H_2O content was calculated by difference. The chemical compositions of rhabdophanes in Hinodematsu correspond to rhabdo-

Figure 2. Back scattered electron image of rhabdophane-(Y).

Table 1. Chemical composition of rhabdophane-(Y)

wt%	1	2	3	4	5	6	7	8	9	Average
Y_2O_3	14.83	15.46	14.59	15.02	16.02	14.35	14.75	16.37	15.88	15.25
La_2O_3	20.71	20.75	23.00	19.96	19.63	23.76	20.12	20.64	18.29	20.76
Ce_2O_3	1.27	0.86	0.77	0.98	1.59	0.44	0.63	1.00	2.34	1.10
Pr_2O_3	5.16	5.72	6.33	5.42	5.04	5.83	5.28	4.42	4.36	5.28
Nd_2O_3	14.36	15.43	15.61	14.51	14.98	15.98	14.22	14.06	13.43	14.73
Sm_2O_3	0.15	0.85	0.05	0.24	0.00	0.22	0.54	0.08	0.86	0.33
Gd_2O_3	3.72	4.08	4.45	3.89	3.99	3.87	4.11	4.04	4.01	4.02
ΣREE	60.19	63.14	64.78	60.02	61.25	64.45	59.66	60.60	59.15	61.47
CaO	2.45	2.31	2.19	1.90	1.97	1.92	1.78	1.76	2.01	2.03
P_2O_5	27.65	28.59	27.36	26.90	28.62	25.56	29.48	27.23	30.43	27.98
H_2O	9.71	5.96	5.67	11.19	8.17	8.07	9.09	10.40	8.40	8.52
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
No. of ions (O=4)										
Y	0.32	0.33	0.31	0.34	0.34	0.32	0.31	0.36	0.33	0.33
La	0.31	0.30	0.34	0.31	0.29	0.37	0.30	0.32	0.26	0.31
Ce	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.03	0.02
Pr	0.08	0.08	0.09	0.08	0.07	0.09	0.08	0.07	0.06	0.08
Nd	0.21	0.22	0.23	0.22	0.21	0.24	0.20	0.21	0.19	0.21
Sm	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Gd	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.06	0.05	0.05
ΣREE	1.00	1.01	1.05	1.02	0.99	1.09	0.96	1.02	0.94	1.01
Ca	0.11	0.10	0.09	0.09	0.08	0.09	0.08	0.08	0.08	0.09
P	0.96	0.96	0.94	0.96	0.97	0.91	0.99	0.96	1.00	0.96
H_2O^*	1.33	0.79	0.76	1.57	1.09	1.14	1.21	1.44	1.09	1.15

* H_2O is calculated by difference.

phane-(Y) or rhabdophane-(La). Nine crystals of rhabdophane were analyzed, and the results are given in Table 1. Seven crystals are Y dominant, and the other crystals are La dominant. The empirical formula, on the basis of four O structural atoms, is $(Y_{0.33}, La_{0.31}, Nd_{0.21}, Pr_{0.08}, Gd_{0.05}, Ce_{0.02}, Sm_{0.00})_{1.01}, Ca_{0.09}P_{0.96}O_4 \cdot 1.15H_2O$, and its simplified and ideal formulas are $(Y, La, Nd)PO_4 \cdot H_2O$ and $YPO_4 \cdot H_2O$, respectively.

CRYSTALLOGRAPHY

Single-crystal X-ray diffraction studies could not be carried out because of the small crystal-size.

X-ray diffraction data (Table 2) were obtained using a diffractometer (BRUKER AXS M18XHF22-SRA, MXP18) with $CuK\alpha$ radiation generated at 40 kV and 100 mA, and monochromated with graphite. The data from the step-scan mode (step-width 0.02°) showed that rhabdophane-(Y) is hexagonal, and the space group is $P6_222$. The X-ray powder diffraction pattern was indexed by reference to the cell parameters of the synthetic analog of rhabdophane-(Y), $YPO_4 \cdot H_2O$ (Mogilevsky and Boakye, 2007). The unit cell parameters refined from the powder data are $a = 6.959(2)$ Å, $c = 6.384(2)$ Å, $V = 267.7(1)$ Å³, and $Z = 3$.

The rhabdophane-group minerals consist of rhabdophane-(La), rhabdophane-(Ce), rhabdophane-(Nd), grayite (hydrated Th phosphate), trisramite (hydrated U-Ca

phosphate), and brockite (hydrated Ca-Th phosphate). Ningyoite is a pseudohexagonal (orthorhombic) hydrated Ca-U phosphate closely related to the rhabdophane-group minerals (Gaines et al., 1997). The lattice parameters of the rhabdophane-group minerals are given in Table 3 for comparison. The lattice parameters of rhabdophane-(Y) are consistent with those of the synthetic equivalent of rhabdophane-(Y) $[(Y_{0.7}La_{0.3})PO_4 \cdot 0.7H_2O]$, $a = 6.917$ Å and $c = 6.366$ Å] and rhabdophane-(La). Because of the lower Y content in rhabdophane-(Y) from Hinodematsu, the obtained lattice parameters are slightly larger than those of the synthetic analog. The lattice parameters of some rhabdophane-group minerals are of low accuracy; this may be caused by the small crystal-size of these minerals.

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SUPPLEMENTARY MATERIAL

Color version of Figure 1 is available online from <http://joi.jlc.jst.go.jp/JST.JSTAGE/jmps/111020j>.

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Table 2. X-ray diffraction pattern of rhabdophane-(Y)

<i>h k l</i>	<i>d</i> _{obs} (Å)	<i>d</i> _{calc} (Å)	<i>I/I</i> ₀
1 0 0	6.026	6.026	76
1 0 1	4.385	4.382	47
1 1 0	3.480	3.479	44
2 0 0	3.013	3.013	77
1 0 2	2.821	2.821	100
1 1 2	2.353	2.352	9
2 1 1	2.144	2.145	19
0 0 3	2.127	2.128	28
2 1 2	1.854	1.854	26
2 2 0	1.739	1.740	17

Table 3. Lattice parameters of rhabdophane-group minerals*

	Formula	Space group	<i>a</i>	<i>b</i>	<i>c</i>
Rhabdophane-(Y)**	$YPO_4 \cdot H_2O$	$P6_222$	6.959		6.384
Rhabdophane-(La)	$LaPO_4 \cdot H_2O$	$P6_222$	6.98		6.39
Rhabdophane-(Ce)	$CePO_4 \cdot H_2O$	$P6_222$	6.960		6.372
Rhabdophane-(Nd)	$NdPO_4 \cdot H_2O$	$P6_222$			
Grayite	$ThPO_4 \cdot H_2O$	$P6_222$	6.957		6.396
Brockite	$(Ca,Th,REE)PO_4 \cdot H_2O$	$P6_222$	6.98		6.40
Trisramite	$(Ca,U^{4+},Fe^{3+})PO_4 \cdot H_2O$	$P6_222$	6.913		6.422
Ningyoite	$(U,Ca,Fe)_2(PO_4)_2 \cdot 1-2H_2O$	$P222$	6.78	12.1	6.38

* Modified after Gaines et al., 1997.

** This study.

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