Chemical composition and physical properties of dachiardite group zeolites

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Abstract

An intermediate mineral between original type dachiardite and sodium-rich dachiardite has been found from Hatsuneura, the Ogasawara Islands. New data for dachiardite from the Onoyama mine, Kagoshima Pref., are also given. Based on the data for the above two dachiardites and literature data, mode of occurrence, chemical composition, optical, X-ray and thermal properties of dachiardite group zeolites were examined. The wide variation of chemical composition in this group seems to be due to the substitution of NaNa for Ca among the exchangeable cations with apparently independent substitution of Al for Si in the framework. The X-ray powder diffraction patterns are not distinguishable among the dachiardite group zeolites, and structural disorder is commonly observed in them. Correlation between $\text{Si}/(\text{Al} + \text{Fe}^{3+})$ ratio and β angle is recognized. Refractive indices, $2V$ and $c \wedge Z$ are closely related to $\text{R}^{2+}/(\text{R}^{2+} + \text{R}^{3+})$ ratio, in which R^{2+} and R^{3+} are numbers of divalent and monovalent exchangeable cations, respectively. Some differences are recognized in TG-DTA curves and thermal stability between the original type dachiardite and the sodium-rich dachiardite. The results suggest that the isomorphous substitution may be expected in the dachiardite group zeolites.

Introduction

Dachiardite, a rare high silica zeolite, was first found by D'Achiardi (1906) from S. Piero di Campo, Elba, Italy, where it occurred in pegmatite fissures as twin crystals showing eight-sided prisms associated with mordenite, heulandite, stilbite, pollucite and tourmaline (Berman, 1925). Its chemical composition was given as $\text{K}_{0.67}\text{Na}_{1.05}\text{Ca}_{1.63}\text{Mg}_{0.10}(\text{Al}_{5.20}\text{Si}_{18.80}\text{O}_{48})12.68\text{H}_2\text{O}$ by Gottardi (1960). Subsequently, Gottardi and Meier (1963) determined its space group $C2/m$ and discussed the structural relationship between dachiardite and mordenite. No additional occurrences had been noted until 1964, when Minato announced the second occurrence of dachiardite associated with mordenite in hydrothermal quartz veins of the Onoyama mine, Kagoshima Pref., Japan. However, the

description of this mineral remains unpublished, except for the mode of occurrence (Kato, 1973).

A sodium analogue of dachiardite (sodium-rich dachiardite) was found in basalt of Alpe di Siusi, Bolzano, Italy by Alberti (1975). He pointed out that it differs from the original dachiardite of Elba with respect to the following; 1) its higher Si/Al ratio, 2) its strong predominance of Na (instead of Ca) as the exchangeable cation and 3) its structural disorder in the framework. The subsequent occurrences of the sodium-rich dachiardite were described in altered rhyolite in the Tsugawa district, Niigata Pref., Japan by Yoshimura and Wakabayashi (1977), and in amygdules in andesite pillow lava at Susaki, Chichijima, the Ogasawara Islands, Japan by Nishido *et al.* (1979). Recently, Wise and Tschernich (1978) reported new dachiardite localities at Altoona, Washington and at Cape Lookout and Agate Beach, Oregon, U. S. A. These minerals have chemical and optical peculiarities.

During the course of an extensive study of zeolitization in Chichijima, the first author (H.N.) found a dachiardite-like zeolite at Hatsuneura at the east coast of Chichijima, followed by the description of the sodium-rich dachiardite from Susaki at the west coast (Nishido *et al.*, 1979). A detailed examination of that mineral indicated that it has intermediate properties between the original dachiardite and the sodium-rich dachiardite. In this paper, mineralogical properties of the Hatsuneura and the Onoyama dachiardites are given. Furthermore, based on the present and literature data, the relationship between the two dachiardites is discussed.

Experimental

Mineralogical properties of two specimens from Hatsuneura and the Onoyama mine were examined. A portion of the specimen from the latter was made available through the courtesy of Dr. Kin-ichi Sakurai, National Science Museum, Tokyo. The sample was carefully purified by hand-picking under the binocular and by washing with pure water. Chemical analysis was made by the normal wet method, except Sr and Ba which were determined by the spectrochemical analysis. Refractive indices were measured by the immersion method with Na_D-light at 20°C, and 2V, optical orientation and extinction angle were determined using the U-stage. Density was measured three times by the pycnometer method. Cell parameters were derived by a least-squares refinement from the powder diffraction data calibrated with reflections of silicon ($a=5.4306 \text{ \AA}$) as an internal standard. Oscillation photograph was taken with CuK α radiation, using tabular crystal fragments of about 0.2×0.4 mm. TG-DTA curves were simult-

aneously recorded with "Rigaku Thermoflex" (Micro TG-DTA unit) at a programmed heating rate of 10°C/min in static air atmosphere. The sample weight was 15.0 mg and α -Al₂O₃ was used as a reference material. Thermal stability was investigated by X-ray examination. The sample was heated for two hours at an interval of 150°C from room temperature to 900°C. After each heating, the sample was cooled in a desiccator to the room temperature and then its X-ray diffraction patterns were taken after a delay of 10 minutes.

Mode of occurrence

Mode of occurrence of the newly found Hatsuneura dachiardite (No. 3) is shown in Table 1, together with the data for other six dachiardite group

TABLE 1. Mode of occurrence of dachiardite group zeolites.

No.	Locality of occurrence	Mode of occurrence	Reference
1	San Piero di Campo, Elba, Italy	prismatic crystals, sometimes twinned on {110} often cyclic tetragonal, with mordenite, heulandite, stilbite, pollucite and tourmaline in pegmatite fissures in granodiorite	D'Achiardi, G. (1906), Berman, H. (1925), Gottardi, G. and Meier, W. M. (1963)
2	Onoyama mine, Kagoshima	fine prismatic crystals, with mordenite, heulandite and quartz in hydrothermal veins	Kato, A. (1973)
3	Hatsuneura, Ogasawara Islands, Japan	radiated aggregates of platy prismatic crystals, with mordenite in chalcidony veins in altered boninite* pillow lava	this study
4	Tsugawa, Niigata Pref., Japan	aggregates of fibrous crystals, with mordenite, clinoptilolite, barite and sulfide minerals in veins in altered rhyolite	Yoshimura, T. and Wakabayashi, S. (1977)
5	Alpe di Siusi, Bolzano, Italy	aggregates of thin, parallel fibers with mordenite and clinoptilolite in basalt	Alberti, A. (1975)
6	Susaki, Ogasawara Islands, Japan	radiated aggregates of prismatic fibers, with mordenite and heulandite in amygdulose of altered andesite pillow lava	Nishido, H., Otsuka, R. and Nagashima, K. (1979)
7	Altoona, Washington; Cape Lookout, Oregon; Agate Beach, Oregon; U. S. A.	small bundles of tiny blades, with mordenite, clinoptilolite and ferrierite (Altoona); erionite, mordenite, clinoptilolite and phillipsite (Cape Lookout); clinoptilolite (Agate Beach), in tholeiitic basalt	Wise, W. S. and Tschernich, R. W. (1978)

* boninite referred to Kuroda, N. and Shiraki, K. (1975) and Shiraki, K. and Kuroda, N. (1977)

zeolites reported so far. All these dachiardites are considered to have been formed from hydrothermal solution corresponding to the last stage of magmatic activity. No sedimentary dachiardite has been reported to occur in nature. Table 1 shows that the dachiardite group zeolites are closely associated with high silica zeolite such as mordenite, heulandite and/or clinoptilolite and silica minerals, but not with carbonate minerals. Therefore it may be inferred that silica activity and P_{CO_2} play an important role in the formation of dachiardite, of which appropriate condition seems to be high silica activity and low P_{CO_2} .

Chemical composition

New chemical analyses of the samples from the Onoyama mine (No. 2) and Hatsuneura (No. 3) are shown in Table 2, comparing with the literature data. Sr and Ba could be detected in neither samples. Unit cell content and balance error (Passaglia, 1970) are also given. In this Table, as in Table 1, the samples are listed in order of their increasing Si/Al ratios. Recently Bonardi (1979) re-examined the chemical composition of the Elba dachiardite (No. 1) by the energy dispersive analysis using EPMA, and revealed the presence of Cs in its sample. Nevertheless, as a whole the result by Bonardi agrees well with that reported by Gottardi (1960). Wise and Tschernich (1978) described four analyses of dachiardite from the Pacific Northwest, U.S.A. by EPMA. However, only one analysis from Altoona has been adopted for comparison in this paper, since the data for the others are incomplete. The Altoona sample (No. 7) has a remarkably high SiO_2 content of 72.62%. This exceeds the SiO_2 content of 69.58% for svetlozarite (Maleev, 1976), which is the most silicic zeolite described up to the present. Moreover, the total amount of the analysis of No. 7 shows 102.34% and its balance error is more than 10%. According to Passaglia (1970), the reliable chemical analysis indicates a balance error of less than $\pm 10\%$. Therefore, though it may be necessary to re-examine the composition of No. 7, this analysis has been employed for comparison because of the meager published analyses of the dachiardite group zeolites.

The cation content of each dachiardite is plotted in a triangular diagram with $\text{Mg}+\text{Ca}+\text{Ba}$, Na and K as its vertices (Fig. 1). The atomic percentage of potassium varies within a relatively narrow limit from 10.3% (No. 4) to 27.8% (No. 2) when compared with the distribution of the other plotted cations. Thus, the substitution of the exchangeable cations widely occurs between Ca and Na, since the Mg and Ba contents are rather low. Nos. 4, 5 and 6 described as a sodium-rich dachiardite, are characterized by the predominance of sodium ion. No. 2 has the largest Ca content. Nos. 1, 3 and 7 give the intermediate

TABLE 2. Chemical composition of dachiardite group zeolites.

	1	2	3	4	5	6	7
SiO ₂	63.00	63.63	64.53	67.38	65.72	66.50	72.26
Al ₂ O ₃	14.78	14.62	13.77	12.65	12.15	12.38	10.18
Fe ₂ O ₃	tr	0.17	0.01	0.27	0.50	0.05	0.08
MnO		tr.			tr.		
MgO	0.21	0.06	0.00	0.03	0.08	0.01	
CaO	5.10	5.76	5.60	0.51	1.65	2.10	3.28
SrO	tr.			tr.	0.01		
BaO				0.13	0.06		
Na ₂ O	1.81	0.60	2.16	5.15	4.47	3.73	1.10
K ₂ O	1.77	2.25	1.31	0.97	1.87	1.41	0.94
H ₂ O(+)	10.05	10.53	11.23	11.33	13.50	10.21	14.5
H ₂ O(-)	2.69	3.11	1.04	1.58		3.33	
Total	99.41	100.73	99.65	100.00	100.01	99.72	102.34
Numbers of ions on the basis of 48 oxygens							
Si	18.80	18.90	19.08	19.76	19.61	19.74	20.67
Al	5.20	5.12	4.80	4.37	4.27	4.33	3.43
Fe ³⁺		0.04	0.00	0.06	0.11	0.01	0.02
Si/(Al+Fe ³⁺)	3.62	3.66	3.98	4.46	4.48	4.55	5.99
Mg	0.10	0.03	0.00	0.01	0.04	0.00	
Ca	1.63	1.83	1.77	0.16	0.53	0.67	1.01
Ba				0.02	0.01		
Na	1.05	0.35	1.24	2.93	2.59	2.15	0.61
K	0.67	0.85	0.49	0.36	0.71	0.53	0.34
R ²⁺ /(R ⁺ +R ²⁺)	0.50	0.61	0.51	0.05	0.15	0.20	0.52
H ₂ O	12.68	13.51	12.10	12.63	13.43	13.41	14.2
E*	0.4	4.9	-9.1	20.7	-1.2	8.0	16.2

* balance error (%) (Passaglia, E. 1970)

1. Elba, Italy (Gottardi, G. 1960)
2. Onoyama mine, Kagoshima Pref. (analyst: H. Nishido)
3. Hatsuneura, Ogasawara Isls. (analyst: H. Nishido)
4. Tsugawa, Niigata Pref. (Yoshimura, T. and Wakabayashi, S. 1977)
5. Alpe di Siusi, Italy (Alberti, A. 1975)
6. Susaki, Ogasawara Isls. (analyst: K. Nagashima; Nishido *et al.* 1979)
7. Altoona, Washington (Wise, W. S. and Tschernich, R. W. 1978)

ratio of monovalent cations (K, Na) to divalent cations (Mg, Ca, Ba). In Fig. 2, Si atoms per unit cell are plotted against (Al+Fe³⁺) atoms per unit cell. It appears that the group of the original type dachiardite (Nos. 1 and 2) is separated from that of the sodium-rich dachiardite (Nos. 4, 5 and 6), and that

FIG. 1. Variation of atomic percentages of Ca+Ba Na and K for dachiardite group zeolites. The numbers correspond to those employed in Table 2.

FIG. 2. Relation between Si and $\text{Al} + \text{Fe}^{3+}$ atoms per unit cell for dachiardite group zeolites. The numbers correspond to those employed in Table 2.

No. 3 falls into the intermediate area between these two groups. Furthermore, No. 7 stands extremely apart from the others. The $\text{Si}/(\text{Al}+\text{Fe}^{3+})$ ratio for the dachiardite group zeolites widely varies from 3.62 to 5.99, including the exceptionally high-silica dachiardite No. 7. This result suggests that the wide range of Si-Al substitution might be expected in the series of these zeolites. In Fig. 3, the analysis of each dachiardite is plotted in terms of molecular ratios of the components $\text{Si}_{24}\text{O}_{48}$, $\text{R}^{2+}_{3.5}\text{Al}_7\text{Si}_{17}\text{O}_{48}$ and $\text{R}^+_{7}\text{Al}_7\text{Si}_{17}\text{O}_{48}$, where R^{2+} and R^+ express divalent and monovalent cations, respectively. It is noted that the sodium-rich dachiardites indicate an extremely limited range from 19.60 to 19.67 in Si content when $\text{Si}+\text{Al}+\text{Fe}^{3+}$ is equal to 24, while the substitution among their exchangeable cations, mainly between Ca and Na, occurs to some extent. Also the original type dachiardites (Nos. 1 and 2) have a similar value of about 18.8 in Si content. It appears that Ca-NaNa replacement takes place in individual members of the Si-Al substitutional series. Therefore, the dachiardite group zeolites seem to be characterized by the difference of Si/Al ratio rather than the variation of the prevalent exchangeable cations. From these facts, it may be inferred that No. 3 newly described here, is regarded as an intermediate mineral between the original type dachiardite and the sodium-rich dachiardite.

FIG. 3. Molar plot of $\text{Si}_{24}\text{O}_{48}$, $\text{R}^{2+}_{3.5}\text{Al}_7\text{Si}_{17}\text{O}_{48}$, $\text{R}^+_{7}\text{Al}_7\text{Si}_{17}\text{O}_{48}$ for dachiardite group zeolites. The numbers correspond to those employed in Table 2.

Optical properties

The optical properties of the dachiardite group zeolites are summarized in Table 3. It is recognized that refractive indices, $2V$ and extinction angle considerably vary among these samples and that the optical orientation of No. 7 remarkably differs from those of all the other. The refractive indices of the original type dachiardites (Nos. 1 and 2) are higher than those of the sodium-rich dachiardites (Nos. 4, 5 and 6), as already mentioned by Alberti (1975), Yoshimura and Wakabayashi (1977) and Nishido *et al.* (1979). Further, it is noted that the original type dachiardites show larger $2V_x$ angle and larger extinction angle than those of the sodium-rich dachiardites. Fig. 4 is a plot of the refractive indices, $2V_x$ and $c \wedge Z$ against the $R^{2+}/(R^+ + R^{2+})$ ratio for the dachiardite group zeolites. The data for No. 7 are not included here, because of the remarkable difference from the others. Fig. 4 shows that these optical properties closely relate to the $R^{2+}/(R^+ + R^{2+})$ ratio. The variation may be attributed to the prevalent exchangeable cations due to the Ca-NaNa substitution. In general, however, the optical properties of zeolites are also influenced by other factors such as the Si/Al ratio, the presence of Sr, Ce and Ba and the water content. Accordingly, the correlation between optical properties and chemical compositions of the dachiardite group zeolites can not be thoroughly explained at present because of the paucity of the data.

TABLE 3. Optical properties of dachiardite group zeolites.

	1	2	3	4	5	6	7
α	1.491	1.489	1.484	1.471	1.480	1.479	1.480
β	1.496						1.481
γ	1.499	1.494	1.489	1.477	1.482	1.482	1.485
$\gamma - \alpha$	0.008	0.005	0.005	0.006	0.002	0.003	0.005
$2V$	(+)65-73°	(+)58-62°	(+)67-70°	(-)76-80°		(-)88-92°	(+)55-60°
optical orientation	$b=X$	$b=X$	$b=X$	$b=X$	$b=X$	$b=X$	$b=Z$
extinction angle	$c \wedge Z=38^\circ$	$c \wedge Z=58^\circ$	$c \wedge Z=50^\circ$	$c \wedge Z=8^\circ$		$c \wedge Z=23^\circ$	$c \wedge X=2^\circ$
elongation	negative	negative	negative	negative	negative	negative	

1. Elba, Italy (Bonatti, S. 1942; Bonatti, S. and Gottardi, G. 1960)
2. Onoyama mine, Kagoshima Pref. (this study)
3. Hatsuneura, Ogasawara Isls. (this study)
4. Tsugawa, Niigata Pref. (Yoshimura, T. and Wakabayashi, S. 1977)
5. Alpe di Siusi, Italy (Alberti, A. 1975)
6. Susaki, Ogasawara Isls. (Nishido, H. *et al.* 1979)
7. Altoona, Washington and Cape Lookout, Oregon (Wise, W.S. and Tschernich, R.W. 1978)

FIG. 4. Variation of the optical properties, refractive index (solid lines), $2V_x$ (broken lines) and $c^A Z$ (circles) with $R^{2+}/(R^++R^{2+})$ ratio for dachiardite group zeolites. Numbers correspond to those employed in Table 3.

X-ray data

The X-ray powder diffraction patterns of Nos. 2 and 3 are essentially identical with those of the other dachiardites (Nos. 1, 4, 5 and 6). The unit cell parameters of Nos. 2 and 3 are given in Table 4, together with previous data. In spite of very limited variations in other parameters, the β angle of these minerals varies in a considerably wide range, as already noted by Nishido *et al.* (1979). The β angle is plotted against the $Si/(Al+Fe^{3+})$ ratio in Fig. 5, where No. 7 was omitted because of insufficient data. It is recognized that the β angle depends on the $Si/(Al+Fe^{3+})$ ratio, even taking account of the experimental error. Nos. 1 and 2 show smaller β angles than those of Nos. 4, 5 and

6, and No. 3 has the intermediate β angle between the two groups. The oscillation photograph around the elongation direction of fibers coinciding with b -axis indicates that all spots of the odd layer lines show diffuse streaks in both samples of Nos. 2 and 3. This fact shows the presence of stacking disorder in their frame structure. As to the sodium-rich dachiardite, the same observations were already reported by Alberti (1975), Yoshimura and Waka-

FIG. 5. Variation of β angle with $\text{Si}/(\text{Al}+\text{Fe}^{3+})$ ratio for dachiardite group zeolites. Error is represented by bar. The numbers correspond to those employed in Table 4.

TABLE 4. Cell parameters and densities of dachiardite group zeolites.

	1	2	3	4	5	6	7
$a(\text{\AA})$	18.685	18.652(5)	18.650(5)	18.641	18.647(7)	18.642(8)	18.62(2)
$b(\text{\AA})$	7.495	7.517(3)	7.516(4)	7.512	7.506(4)	7.512(3)	7.50(1)
$c(\text{\AA})$	10.26	10.274(5)	10.315(5)	10.299	10.296(4)	10.313(5)	10.24(1)
β	107°54'	108°01'(3)	108°19'(3)	108°29'	108°22'(2)	108°27'(4)	108°16'(5)
$V(\text{\AA}^3)$	1364	1370(1)	1373(1)	1368	1368(1)	1370(1)	1358
$D_{\text{meas.}}$	2.165	2.156(5)	2.165(5)	2.16	2.16(1)	2.169(5)	2.16
$D_{\text{calc.}}$	2.138	2.179	2.141	*2.14	*2.17	2.157	2.16

* calculated from data in the literature

1. Elba, Italy (Galli, E. 1965)
2. Onoyama mine, Kagoshima Pref. (this study)
3. Hatsuneura, Ogasawara Isls. (this study)
4. Tsugawa, Niigata Pref. (Yoshimura, T. and Wakabayashi, S. 1977)
5. Alpe di Siusi, Italy (Alberti, A. 1975)
6. Susaki, Ogasawara Isls. (Nishido, H. *et al.* 1979)
7. Altoona, Washington and Cape Lookout, Oregon (Wise, W.S. and Tschernich, R. W. 1978)

bayashi (1977) and Nishido *et al.* (1979). Therefore, it appears that the structural disorder is rather common through the dachiardite group zeolites. The measured and calculated densities of the seven samples are shown in Table 4. It is obvious that the variation in the measured density is negligible.

Thermal properties

The TG-DTA curves of Nos. 2, 3 and 6 are given in Fig. 6. The TG curve of No. 2 indicates three steps of the weight loss due to dehydration; the initial gradual weight loss of 7.3% below 250°C, the second weight loss of 4.2% between 250 and 405°C, and the final slight weight loss of 1.9% between 405 and 600°C. The DTA curve is characterized by the following three endothermic peaks corresponding to the TG curve; a large broad peak around 110°C,

FIG. 6. Simultaneous TG and DTA curves of samples 2,3 and 6.

followed by a small but distinct peak at about 270°C, and a small peak at 420°C. Bonatti and Gottardi (1960) reported the DTA curve of No. 1 which represents three endothermic peaks at about 140, 310 and 470°C. Although the temperatures of the three peaks of No. 1 are relatively higher than those of No. 2, the two curves show very similar patterns. The TG curve of No. 6 gives a gradual weight loss of 13.4% in a wide temperature range from room temperature to 600°C. The DTA curve shows a large broad endothermic peak with the maximum at about 120°C having a shoulder at 235°C. These curves were already reported by Nishido *et al.* (1979), and they are similar to the curve of No. 4 obtained by Yoshimura and Wakabayashi (1979), except the very small exothermic peak at 920°C of No. 4. No. 3 is characterized by a large broad endothermic peak with the maximum at 120°C having a broad shoulder at 250°C, corresponding to the continuous dehydration of 12.1% over a wide temperature range from room temperature to 600°C. Thus the TG-DTA data for the intermediate dachiardite is in good agreement with that for the sodium-rich dachiardite.

In order to investigate the thermal stability, the X-ray examination of Nos. 2, 3 and 6 were carried out after heating. The change in *d*-spacings and intensities of the (200) and (220) reflections are shown in Fig. 7. In the case of No. 2, the *d*-spacings and intensities of the (200) and (220) reflections were unchanged up to 150°C. At 300°C the *d*-spacings of both reflections showed a slight contraction with the decrease in intensities. With increasing temperature up to 450°C the abrupt change of the reflections was observed. Such discontinuous change between 300 and 450°C seems to be correlated with the endothermic effect at 420°C in the DTA curve. Thereafter these reflections gradually weakened up to 750°C and finally disappeared at 900°C. As to No. 6 (Nishido *et al.*, 1979), both the (200) and (220) reflections were kept constant in *d*-spacing and intensity until 300°C. Above that temperature the positions of two reflections remained constant up to 750°C, but these intensities gradually decreased, and disappeared at 900°C. A similar observation on No. 4 was reported by Yoshimura and Wakabayashi (1977). The above results show that the structural contraction on heating is more remarkable for the original type dachiardite than for the sodium-rich one. This suggests that the latter has a greater resistance on heating than the former.

The structural change of the intermediate dachiardite (No. 3) on heating occurred in the same manner as that of No. 2. However, such a behaviour did not correspond to the DTA curve, in which No. 3 was very similar to No. 6. This discrepancy can not be explained yet.

FIG. 7. Changes of d -spacings and intensities of (200) and (220) reflections of samples 2 and 6.

Discussion

Recently, the sodium-rich dachiardite has been approved as a new zeolite in terms of "Sodium analogue of dachiardite" (Fleischer *et al.*, 1979). As indicated above, the sodium-rich dachiardite is distinguished from the original type dachiardite by the following; 1) its higher $\text{Si}/(\text{Al} + \text{Fe}^{3+})$ ratio, 2) its lower $\text{R}^{2+}/(\text{R}^+ + \text{R}^{2+})$ ratio, 3) its lower refractive indices, 4) its smaller $2V_x$ angle and smaller extinction angle, and 5) its larger β angle. In addition, Alberti (1975) pointed out that the sodium-rich dachiardite is characterized by the evident disorder in the structure. This study, however, revealed that the structural disorder can be commonly recognized through the dachiardite group zeolites. It suggests that the existence of the structural disorder does not discriminate between the original type and the sodium-rich dachiardite. The X-ray powder

data for them are too similar to distinguish them, and their cell parameters show nearly constant values except β angles. Hence it seems reasonable to bear an isomorphous relationship between their structures.

This study indicated that the dachiardite newly found from Hatsuneura is an intermediate zeolite between the original type and the sodium-rich dachiardite with respect to chemical and physical properties. It suggests that a continuous isomorphous substitution may be expected in the series of the dachiardite group zeolites. More occurrences of intermediate zeolites will be found to fill the apparent compositional gap in the future.

Acknowledgement—The authors wish to express their sincere thanks to Dr. Kin-ichi Sakurai, National Science Museum, Tokyo for the kind advice and criticism during the course of this study and for generously providing the specimen from the Onoyama mine. Thanks are also due to Prof. Kozo Nagashima, Tsukuba University for chemical analysis and useful discussion. They also are much indebted to Prof. Naoya Imai and Prof. Sadao Tsutsumi, Waseda University for their encouragement and supplying the facilities during this work.

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Received June 29, 1981.