NEW MINERALS, CLASSIFICATION, AND NOMENCLATURE OF MINERALS

Dachiardite-K, (K₂Ca)(Al₄Si₂₀O₄₈) · 13H₂O, a New Zeolite from Eastern Rhodopes, Bulgaria¹

N. V. Chukanov^{*a*, *}, S. Encheva^{*b*}, P. Petrov^{*b*}, I. V. Pekov^{*c*}, D. I. Belakovskiy^{*d*}, S. N. Britvin^{*e*}, and S. M. Aksenov^{*e*, *f*}

^aInstitute of Problems of Chemical Physics, Russian Academy of Sciences, Chernogolovka, Moscow oblast, 142432 Russia ^bEarth and Man National Museum, 4 Cherni Vruh boulevard, Sofia 1421, Bulgaria

^cFaculty of Geology, Moscow State University, Moscow, 119991 Russia

^d Fersman Mineralogical Museum of Russian Academy of Sciences, Leninsky pr. 18–2, Moscow, 119071 Russia

^e Faculty of Geology, St. Petersburg State University, Universitetskaya nab. 7/9, St. Petersburg, 199034 Russia

^fInstitute of Crystallography, Russian Academy of Sciences, Leninsky pr. 59, Moscow, 117333 Russia

*e-mail: chukanov@icp.ac.ru

Received October 13, 2015

Abstract—Dachiardite-K (IMA No. 2015-041), a new zeolite, is a K-dominant member of the dachiardite series with the idealized formula $(K_2Ca)(Al_4Si_{20}O_{48}) \cdot 13H_2O$. It occurs in the walls of opal-chalcedony veinlets cutting hydrothermally altered effusive rocks of the Zvezdel paleovolcanic complex near the village of Austa, Momchilgrad Municipality, Eastern Rhodopes, Bulgaria. Chalcedony, opal, dachiardite-Ca, dachiardite-Na, ferrierite-Mg, ferrierite-K, clinoptilolite-Ca, clinoptilolite-K, mordenite, smectite, celadonite, calcite, and barite are associated minerals. The mineral forms radiated aggregates up to 8 mm in diameter consisting of split acicular individuals. Dachiardite-K is white to colorless. Perfect cleavage is observed on (100). $D_{\text{meas}} = 2.18(2)$, $D_{\text{calc}} = 2.169 \text{ g/cm}^3$. The IR spectrum is given. Dachiardite-K is biaxial (+), $\alpha = 1.477$ (calc), $\beta = 1.478(2)$, $\gamma = 1.481(2)$, $2V_{\text{meas}} = 65(10)^\circ$. The chemical composition (electron microprobe, mean of six point analyses, H₂O determined by gravimetric method) is as follows, wt %: 4.51 K₂O, 3.27 CaO, 0.41 BaO, 10.36 A12O3, 67.90 SiO2, 13.2 H2O, total is 99.65. The empirical formula is H_{26,23}K_{1,71}Ca_{1,04}Ba_{0,05}Al_{3,64}Si_{20,24}O₆₁. The strongest reflections in the powder X-ray diffraction pattern [d, A, (I, %), (hkl)] are: 9.76 (24) (001), 8.85 (58) (200), 4.870 (59) (002), 3.807 (16) (202), 3.768 (20) (112, 100) 020), 3.457 (100) (220), 2.966 (17) (602). Dachiardite-K is monoclinic, space gr. C2/m, Cm or C2; the unit cell parameters refined from the powder X-ray diffraction data are: a = 18.670(8), b = 7.511(3), c = 10.231(4) Å, $\beta = 107.79(3)^\circ$, V = 1366(1) Å³, Z = 1. The type specimen has been deposited in the Earth and Man National Museum, Sofia, Bulgaria, with the registration number 23927.

Keywords: dachiardite-K, zeolite, new mineral species, Zvezdel paleovolcanic complex, Eastern Rhodopes, Bulgaria

DOI: 10.1134/S1075701516080079

INTRODUCTION

Despite zeolites of the dachiardite series $A_{4-5}(Al_{4-5}Si_{20-19}O_{48}) \cdot 13H_2O$, with $Ca_{0.5}$, Na, and K as species-defining extra-framework *A* cations, are comparatively rare in nature, their mineralogy and crystal chemistry are discussed in numerous publications (D'Achiardi, 1906; Berman, 1925; Gottardi, 1960; Bonatti and Gottardi, 1960; Gottardi and Meier, 1963; Alberti, 1975; Maleev, 1976; Wise and Tschernich, 1976; Yoshimura and Wakabayashi, 1977;

666

Bonardi, 1979; Demartin and Stolcis, 1979; Bonardi et al., 1981; Nishido and Otsuka, 1981; Gellens et al., 1982; Vezzalini, 1984; Postl and Moser, 1986; Bargar et al., 1987; Quartieri et al., 1990; Rychly et al., 1996; Vattuone et al., 2006; Mel'chakova et al., 2007; Pauliš et al., 2014). Partial interest in dachiardite results from its structural relationship to mordenite, which is widepore zeolite with pronounced ion-exchange properties (Gottardi, 1960; Barrer and Klinovski, 1974).

The crystal structure of dachiardite is based on a 3D tetrahedral framework consisting of chains of fiveand four-membered aluminosilicate rings (Gottardi and Meier, 1963; Smith, 1963). Until recently, only two members of this solid solution series, dachiardite-Ca and dachiardite-Na, were regarded as individual

¹ A new mineral dachiardite-K and its name was approved by the Commission on New Minerals, Nomenclature, and Classification of Minerals, International Mineralogical Association, August 10, 2015, IMA no. 2015-041.



Fig. 1. Geological sketch map of the area in the vicinity of Zvezdel village (Georgiev et al., 1997). (*I*) Andesite and basaltic andesite flows, (*2*) andesite and basaltic andesite lava breccia, (*3*) epiclastic rocks, (*4*) type locality of dachiardite-K

mineral species (Coombs et al., 1997). In this article, we report a new mineral species, dachiardite-K, which is a K-dominant member of this zeolite subgroup.

The type specimen has been deposited in the Earth and Man National Museum, Sofia, Bulgaria, with the registration number 23927.

OCCURRENCE

Dachiardite-K has been found in hydrothermally altered rocks of the Zvezdel paleovolcanic complex in the Eastern Rhodopes, Bulgaria, outcropped 1 km northwest of the village of Zvezdel and 0.5 km east of the village of Austa (Fig. 1) near the town of Momchilgrad.

The Zvezdel paleovolcanic complex is predominantly composed of pyroclastic rocks and numerous lava rocks forming flows, covers, and cupola. The rocks composing the Zvezdel paleovolcano are referred to high-K branch of the calc—alkaline series. Volcanic rocks are predominantly basaltic andesite, andesite, and occasional basalt. The central part of the the volcanic edifice predominantly is made up of massive and brecciated lava rocks, while epiclastic rocks are in the margin of the volcano. These volcanic rocks are intruded by monzonite. Effusive and intrusive rocks are cut by dacite and rhyolite dikes (Raicheva, 2013).

The K–Ar age of the effusive rocks is 31.5 Ma, which corresponds to the Lower Oligocene. Numerous veins containing late hydrothermal minerals crosscut the volcanic rocks. In the outcrop where dachiardite-K was found, numerous zeolite–chalced-ony veinlets crosscut epiclastic rocks.

A flow a few meters thick overlaps epiclastic rocks north of this outcrop.

Dachiardite-K crystallized from hydrothermal solutions probably owing to low-grade metamorphism of volcanic rocks. It is associated with chalcedony, opal, dachiardite-Ca, dachiardite-Na, ferrierite-Mg, ferrierite-K, clinoptilolite-Ca, clinoptilolite-K, mordenite, smectite, celadonite, calcite, and barite.

MORPHOLOGY AND PHYSICAL PROPERTIES

Dachiardite-K occurs on the walls of veinlets predominantly composed of chalcedony and opal (Fig. 2). It forms radiated aggregates up to 8 mm in diameter consisting of slightly flattened acicular split individuals (Fig. 3).

The mineral is white, some individuals are colorless transparent, and the luster is vitreous. Dachiardite-K is brittle, its Mohs hardness is 4, cleavage is perfect parallel to (100), fracture is stepped. The density measured by floatation in heavy liquids is 2.18(2) g/cm³; the calculated density is 2.169 g/cm³.

Dachiardite-K is optically biaxial, positive, $\beta = 1.478(2)$, $\gamma = 1.481(2)$; $2V_{meas} = 65(10)^{\circ}$. The value of α was not measured because of perfect cleavage of the mineral. This value estimated from the average β , γ , and 2V values is 1.477. Dispersion is distinct, r < v. Dachiardite is nonpleochroic. The Y axis coincides with b, which is the direction of elongation of crystals. The perfect cleavage plane coincides with the (YZ) plane, in which dachiardite-K shows straight extinction.



Fig. 2. Opal-chalcedony veinlet with zeolites in walls.

The IR spectrum of the dachiardite-K powdered sample prepared as a pellet pressed with KBr (Fig. 4a) was measured using a Bruker Optics ALPHA FTIR spectrometer within the wavenumber range $360-3800 \text{ cm}^{-1}$ at a resolution of 4 cm^{-1} with 16 scans. A pure KBr disc was used as a reference. The IR spectra of dachiardite-Na and dachiardite-Ca from the same locality were measured for comparison under the same conditions (Fig. 4).

The positions (cm⁻¹) and assignment of the bands in the IR spectrum of dachiardite-K are as follows (s is strong band, w is weak band, and sh is shoulder): 3629, 3450, 3250sh (O–H stretching vibrations of H₂O molecules), 1640w (bending vibrations of H₂O molecules), 1215s, 1063s (stretching vibrations of the tetrahedral framework), 780w, 726w, 665sh, 631, 570sh, 558, 523 (mixed vibrations of the tetrahedral framework), and 442s (lattice modes involving Si–O–Si bending vibrations). The IR spectrum of dachiardite-K is close to those of dachiardite-Ca and dachiardite-Na.

CHEMICAL COMPOSITION

The chemical compositions of dachiardite-K and associated zeolites were measured on a Tescan Vega II XMU scanning electron microscope equipped with an INCAx-sight EDS operating at an accelerating voltage of 20 kV, current intensity of 190 nA, and beam diameter of 180 nm and on an Oxford INCA Wave 700 electron microprobe operating at an accelerating voltage of 20 kV, current intensity of 20 nA, and beam diameter of 3 μ m. The H₂O content was determined by the thermogravimetric method: the weight loss after ignition at 700°C was 13.2(5)%. The chemical composition in wt % is given in Table 1.

The empirical formula calculated on the basis of 61O atoms is $H_{26.23}K_{1.71}Ca_{1.04}Ba_{0.05}Al_{3.64}Si_{20.24}O_{61}$. The idealized formula is (K₂Ca) (Al₄Si₂₀O₄₈) \cdot 13H₂O.

Correct determination of the chemical composition and physical properties of dachiardite-K is confirmed by the "superior" compatibility calculated from the Gladstone–Dale equation: $(1 - K_p/K_c) = 0.017$.

X-RAY CRYSTALLOGRAPHY

The powder X-ray diffraction data of dachiardite-K (Table 2) were collected on a Rigaku R-AXIS Rapid II single crystal diffractometer equipped with a cylindrical IP detector (Debye–Scherrer geometry, d = 127.4 mm, Co K_{α} radiation). All reflections are well indexed in the monoclinic (space gr. C2/m, Cm or C2) unit cell with parameters refined from the powder X-ray diffraction data as follows a = 18.670(8), b = 7.511(3), c = 10.231(4) Å, $\beta = 107.79(3)^{\circ}$, V = 1366(1) Å³, Z = 1.



Fig. 3. Spherical aggregate of dachiardite-K in massive chalcedony.

2016



Fig. 4. IR spectra of (a) dachiardite-K, (b) dachiardite-Na, and (c) dachiardite-Ca. All three samples are from the same deposit near Austa village, Eastern Rhodopes, Bulgaria.

The single-crystal X-ray data for dachiardite-K were collected on an Xcalibur Oxford Diffraction CCD diffractometer operating with Mo K_{α} radiation. The calculated unit cell parameters are as follows: a = 18.75(10), b = 7.53(2), c = 10.3(1) Å, $\beta = 109(2)^{\circ}$, V = 1379(20) Å³. An X-ray structural study of dachiardite-K failed due to the absence of suitable single crystals: the mineral was observed only as aggregates consisting of thin, divergent individuals. As a result, reflections in the single-crystal X-ray diffraction pattern are strongly broadened.

Zeolites were identified (in terms of their belonging to a particular structural type) from powder X-ray diffraction data collected on a Bruker D2 Phaser diffractometer with applications in the Bragg–Brentano geometry, operating with CuK_{α} radiation.

DISCUSSION

Natural zeolites of the dachiardite solid solution series are characterized by widely variable contents of extraframework cations, especially those of Na and Ca. Mel'chakova et al. (2007) determined dachiardite-Na, $Na_4(Al_4Si_{20}O_{48})$ 13H₂O, dachiardite-K, $K_4(Al_4Si_{20}O_{48})$ $13H_2O$, and dachiardite-Ca, $Ca_2(Al_4Si_{20}O_{48}) \cdot 13H_2O$ as endmembers of this series and estimated their thermodynamic parameters. According to the approved nomenclature of the zeolite group minerals, mineral species of this solid solution series, like other isostructural zeolites, are defined in accordance with the predominant extraframework cation: "Separate species are recognized in topologically distinctive compositional series in which different extra-framework cations are the most abundant in atomic proportions" (Coombs et al., 1997).

Component	Average content	Range of content	Standard deviation	Reference material
K ₂ O	4.51	3.95-4.89	0.30	Microcline
CaO	3.27	2.93-3.54	0.19	Wollastonite
BaO	0.41	0.28 - 0.60	0.41	$BaSO_4$
Al_2O_3	10.36	10.03-10.68	0.23	Albite
SiO ₂	67.90	67.47-68.51	0.39	SiO ₂
H ₂ O	13.2(5)			
Total	99.65			

Table 1. Chemical composition (wt %) of dachiardite-K based on six point analyses

Contents of other elements with atomic numbers >8 are below their detection limits.

CHUKANOV et al.

Table 2.	Powder	X-ray	diffraction	data	for	dachiar	dite-K	and	dachiar	dite-Ca

Dachiardite-K (this study)		Dachiardite structure da	e-Ca (calculated from ta by Vezzalini, 1984)	hkl	
I _{obs}	d _{obs}	$d_{ m calc}$	I_{calc}^*	$d_{ m calc}$	
24	9.76	9.742	8	9.752	001
58	8.85	8.889	100	8.887	200
9	6.88	6.919	65	6.924	110
3	5.999	5.987	31	5.994	<u>1</u> 11
4	5.319	5.349	10	5.352	111
13	4.985	4.957	35	4.965	$\overline{2}02$
59	4.870	4.871	52	4.876	002
7	4.630	4.655, 4.610	5, 6	4.654, 4.613	$\overline{3}11, \overline{4}01$
2	4.430	4.444	3	4.444	400
13	3.949	3.936	34	3.941	$\overline{4}02$
16	3.807	3.809	42	3.810	202
20	3.768	3.777, 3.756	16, 11	3.779, 3.759	112, 020
5	3.623	3.645	9	3.644	401
100	3.467	3.459	99	3.462	220
3	3.322	3.338	17	3.340	511
5	3.245	3.247	4	3.250	003
2	3.194	3.213	53	3.214	510
0.5	3.117	3.114, 3.112	5,4	3.119, 3.109	403, 601
17	2.966	2.965	25	2.968	602
11	2.861	2.875	26	2.870	402
6	2.719	2.717	11	2.720	4 22
7	2.665	2.674	13	2.676	222
3	2.573	2.556	10	2.560	$\overline{2}04$
1	2.490	2.511, 2.479	2,4	2.512, 2.483	$\overline{7}11, \overline{4}04$
3	2.454	2.458	7	2.459	712
1	2.406	2.408, 2.397	2, 6	2.412, 2.400	$\overline{3}14, \overline{4}23$
2	2.292	2.307, 2.306, 2.273	4, 4, 4	2.308, 2.308, 2.276	403, 330, 713
3	2.174	2,187, 2.172, 2.169	2, 1, 1	2.186, 2.174, 2.171	331, 132, 803
4	2.137	2.149	0.5	2.149	621
5	2.047	2.043, 2.038	2, 5	2.045, 2.041	$024, \overline{2}05$
5	1.984	1.989	3	1.989	<u>9</u> 12
6	1.967	1.972, 1.966	2, 3	1.971, 1.966	314, 423
4	1.935	1.936, 1.936, 1.931	2, 2, 3	1.939, 1.937, 1.932	$\overline{1}$ 15, 531, 133
4	1.921	1.927, 1.919, 1.917	3, 2, 0.5	1.927, 1.922, 1.916	$622, \overline{6}05, 603$
11	1.874	1.878	11	1.879	823
4	1.840	1.844, 1.837	1, 0.5	1.845, 1.839	041, 240
3	1.784	1.783, 1.780	7, 7	1.784, 1.784	730. 914
4	1.771	1.778, 1.776	7, 7	1.777, 1.777	$10.0.0, \overline{1}34$
1	1.729	1.730, 1.724	1, 1	1.731, 1.725	$025, \overline{5}34$
1	1.704	1.707, 1.702	2, 1	1.707, 1.703	623, 406

GEOLOGY OF ORE DEPOSITS Vol. 58 No. 8 2016

Dachiardite-K (this study)		Dachiardite structure da	e-Ca (calculated from ta by Vezzalini, 1984)	hkl	
I _{obs}	d _{obs}	d _{calc}	I_{calc}^*	d _{calc}	
1	1.669	1.669, 1.662	2, 3	1.670, 1.664	441, 316
0.5	1.648	1.650, 1.644	1, 1	1.650, 1.646	604, 243
1	1.625	1.624, 1.624	2,2	1.625, 1.625	$\overline{1}1.1.3,006$
2	1.586	1.586, 1.583	2, 3	1.588, 1.584	$\overline{6}42,334$
1	1.571	1.572, 1.569	1, 2	1.573, 1.570	442, 732
1	1.559	1.557	2	1.559	806
1	1.552	1.552, 1.550	3, 3	1.553, 1.553	$\overline{9}33, \overline{4}26$
1	1.540	1.542, 1.537	2, 1	1.544, 1.538	$\overline{2}26$, 12.0.3
0.5	1.520	1.519	3	1.518	10.2.1
0.5	1.508	1.511, 1.507	2, 1	1.511, 1.507	624, 714
0.5	1.489	1.490, 1.487, 1.486	1, 1, 1	1.492, 1.489, 1.486	026, 044, 823
0.5	1.480	1.482	1	1.482	425

Table 2. (Contd.)

*Only reflections with intensities $\geq 0.5\%$ are given.

Table 3. Comparative data for dachiardite-K, dachiardite-Ca and dachiardite-Na

Mineral	Dachiardite-K*	Dachiardite-Ca	Dachiardite-N	
Formula	$(K_2Ca)(Al_4Si_{20}O_{48})$ ·	$(Ca_{1.5}K)(Al_4Si_{20}O_{48})$ ·	$(Na,K)_{3}Ca_{0.5}(Al_{4}Si_{20}O_{48})$ ·	
	13H ₂ O	13H ₂ O	13H ₂ O	
Crystal system	Monoclinic	Monoclinic	Monoclinic	
Space group	<i>C</i> 2 <i>/m</i> , <i>Cm</i> or <i>C</i> 2	<i>C</i> 2/ <i>m</i> or <i>Cm</i>	<i>C</i> 2/ <i>m</i> or <i>Cm</i>	
<i>a</i> , Å	18.670	18.636-18.676	18.641-18.67	
b, Å	7.511	7.505-7.518	7.488-7.512	
c, Å	10.231	10.239-10.274	10.282-10.299	
β, °	107.79	107.87-108.00	108.37-108.74	
$V, Å^3$	1366	1362-1370	1361-1368	
Strong lines of powder X-ray	9.76 (24)	8.887 (100)	8.88 (80)	
diffraction pattern: d , Å (I , %);	8.85 (58)	6.924 (65)	6.92 (80)	
	4.870 (59)	4.876 (52)	4.86 (60)	
	3.807 (16)	3.941 (34)	3.75 (70)	
	3.768 (20)	3.810 (42)	3.45 (100)	
	3.457 (100)	3.462 (99)	3.38 (60)	
	2.966 (17)	3.214 (53)	3.20 (60)	
Optical data	Biaxial (+)	Biaxial (+)	Biaxial $(+)$ or $(-)$	
	$\alpha = 1.477$ (calc)	$\alpha = 1.484 - 1.494$	$\alpha = 1.471 - 1.490$	
	$\beta = 1.478$	$\beta = 1.484 - 1.496$	$\beta = 1.475 - 1.496$	
	$\gamma = 1.481$	$\gamma = 1.489 - 1.500$	$\gamma = 1.476 - 1.499$	
	$2V = 65^{\circ}$	$2V = 58 - 73^{\circ}$	$2V = 55 - 142^{\circ}$	
Density, g/cm ³	2.18	2.165	2.14-2.17	
References	This study	Vezzalini, 1984; Coombs et al., 1997; Bonardi, 1979; Bargar et al., 1987	Bonardi et al., 1981; Bargar et al., 1987; Coombs et al., 1997; Nishido, Otsuka, 1981; Alberti, 1975	

*X-ray crystallographic data by analogy with structurally studied dachiardite-Ca.



Fig. 5. Triangular diagrams in terms of Na, K and Ca for (a) dachiardite, (b) clinoptilolite, and (c) ferrierite from Austa, Eastern Rhodopes, Bulgaria.

The mineral with the composition $Na_{2.98}K_{0.38}Sr_{0.01}Ca_{0.01}(Al_{3.59}Si_{20.47}O_{48})$ · 12.43H₂O close to the Na endmember of the dachiardite solid solution series was found in dawsonite-bearing silico-carbonatite discovered in the Francon Quarry in Que-



Fig. 6. Triangular diagrams in terms of K, Mg and Ca + Na for ferrierite from Austa, Eastern Rhodopes, Bulgaria.

bec, Canada (Bonardi et al., 1981). The dachiardite richest in Ca and comparatively depleted in Si was identified in hydrothermally altered Pleistocene effusive rocks from Yellowstone National Park, United States (Bargar et al., 1987). The empirical formula of that sample is $Ca_{2.66}Na_{0.05}K_{0.01}(Al_{5.44}Si_{18.58}O_{48}) \cdot nH_2O$.

Gottardi and Meier (1963) studied the crystal structure of Ca-dominant dachiardite $Ca_{1.6}Na_{1.1}K_{0.7}Mg_{0.1}(Al_{5.2}Si_{18.8}O_{48}) \cdot 12.7H_2O$ from the island of Elba, Italy, and demonstrated the structural relation of this mineral to mordenite. The frameworks of both types are based on a tetrahedral chain consisting of alternated couples of five-membered rings and single four-membered rings; however, neighboring chains in dachiardite and mordenite are linked in a different mode. In another sample with a solved structure from Hokiya-dake in Nagano, Japan, two acentric configurations are present in equal proportions, forming a statistical C2/m symmetry, whereas its true symmetry corresponds to space gr. Cm (Quartieri et al., 1990; Coombs et al., 1997).

Dachiardite enriched in K is rare in nature. It should be noted that the variety of dachiardite-Ca enriched in K (3.00 wt % K_2O , empirical formula $Ca_{1.22}K_{1.11}Na_{0.48}Mg_{0.13}(Al_{3.51}Fe_{0.15}Si_{20.19}O_{48}) \cdot 10.59H_2)$ was described for the first time just from Austa as the new zeolite svetlozarite (Maleev, 1976). Dachiardite-Na containing 3.18 wt % K_2O was identified in hydrothermal assemblages of the Yellowstone National Park (Bargar et al., 1987). The empirical formula of that sample is $Na_{1.24}K_{1.18}Ca_{0.96}Mg_{0.03}Mn_{0.02}(Al_{4.66}Fe_{0.02}Si_{19.39}O_{48}) \cdot nH_2O$. In another sample from the same district, 2.77 wt % K_2O was determined (Bargar, Beeson, 1981), but the composition given in that paper is most likely wrong, because the formula coefficient of Al is much greater than the total charge of extraframework cations.

The other large extraframework cations Ba and Sr are less important than K in the composition of typical

dachiardite. Dachiardite-Na, dachiardite-K, and dachiardite-Ca from Austa are Ba-bearing varieties of these minerals; however, the BaO content in them is comparatively low, ranging from 0.3 to 1.1 wt %, whereas in associated clinoptilolite-K and clinoptilolite-Ca, it varies from 1.2 to 2.7 wt %, and in ferrierite from the same locality, the BaO content is in the range of 1.0-2.7 wt %.

The proportions of Na, K, and Ca in zeolites from Austa are shown in Fig. 5. In addition, the proportions of K, Mg, and Ca + Na in ferrierite are shown in Fig. 6 (in this case, Ca and Na are regarded together taking into account their close ion radii and comparatively low concentrations in zeolites of the ferrierite solid solution series from Austa).

The comparative data for zeolites of the dachiardite solid solution series are given in Table 3. As follows from these data, these minerals nearly do not differ in physical properties.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research (project no. 14-05-00190-a). The equipment of the St. Petersburg State University X-Ray Diffraction Methods Resource Center was used.

REFERENCES

Alberti, A., Sodium-rich dachiardite from Alpe di Siusi, Italy, *Contrib. Mineral. Petrol.*, 1975, vol. 49, pp. 63–66.

Bargar, K.E., Erd, R.C., Keith, T.E.C., and Beeson, M.H., Dachiardite from Yellowstone National Park, Wyoming, *Can. Mineral.*, 1987, vol. 25, pp. 475–483.

Barrer, R.M. and Klinovski, J., Ion exchange in mordenite, *J. Chem. Soc., Faraday Trans. 1: Phys Chem. Condens. Phas.*, 1974, vol. 70, pp. 2362–2367.

Berman, H., Notes on d'achiardite, Am. Mineral., 1925, vol. 10, pp. 421–428.

Bonardi, M., Composition of type dachiardite from Elba: a re-examination, *Mineral. Mag.*, 1979, vol. 43, pp. 548–549. Bonardi, M., Roberts, A.C., Sabina, A.P., and Chao, G.Y., Sodium-rich dachiardite from the Francon Quarry, Montreal Island, Quebec, *Can. Mineral.*, 1981, vol. 19, pp. 285–289.

Bonatti, S. and Gottardi, G., Dati ottici e strutturali sulla dachiardite, *Periodico di Mineralogia*, 1960, vol. 29, pp. 103–108.

Coombs, D.S., Alberti, A., Armbruster, T., Artioli, G., Colella, C., Galli, E., Grice, J.D., Liebau, F., Mandarino, J.A., Minato, H., Nickel, E.H., Passaglia, E., Peacor, D.R., Quartieri, S., Rinaldi, R., Ross, M., Sheppard, R.A., Tillmanns, E., and Vezzalini, G., Recommended nomenclature for zeolites minerals—report of the subcommittee on zeolites of the international mineralogical association, commission on new minerals and mineral names, *Can. Mineral.*, 1997, vol. 35, pp. 1571–1606.

Demartin, F. and Stolcis, T., Nuovo giacimento di dachiardite in Val di Fassa, *Riv. Mineral. Ital.*, 1979, no. 4, pp. 93–95. Gellens, L.R., Price, G.D., and Smith, J.V., The structural relation between svetlozarite and dachiardite, *Mineral. Mag.*, 1982, vol. 45, pp. 157–161. Georgiev, V., I., Bratvanov G., Gerdzhikov S., Klimova R., Kiosovski R., Marinova I., Metodiev N., Milovanov P., Nikova L., Pavlov Al., and Sirakov D. *Report of Geology Mapping in 1 : 25000 Scale and Geomorphology Mapping in 1 : 100000 Scale with a Complex Evaluation of Mineral Resources of Part of the Eastern Rhodopes the Towns of Momchilgrad and Dzhebel and the Village of Zvezdel, Carried out during 1997*, Sofia: Geology and Geophysics, 1997.

Gottardi, G., Sul dimorfismo mordenite-dachiardite, *Period. Mineral*, 1960, vol. 29, pp. 183-191.

Gottardi, G. and Meier, W.M., The crystal structure of dachiardite, *Z. Kristallogr.*, 1963, vol. 119, pp. 53–64.

Kiseleva, I. and Ogorodova, L., A study of dachiardite, a natural zeolite of the mordenite group, *Russ. J. Phys. Chem. A*, 2007, vol. 81, pp. 1748–1750.

Maleev, M.N., Svetlozarite, a new high-silica zeolite, *Zap. Ross. Mineral O-va*, 1976, vol. 105, no. 4, pp. 449–453.

Mel'chakova L., Kiseleva I., and Ogorodova L. A study of dachiardite, a natural zeolite of the mordenite group. *Russ. J. Phys. Chem. A.*, 2007, vol. 81, pp. 1748–1750.

Nishido, H. and Otsuka, R., Chemical composition and physical properties of dachiardite group zeolites, *Mineral. J.* (*Japan*), 1981, vol. 10, pp. 371–384.

Pauliš, P., Hrůzek, L., Janeček, O., Sejkora, J., Maliková, R., and Fedyuk, F., Dachiardite-Ca and associated mineralization from Doubice-Vápenka near Krásná Lípa (Czech Republic), *Bull. Mineral.-Petrol. Oddil. Narod. Muz.*, 2014, vol. 22, p. 1.

Postl, W. and Moser, B., Arsenkies sowie weitere daten uber dachiardit vom tanzenbergtunnel bei kapfenberg, steiermark, *Mitteilungen der Abteilung fur Mineralogie am Landesmuseum Joanneum*, 1986, vol. 54, pp. 23–26.

Quartieri, S., Vezzalini, G., and Alberti, A., Dachiardite from Hokiya-dake: evidence of a new topology, *Eur. J. Mineral.*, 1990, vol. 2, pp. 187–194.

Raicheva, R., *The Role of Magma Mixing in the Petrologic Evolution of the Zvezdel Palaeovolcano* Phd. Thesis. Sofia: Bulgarian Academy of Sciences, Institute of Geology Strashimir Dimitrov, Geochemistry and Petrology Division, 2013.

Rychly, R., Veselovsky, F., and Ondruš, P., *Dachiardite from Svojanov, Czech Republic, Scripta Fac. Sci. Nat. Univ. Masaryk. Brno: Faculty of Geology*, 1996, vol. 26, pp. 42–43. Smith, J.V., Structural classification of zeolites, *Mineral. Soc. Am., Sp. Pap., 1. IMA Papers, Third General Meeting*, 1963, pp. 281–290.

Vattuone, M.E., Latorre, C.O., and Leal, P.R., Mineralogy and paragenesis of Ca-dachiardite in Cretaceous zeolitized volcanic rocks, Esquel, Chubut, Argentinian Patagonia, *Revista Geol. Chile*, 2006, vol. 33, pp. 161–176.

Vezzalini, G., A refinement of Elba dachiardite: opposite acentric domains simulating a centric structure, *Z. Kristallogr.*, 1984, vol. 166, pp. 63–71.

Wise W.S. and Tschernich R.W., Dachiardite-bearing zeolite assemblages in the Pacific Northwest, in *Natural Zeolites Occurrence, Properties, Use*, Sand L.B. and Mumpton F. Eds., Oxford and New York: Pergamon Press, 1976, pp. 105–111.

Yoshimura, T. and Wakabayashi, S., Na-dachiardite and associated high-silica zeolites from Tsugawa, Northeast Japan, *Sci. Rept. Niigata Univ., Ser. E, Geol. Mineral.*, 1977, vol. 4, pp. 49–65.

Translated by I. Baksheev