YUGAWARALITE FROM THE A.E. FERSMAN OUTCROP OF THE OSHURKOVSKOE APATITE DEPOSIT, BURYATIYA, RUSSIA

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During research on mineralization of the A.E. Fersman outcrop, Oshurkovskoe apatite deposit (Buryatia), the following Ca-zeolites were identified: yugawaralite $Ca[AlSi_3O_8]_2{\cdot}4H_2O$, stellerite $Ca_4[Al_2Si_7O_{18}]_4{\cdot}28H_2O$, laumontite $Ca[AlSi_2O_6]_2{\cdot}4H_2O$, heulandite-Ca $Ca(Ca,Na)_{2\text{-}3}Al_3(Al,Si)_2Si_{13}O_{36}{\cdot}12H_2O$, and stilbite $(Na,K,Ca)_9\,[Al_9Si_{27}O_{72}]{\cdot}28H_2O$. This is the first time that yugawaralite has been found in Russia. The minerals were found both in zeolitic veinlets, which are split monzodiorites, and on the surface of monzodiorite fragments in association with augite, pigeonite, diopside-hedenbergite series, ferroedenite, and almandine-spessartite series.
4 tables, 6 figures, 20 references.
Keywords: Oshurkovskoe deposit, A.E. Fersman outcrop, yugawaralite, laumontite, stellerite, heulandite-Ca, pigeonite, hedenbergite.

The Oshurkovskyi apatite-bearing massif is located in the Oshurkova and Utochkina pad'[1], on the left bank of the Selenga River 10 km to the north-west of Ulan-Ude (Fig. 1), and occupies an area of 14 km^2. The apatite deposit of the same name is a part of the Oshurkovskyi massif as well. The A.E. Fersman outcrop (Fig. 2) is located in the Utochkina pad' (Kislov, 2011). In 1915 A.E. Fersman studied granite pegmatites containing scapolite and zeolites in this location. The host rocks are strongly squeezed granite-gneisses, altered to amphibolites in places. The rocks of the massif are split by numerous dykes and veins of microdiorites, lamprophyres, carbonatites, granite pegmatites and aplites, and also by quartz and zeolitic veins. The general character of the veins varies, depending on the host rocks, which are mainly contact pegmatites with hornblende, titanite, and albite in the contact zones. In other veins, a gradual change of mineralization after introduction (intrusion) in amphibolite is observed. Feldspar is replaced by scapolite and hornblende, and then scapolite is replaced by zeolites (heulandite, stilbite); i.e. transition from contact pegmatite to migmatites is observed (Gavrusevich, Semenenko, 1935; Fersman, 1940).

Later research (Zanvilevich *et al*., 1999; Semenov, 2010; Lastochkin *et al*., 2011) showed that the massif is composed of rocks consisting of SiO_2 41 – 53 wt.%; the mineral composition corresponds to monzonites and monzodiorites. Alkaline – feldspar syenites occur in the massif as well, forming some small irregular bodies.

The mineral paragenesis characteristic for monzonites and monzodiorites is as follows: Ti-rich pargasite, augite, biotite, oligoclase, K-Na-feldspar, apatite, ilmenite, titanomagnetite, and titanite.

The syenites are comprised of coarse grains of alkaline feldspars, apatite, titanite, ilmenite, and titanomagnetite. There are albite-oligoclase grains in lesser amounts, as well as grains of pure albite and orthoclase in the interstices; quartz is either absent, or in quantity not exceeding 10%. Amphiboles and clinopyroxenes in the syenites are comprised of edenite and ferrous diopside (salite), respectively.

The mineral composition of dike and vein formations is more varied. Carbonatite veins are found on the left bank of the Utochkina pad' (A.E. Fersman's outcrop). Their thickness varies from 2 – 3 to 60 cm, averaging 30 cm. The main carbonatite mineral is a milky-white calcite (80 – 95%); and the minor minerals are as follows: barite, phlogopite, magnetite, titanite, and allanite. Zeolitization and silicification has been observed in the host rocks.

The granite pegmatites are comprised mainly of quartz (20 – 30%), potassium feldspar (40 – 50%), and albite (10 – 30%); minor minerals are as follows: biotite, beryl, muscovite, allanite, zircon, titanite, apatite, spessartite, pyrochlore, magnetite, columbite, ilmenite, rutile, fluorite, and uraninite.

The main rock forming minerals of the gabbro pegmatites are pyroxenes and feldspars. Pyroxene is present as salite; the other minerals of gabbro pegmatites include: apatite (with an increased amount of Sr), titanite, epidote (as a secondary mineral), amphibole, scapolite, magnetite, and biotite. In the east, the intrusive is overlaid by alluvial sediments.

The Oshurkovskoe apatite deposit has been studied on multiple occasions (Gavrusevich, Semenenko, 1935; Fersman, 1940; Kuznetsova *et al*., 1995; Zanvilevich *et al*., 1999; Semenov, 2010; Lastochkin *et al*., 2011), but these studies

[1] – creek valleys in Siberia and Far East.

mainly focused on rock forming minerals. The mineral composition of the zeolitic veins has not yet been described in detail. According to E.V. Kislov (oral communication), the zeolitic veins are comprised of natrolite, stilbite and heulandite.

In summary, the minerals known from the Oshurkovskoe deposit are as follows: augite (including Na-augite), allanite, apatite (with increased Sr content), biotite (enriched with Ti), ilmenite, calcite, magnetite, muscovite, orthoclase, pyrochlore, plagioclases, scapolite, titanite, titanomagnetite, uraninite, zircon, and the zeolite minerals heulandite, natrolite, and stilbite. Despite considerable apatite reserves, the deposit was never developed for reasons of ecological safety, as it is in the area of the Selenga river delta at Lake Baikal.

Samples from the A.E. Fersman outcrop (Utochkina pad') of the Oshurkovskoe apatite deposit were collected in 2011 during a field trip organized for participants of the Second All-Russian Scientific and Practical Conference *"Minerageny of North-East Asia"* which took place in Ulan-Ude. When the samples were investigated, special attention was paid to zeolites, while amphiboles, pyroxenes, feldspars and other minerals studied earlier were not examined in detail (Kuznetsova *et al*., 1995; Zanvilevich *et al*., 1999; Semenov, 2010; Lastochkin *et al*., 2011).

Methods of investigation

The chemical composition of the minerals was determined using a JCXA-733 Superprobe JEOL microprobe analyzer (equipped with an INCA Energy Oxford analysis system, including

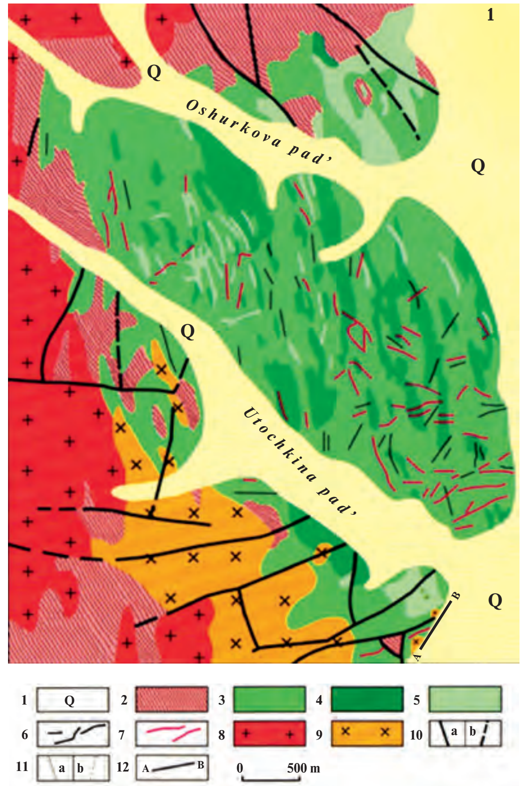

Fig. 1. The geological structure of the Oshurkovskyi massif (Kislov, 2011).
1 — quarternary sediments; 2 — gneisses and crystalline slates; 3 — alkaline melamonzonites; 4 — alkaline monzodiorites; 5 — alkaline monzonites; 6 — dikes of fine-grained monzodiorites, monzonites, lamprophyres and syenites; 7 — granite pegmatites; 8 — gneisso-granites; 9 — alkaline-feldspar syenites; 10 — main breaks; 11 — borders: a — distinct, b — uneven; 12 — A.E. Fersman outcrop.

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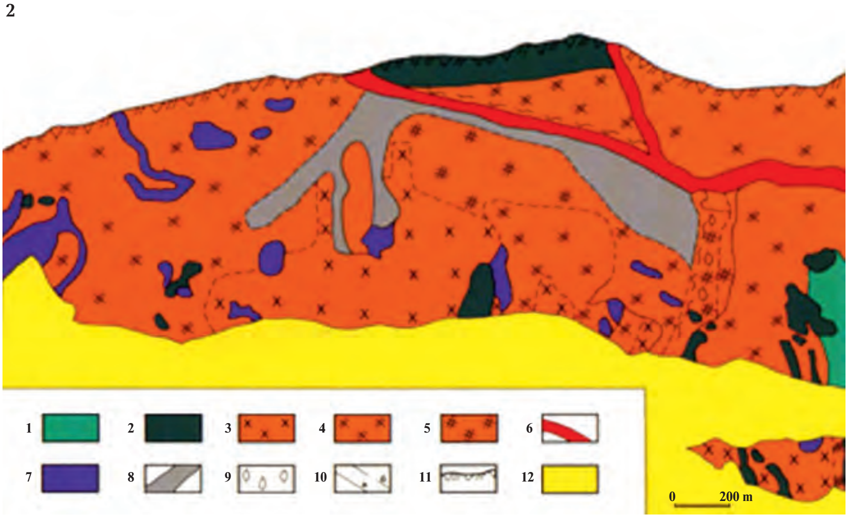


Fig. 2. Sketch of the A.E. Fersman outcrop (Kislov, 2011). Length of the outcrop is 200 m.
1 — monzonites;
2 — lamprophyre dyke;
3 — monzonites medium-grained;
4 — monzonites coarse-grained;
5 — gabbro pegmatites;
6 — granite pegmatites;
7 — vein-disseminated zeolites;
8 — carbonatites;
9 — coarse-grained apatite;
10 — contacts:
a — distinct,
b — gradual;
11 — soil layer;
12 — talus.

Table 1. **Chemical composition (wt.%) of yugawaralite from the A.E. Fersman outcrop (1–6) and foreign locations (7–15)**

Comp.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	59.96	58.82	59.63	59.16	59.04	57.59	61.44	61.47	57.94	58.44	59.58	61.14	61.81	61.74	62.30
Al_2O_3	17.02	16.78	16.83	16.52	15.81	15.92	17.43	17.38	17.65	17.31	18.54	17.65	16.85	16.67	17.24
CaO	8.10	7.88	8.08	7.95	8.17	8.02	8.51	8.51	9.79	9.75	8.96	9.24	9.28	8.29	9.41
MgO				0.13		0.25	< 0.05	< 0.01	0.86	0.42				0.08	
Na_2O	0.41	0.38	0.30	0.27	0.22	0.58	0.07	0.06	0.38	0.38	0.19	0.08	0.05	0.11	0.10
K_2O	0.95	0.93	0.94	0.91	0.54	0.58	0.06	0.09	0.41	0.12	0.05	0.03		0.17	0.05
SrO							0.21	0.21				0.04			0.01
TiO_2							< 0.01	< 0.01							
Fe_2O_3							< 0.05	< 0.04	0.35	0.36	0.19	0.05		0.11	
H_2O^+							9.23	9.33			13.00	9.07			
H_2O-							2.84	2.79	10.70	10.55		2.73			
H_2O									1.80	2.03			12.01	12.77	
Total	85.44	84.79	85.78	84.93	83.78	82.94			99.88	99.34	100.51	100.03	100.00	99.94	89.13
Si/Al	2.99	2.98	3.00	3.03	3.17	3.07									

Formulae, calculated on the basis of O = 16 apfu

1 – $(Ca_{0.87}K_{0.12}Na_{0.08})_{1.07}[Al_{2.01}Si_{6.01}O_{16}]\cdot 4H_2O$

2 – $(Ca_{0.86}K_{0.12}Na_{0.08})_{1.06}[Al_{2.02}Si_{6.01}O_{16}]\cdot 4H_2O$

3 – $(Ca_{0.87}K_{0.12}Na_{0.06})_{1.05}[Al_{2.00}Si_{6.00}O_{16}]\cdot 4H_2O$

4 – $(Ca_{0.87}K_{0.12}Na_{0.05}Mg_{0.02})_{1.06}[Al_{1.98}Si_{6.02}O_{16}]\cdot 4H_2O$

5 – $(Ca_{0.90}K_{0.07}Na_{0.04})_{1.03}[Al_{1.92}Si_{6.08}O_{16}]\cdot 4H_2O$

6 – $(Ca_{0.90}K_{0.08}Na_{0.11}Mg_{0.04})_{1.13}[Al_{1.97}Si_{6.03}O_{16}]\cdot 4H_2O$

Average of 1–6 analyses $(Ca_{0.88}K_{0.11}Na_{0.05})_{1.04}[Al_{1.98}Si_{6.02}O_{16}]\cdot 4H_2O$

Average of 7 and 8 analyses $(Ca_{0.92}K_{0.01}Na_{0.01}Sr_{0.01})_{0.95}[Al_{2.07}Si_{5.92}O_{16}]\cdot 4H_2O$

Average of 9 and 10 analyses $(Ca_{1.05}Mg_{0.12}Na_{0.07}K_{0.05})_{1.29}[Al_{2.07}Fe_{0.02}Si_{5.81}O_{16}]\cdot 4H_2O$

Average of 11 and 12 analyses $(Ca_{0.97}Na_{0.02})_{0.99}[Al_{2.03}Si_{5.98}O_{16}]\cdot 3.86H_2O$

13 – $(Ca_{0.97}Na_{0.02})_{0.99}[Al_{1.95}Si_{6.05}O_{16}]\cdot 4H_2O$

14 – $(Ca_{0.88}K_{0.02}Na_{0.02}Mg_{0.01})_{0.93}[Al_{1.94}Fe_{0.01}Si_{6.09}O_{16}]\cdot 4.2H_2O$

15 – $(Ca_{0.98}Na_{0.02}K_{0.01}Sr_{0.01})_{1.02}[Al_{1.96}Si_{6.03}O_{16}]\cdot 4H_2O$.

Ideal formula is $Ca[AlSi_3O_8]_2\cdot 4H_2O$, Si/Al = 3

Note. Yugawaralite from: 1–6 – A.E. Fersman outcrop (1–3 – sample 6, field 3, A-7; 4 – sample 6, field 1, B-3; 5, 6 – sample 2, B-5; our data, analyst: L.A. Pautov); 7, 8 – Chena Hot Springs, Alaska, USA (Eberlein, 1971); 9, 10 – Yugawara Hot Spring, Japan (Sakurai, Hayashi, 1952); 11, 12 – Nukabira,Hokkaido, Japan (Konno, Aoki, 1977); 13 – Khandivali quarry, India (Anthony et al., 1990); 14 – Osilo, Sassari, Sardinia, Italy (Pongiluppi, 1977); 15 – Hvalfjördur, Iceland (Weisenberger, Selbekk, 2009).

a power dispersive (Si-Li) detector with an ATW-2 thin window at 20 kV accelerating voltage, 2 nA probe current). The standards used were as follows: SiK_α – quartz, AlK_α – albite, CaK_α – wollastonite, MgK_α – MgF_2, NaK_α – jadeite, KK_α – microcline, MnK_α – Mn_2SiO_4, FeK_α – FeO, TiK_α – TiO_2, BaK_α – $BaSO_4$, SrL_α – SrF_2. The water amount in zeolites was not determined.

X-ray powder diffraction data were obtained with Debye-Scherer's method using a URS-50, RKD-57.3 camera, FeK_α radiation with Mn filter.

Investigation results

The zeolites found at the Oshurkovskoe deposit included yugawaralite, stellerite, laumontite, heulandite-Ca, and stilbite. Yugawaralite $Ca[AlSi_3O_8]_2\cdot 4H_2O$ – a rare high-silicon zeolite with a Si:Al ratio = 3, was found in Russia for the first time.

The history of this mineral began in 1952. K. Sakurai and A. Hayashi (Sakurai, Hayashi, 1952) described yugawaralite in samples from Yugawara Hot Spring (Kanagawa prefecture, Honshu island, Japan) in association with zeolites, gyrolite, okenite, prehnite, quartz, and calcite. In 1971, yugawaralite was found in Alaska in association with quartz, laumontite, stellerite and stilbite in siliceous xenoliths in a small monzonite pluton, where colourless crystals of yugawaralite up to 8 mm long, usually covered with white powdery laumontite, has encrusted interstitial quartz (Eberlein *et al.*,

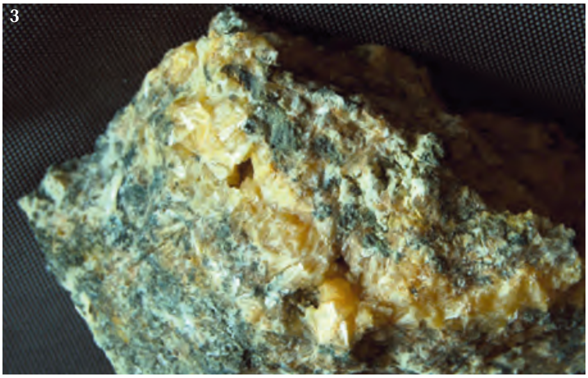


Fig. 3. A zeolitic veinlet in monzodiorite. Sample No. 5, 8 x 6.5 x 3 cm. Photo: I.A. Godovikov.
Fig. 4. Zeolite crust on a monzodiorite surface. Sample No. 2, 5 x 3.5 x 3 cm. Photo: I.A. Godovikov.

Table 2. **Electron microprobe analyses (wt.%) for zeolites: laumontite (1–5), stellerite (6, 7), heulandite-Ca (8) from the A.E. Fersman outcrop, Oshurkovskoe apatite deposit**

Comp.	1	2	3	4	5	6	7	8
SiO_2	52.64	52.86	52.91	52.57	53.02	62.96	59.99	57.76
Al_2O_3	21.29	21.54	21.32	21.96	21.27	15.64	14.17	16.71
CaO	11.21	11.15	11.10	11.16	10.81	8.18	7.73	4.89
Na_2O				0.18				
K_2O	0.97	0.81	0.55	0.61	1.15	0.23	0.24	2.08
SrO								4.31
BaO								0.49
Total	86.11	86.36	85.88	86.48	86.26	87.01	82.13	86.26
Si/Al	2.10	2.09	2.11	2.04	2.12	3.42	3.59	2.94

Formulae, calculated on the basis of O = 6 apfu

1 – $(Ca_{0.92}K_{0.10})_{1.02}[Al_{0.97}Si_{2.03}O_6]_2 \cdot 4H_2O$

2 – $(Ca_{0.92}K_{0.08})_{1.00}[Al_{0.97}Si_{2.03}O_6]_2 \cdot 4H_2O$

3 – $(Ca_{0.92}K_{0.06})_{0.98}[Al_{0.97}Si_{2.04}O_6]_2 \cdot 4H_2O$

4 – $(Ca_{0.90}Na_{0.02}K_{0.03})_{0.95}[Al_{0.99}Si_{2.02}O_6]_2 \cdot 4H_2O$

5 – $(Ca_{0.90}K_{0.12})_{1.02}[Al_{0.96}Si_{2.04}O_6]_2 \cdot 4H_2O$

Average of 1–5 analyses $(Ca_{0.91}K_{0.08})_{0.99}[Al_{0.97}Si_{2.03}O_6]_2 \cdot 4H_2O$

6 – $(Ca_{0.97}K_{0.03})_{1.00}[Al_{2.04}Si_{6.97}O_{18.00}]_2 \cdot 28H_2O$

7 – $(Ca_{0.97}K_{0.03})_{1.00}[Al_{1.96}Si_{7.03}O_{18.00}]_2 \cdot 28H_2O$

Average of 6 and 7 analyses

$(Ca_{0.97}K_{0.03})_{1.00}[Al_{2.00}Si_{7.00}O_{18.00}]_2 \cdot 28H_2O$

8 – $(Ca_{2.46}K_{1.23}Sr_{1.19}Ba_{0.09})_{4.97}[Al_{9.17}Si_{26.9}O_{72}] \cdot 24H_2O$

Ideal formulae: laumontite – $Ca[AlSi_2O_6]_2 \cdot 4H_2O$, Si/Al = 2;

stellerite – $Ca[Al_2Si_7O_{18}] \cdot 28H_2O$, Si/Al = 3.5;

heulandite-Ca – $Ca_2(Ca,Na)_{4\text{-}6}Al_6(Al,Si)_4Si_{26}O_{72} \cdot 24H_2O$

Note. Analysed sample # 6. Analyst L.A. Pautov.

1971). In 1977 yugawaralite was found in Italy (Osilo, near Sassari, Sardinia) in altered gray-green andesite in association with laumontite, heulandite, stilbite, chabazite, mordenite, barite, calcite, ankerite and quartz (Pongiluppi, 1977). Crystals of yugawaralite from Iceland were found as plates 0.3–0.6 cm long, sometimes to 1 cm, in strongly altered andesites together with calcite, quartz, heulandite, stilbite and stellerite (Weisenberger, Selbekk, 2009). There were reports on finds of yugawaralite in the USA (Washington and Wyoming), New Zealand, Argentina, and India (Wise, 1978; Barga *et al.*, 1981; Railton, Watters, 1990; Tschernich, 1992; Leal *et al.*, 2011). Microprobe analyses of yugawaralite from the above noted deposits are shown in Table 1 (An. 7–15).

In the A.E. Fersman outcrop of the Oshurkovskoe deposit, yugawaralite was found in zeolitic veinlets, which cut monzodiorite, in association with laumontite, stellerite, heulandite, and stilbite (Fig. 3), as well as botryoidal crusts on the surface of fragments of monzodiorite (Fig. 4). The color of the zeolitic veins and crusts is light-beige, due to stilbite, which is the dominant zeolite component. Yugawaralite is found as colourless thin plates from ~ 70 × 30 to 800 × 100 microns in size. Electron-probe microanalyses of three yugawaralite grains, extracted from two different samples, are shown in Table 1 (an. 1–6). As seen in Table 1, the mineral composition is rather constant, and close to the theoretical formula: $Ca[AlSi_3O_8]_2 \cdot 4H_2O$. The association of yugawaralite (Table 1, an. 4) with heulandite-Ca (Table 2, an. 8) and orthoclase (Table 3, an. 13) is shown in figure 5.

X-Ray powder data on yugawaralite from A.E. Fersman's outcrop, its synthetic analogue, as well as data on this mineral from other locations are shown in Table 4.

Table 3. **Electron microprobe analyses (wt.%) for pyroxenes (1, 2 – augite, 3, 4 – pigeonite, 5–10 – diopside-hedenbergite), ferroedenite (11, 12), orthoclase (13), titanite (14) and ilmenite (15) from the A.E. Fersman outcrop, Oshurkovskoe apatite deposit**

Comp.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	52.37	52.84	52.29	53.19	52.56	51.52	52.65	51.72	53.19	52.12	41.99	41.33	63.53	29.8	
Al_2O_3	1.58	1.59	2.53	2.44	1.84	2.85	1.80	2.69	1.17	1.85	8.93	9.13	19.51	1.07	
CaO	20.15	20.55	11.89	11.92	20.61	21.18	21.58	20.86	21.05	20.14	9.49	9.61		26.32	0.67
MgO	11.30	11.16	15.41	15.15	12.14	11.85	11.76	11.74	11.59	10.91	6.39	5.81			
Na_2O	1.81	1.83	0.87	0.63	1.41	1.57	1.36	1.34	1.54	1.59	2.36	2.13	1.81		
K_2O			0.20	0.18							1.52	1.46	13.17		
BaO													1.77		
MnO	0.44	0.03		0.30	0.25		0.52		0.43	0.17	5.86	6.22			1.64
TiO_2	0.29	0.43	0.32		0.52	0.57		0.60		0.41	0.62	0.49		36.43	45.93
FeO	12.47	11.84	13.26	13.74	10.87	11.07	10.10	10.74	10.87	11.38	21.04	21.01		1.58	48.29
Ce														0.97	
Total	100.41	100.54	96.77	97.55	100.2	100.61	99.77	99.69	99.84	98.57	98.2	97.19	101.13	96.17	96.52

Formulae, calculated on the basis of: O = 6 apfu (1 – 10), O = 24 apfu (11, 12), O = 8 apfu (13), O = 5 apfu (14), O = 3 apfu (15)

1 – $(Ca_{0.81}Na_{0.13})_{0.94}(Mg_{0.64}Fe_{0.39}Ti^{3+}_{0.01})_{1.04}[Al_{0.07}Si_{1.98})_{2.05}O_6]$

2 – $(Ca_{0.83}Na_{0.13})_{0.96}(Mg_{0.62}Fe_{0.37}Ti^{3+}_{0.01})_{1.00}[Al_{0.07}Si_{1.98})_{2.05}O_6]$

3 – $(Ca_{0.49}Fe_{0.42}Na_{0.06}K_{0.01})_{0.98}(Mg_{0.88}Al_{0.11}Ti_{0.01})_{1.00}[Si_{1.99}O_6]$

4 – $(Ca_{0.48}Fe_{0.40}Na_{0.05}K_{0.01})_{0.94}(Mg_{0.85}Al_{0.11}Fe_{0.03}Mn_{0.01}Ti_{0.01})_{1.01}[Si_{2.01}O_6]$

5 – $(Ca_{0.83}Na_{0.10})_{0.93}(Mg_{0.68}Fe_{0.34}Ti_{0.01}Mn_{0.01})_{1.04}[(Al_{0.08}Si_{1.97})_{2.05}O_6]$

6 – $(Ca_{0.85}Na_{0.11})_{0.96}(Mg_{0.66}Fe_{0.35}Ti_{0.02})_{1.03}[(Al_{0.13}Si_{1.93})_{2.06}O_6]$

7 – $(Ca_{0.87}Na_{0.10})_{0.97}(Mg_{0.66}Fe_{0.32}Mn_{0.02})_{1.00}[(Al_{0.08}Si_{1.98})_{2.06}O_6]$

8 – $(Ca_{0.84}Na_{0.10})_{0.94}(Mg_{0.66}Fe_{0.34}Ti_{0.02})_{1.02}[(Al_{0.12}Si_{1.95})_{2.07}O_6]$

9 – $(Ca_{0.85}Na_{0.11})_{0.96}(Mg_{0.65}Fe_{0.34}Mn_{0.01})_{1.00}[(Al_{0.05}Si_{2.0})_{2.05}O_6]$

10 – $(Ca_{0.82}Na_{0.12})_{0.94}(Mg_{0.62}Fe_{0.36}Mn_{0.01}Ti_{0.01})_{1.00}[(Al_{0.08}Si_{1.99})_{2.07}O_6]$

11 – $Na_{0.75}(Ca_{1.67}K_{0.32})_{1.99}Mn^{2+}_{0.81}(Fe_{2.89}Mg_{1.56}Al_{0.61}Ti_{0.08})_{5.14}(OH)_2[(Al_{0.56}Si_{3.44})_{4.00}O_{11}]_2$

12 – $Na_{0.69}(Ca_{1.71}K_{0.31})_{2.02}Mn^{2+}_{0.88}(Fe_{2.92}Mg_{1.44}Al_{0.67}Ti_{0.08})_{5.09}(OH)_2[(Al_{0.56}Si_{3.44})_{4.00}O_{11}]_2$

13 – $(K_{0.77}Na_{0.16}Ba_{0.03}Sr_{0.03}Ni_{0.02})_{1.01}[Al_{1.06}Si_{2.93}O_8]$

14 – $Ca_{0.96}(Ti_{0.93}Fe_{0.04}Ce_{0.01})_{0.98}O[(Si_{1.01}Al_{0.04})_{1.05}O_{3.98}]$

15 – $Fe_{1.08}Ti_{0.93}Ca_{0.02}Mn_{0.03}O_3$

Ideal formulae are as follows: augite (Ca,Na)(Mg,Fe,Al)[(Si,Al)$_2$O$_6$], diopside CaMg[Si_2O_6], hedenbergite CaFe[Si_2O_6], pigeonite (Mg,Fe,Ca)(Mg,Fe)[Si_2O_6], ferroedenite $NaCa_2(Fe^{2+},Mg)_5(OH)_2[Al_{0.5}Si_{3.5}O_{11}]_2$, titanite CaTiO[$SiO_4$], ilmenite $FeTiO_3$.

Notes. 1–3 – sample 5, A-10; 4 – sample 5, A-9; 5 – sample 6, field 3, A-3; 6–8 – sample 6, field 3, A-4; 9, 10 – sample 5, A-9; 11, 12 – sample 6, field 1; 13 – sample 6, field 4; besides (wt. %) NiO 0.39, Sr O 0.97 (corresponds (apfu): Ni 0.02, Sr 0.03); 14 – sample 6, field 3; 15 – sample 5, A-10. Analyst L.A. Pautov.

Laumontite $Ca[AlSi_2O_6]_2{\bullet}4H_2O$ is found as fragile colourless acicular crystals in association with yugawaralite, and also as monomineralic crusts of colourless radial aggregates from 3 mm to 1.5 cm in diameter. The chemical composition of laumontite (Table 2, An. 1 – 5) is constant, and its X-Ray powder data (Tab. 4) correspond to reference literature data.

Stellerite $Ca_4[Al_2Si_7O_{18}]_4{\bullet}28H_2O$ forms small grains (to 500 × 60 – 70 microns), similar to yugawaralite grains. Microprobe analyses agree well with the stellerite formula (Table 2, An. 6, 7); X-Ray powder data (Table 4) correspond to those of stellerite from Sardinia.

Heulandite-Ca $Ca(Ca,Na)_{2\text{-}3}Al_3(Al,Si)_2Si_{13}O_{36}{\bullet}12H_2O$ occurs as colourless tabular crystals with a perfect cleavage, reaching 0.4 × 1 cm size. The association of heulandite-Ca (Table 2, An. 8) with yugawaralite (Table 1, An. 4) and orthoclase (Table 3, An. 13) is shown in figure 5.

Stilbite $(Na,K,Ca)_9[Al_9Si_{27}O_{72}]{\bullet}28H_2O$, is a major constituent of the zeolitic veinlets and crusts, where it forms parallel-lamellar aggregates with a rounded split shape. The length of plates is up to 1.5 cm, and the color is light-beige.

The garnet found at this locality belongs to the almandine $Fe^{2+}_3Al_2[SiO_4]_3$ – spessartite

Table 4. **Comparison of the X-ray powder diffraction data on yugawaralite (1), laumontite (6), stellerite (8) from the the A.E. Fersman outcrop, Oshurkovskoe apatite deposit with literature data**

Yugawaralite										Laumontite				Stellerite			
1		2		3		4		5		6		7		8		9	
I	d_α, Å	*I*	d_α, Å	*I*	d_α, Å	*I*	d_α, Å	*I*	d_α, Å	*I*	d_α, Å	*I*	d_α, Å	*I*	d_α, Å	*I*	d_α, Å
–	–	20	7.79	5	7.81	4	7.80	5	7.78	8	9.93	10	10.00	3	6.40	1	6.37
3	7.02	60	6.99	50	7.01	31	7.01	60	6.99	9	9.06	10	9.00	5w	5.40	3	5.41
3	6.21	25	6.26	5	6.28	4	6.27	5	6.26	5	4.93	2	5.00	4	5.25	4	5.29
3	5.81	90	5.82	50	5.83	52	5.81	64	5.81	8	4.61	4	4.61	6	4.66	15	4.66
4	5.42	5	5.62	–	–	–	–	3	5.62	7	4.29	7	4.29	1	4.50	4	4.56
8	4.69	85	4.68	–	–	70	4.672	73	4.668	10	4.05	8	4.07	4	4.29	6	4.28
9	4.65	85	4.65	100	4.65	67	4.652	64	4.642	9	3.59	8	3.56	10	4.07	45	4.06
8w	4.45	10	4.45	–	–	8	4.442	8	4.439	6	3.38	6	3.40	4w	3.75	5	3.73
–	–	30	4.41	10	4.42	10	4.410	13	4.402	3	3.27	6	3.24	2	3.48	3	3.48
10	4.31	65	4.30	30	4.30	26	4.295	32	4.293	7	3.11	4	3.13	6	3.41	7	3.40
10	4.15	30	4.18	20	4.18	14	4.179	20	4.177	10	3.02	4	3.02	5	3.20	7	3.18
1	3.90	15	3.89	10	3.90	4	3.897	8	3.890	4	2.87	6	2.85	7	3.06	25	3.03
–	–	5	3.87	–	–	–	–	4	3.867	4	2.78	4	2.79	5	3.01	5	2.976
4	3.76	20	3.78	15	3.77	7	3.770	10	3.768	2	2.58	4	2.59	1	2.88	1	2.875
–	–	–	–	–	–	–	–	3	3.740	3	2.45	6	2.43	3	2.73	2	2.703
5	3.33	5	3.30	10	3.30	–	–	6	3.301	3	2.35	4	2.36	4	2.58	4	2.562
–	–	5	3.27	–	–	–	–	6	3.290	2	2.23	2	2.26	1	2.51	4	2.512
8	3.21	55	3.235	40	3.23	20	3.237	30	3.231	4	2.15	6	2.17	2	2.43	1	2.452
–	–	10	3.198	–	–	6	3.193	5	3.191	2	2.06	2	2.08	1	2.27	1	2.267
1	3.12	20	3.135	–	–	6	3.132	5	3.131	3	2.04	2	1.99	1	2.23	1	2.231
–	–	–	–	–	–	5	3.110	5	3.108	2	1.899	4	1.95	1	2.20	1	2.201
10	3.04	100	3.056	80	3.05	100	3.057	100	3.056	4w	1.874	4	1.87	2	2.08	2	2.078
–		10	2.997	5	2.99	4	2.998	5	2.996	1	1.769	2	1.76	3	2.04	2	2.037
1	2.94	30	2.937	25	2.939	10	2.938	17	2.936	3	1.704	2	1.70	1	1.984	1	1.978
1	2.91	60	2.907	20	2.909	22	2.904	19	2.906	4	1.650	6	1.62	1	1.862	1	1.861
2	2.85	10	2.864	10	2.863	3	2.856	5	2.860	3	1.590	2	1.593	1	1.813	2	1.813
2	2.84	–	–	–	–	–	–	2	2.846	2	1.575	2	1.566	2	1792	1	1.786
2	2.77	30	2.763	15	2.766	12	2.767	14	2.765	3	1.525	4	1.524	1	1.699	1	1.699
3	2.72	35	2.720	25	2.718	11	2.718	12	2.715	2	1.488	2	1.492	3w	1.593	2	1.589
–	–	5	2.706	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	2.69	25	2.680	30	2.681	13	2.686	18	2.682	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	5	2.657	–	–	–	–	–	–	–	–
–	–	20	2.650	15	2.646	9	2.648	9	2.644	–	–	–	–	–	–	–	–
1	2.62	15	2.638	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	5	2.603	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	2.58	15	2.578	10	2.578	–	–	–	–	–	–	–	–	–	–	–	–
2	2.56	5	2.562	5	2.561	–	–	–	–	–	–	–	–	–	–	–	–
1	2.52	15	2.513	5	2.516	–	–	–	–	–	–	–	–	–	–	–	–
1	2.46	15	2.474	5	2.478	–	–	–	–	–	–	–	–	–	–	–	–
–	–	15	2.428	10	2.428	–	–	–	–	–	–	–	–	–	–	–	–
–	–	10	2.407	5	2.405	–	–	–	–	–	–	–	–	–	–	–	–
1	2.36	20	2.368	10	2.368	–	–	–	–	–	–	–	–	–	–	–	–
–	–	10	2.360	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	10	2.338	5	2.330	–	–	–	–	–	–	–	–	–	–	–	–

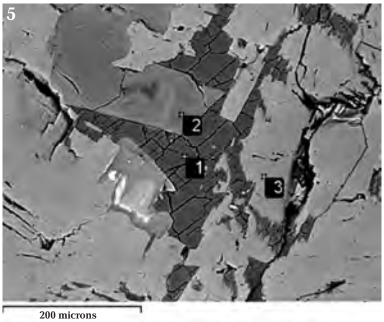
Table 4. **Continuation**

Yugawaralite										Laumontite				Stellerite			
1		2		3		4		5		6		7		8		9	
I	d_{α}, Å	*I*	d_{α}, Å	*I*	d_{α}, Å	*I*	d_{α}, Å	*I*	d_{α}, Å	*I*	d_{α}, Å	*I*	d_{α}, Å	*I*	d_{α}, Å	*I*	d_{α}, Å
2	2.20	5	2.197	5	2.194	—	—	—	—	—	—	—	—	—	—	—	—
2	2.16	5	2.153	5	2.151	—	—	—	—	—	—	—	—	—	—	—	—
—	—	5	1.138	5	2.137	—	—	—	—	—	—	—	—	—	—	—	—
—	—	10	2.106	5	2.105	—	—	—	—	—	—	—	—	—	—	—	—
1	2.09	25	2.092	10	2.091	—	—	—	—	—	—	—	—	—	—	—	—
1	2.02	10	2.018	5	2.017	—	—	—	—	—	—	—	—	—	—	—	—
—	—	15	2.005	10	2.004	—	—	—	—	—	—	—	—	—	—	—	—
1	1.995	10	1.997	15	1.977	—	—	—	—	—	—	—	—	—	—	—	—
2	1.944	—	—	10	1.953	—	—	—	—	—	—	—	—	—	—	—	—
—	—	20	1.934	10	1.932	—	—	—	—	—	—	—	—	—	—	—	—
1	1.904	25	1.900	5	1.907	—	—	—	—	—	—	—	—	—	—	—	—
2	1.881	5	1.883	10	1.899	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	5	1.874	—	—	—	—	—	—	—	—	—	—	—	—
2	1.782	5	1.788	5	1.787	—	—	—	—	—	—	—	—	—	—	—	—
1	1.745	5	1.753	5	1.752	—	—	—	—	—	—	—	—	—	—	—	—
2	1.731	20	1.735	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	1.718	—	—	15	1.722	—	—	—	—	—	—	—	—	—	—	—	—
—	—	10	1.696	10	1.698	—	—	—	—	—	—	—	—	—	—	—	—
3	1.684	5	1.681	5	1.681	—	—	—	—	—	—	—	—	—	—	—	—
2	1.644	5	1.649	5	1.648	—	—	—	—	—	—	—	—	—	—	—	—
2	1.598	5	1.613	5	1.615	—	—	—	—	—	—	—	—	—	—	—	—
1	1.562	5	1.564	5	1.567	—	—	—	—	—	—	—	—	—	—	—	—
1	1.538	15	1.538	10	1.540	—	—	—	—	—	—	—	—	—	—	—	—
2	1.528	10	1.528	5	1.524	—	—	—	—	—	—	—	—	—	—	—	—
—	—	15	1.510	10	1.512	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	5	1.496	—	—	—	—	—	—	—	—	—	—	—	—
1	1.473	15	1.468	10	1.470	—	—	—	—	—	—	—	—	—	—	—	—
2	1.448	10	1.453	5	1.455	—	—	—	—	—	—	—	—	—	—	—	—

Notes. Yugawaralite: 1 — A.E. Fersman outcrop, analyst L.A. Pautov; 2 — synthetical (Barrer, Marshall, 1965); 3 — Nikabira, Japan (Konno, 1977); 4 — Yugawara Hot Spring, Japan (Eberlein, 1971); 5 — Hot Spring, Alaska, USA (Eberlein, 1971). Laumontite: 6 — A.E. Fersman outcrop, analyst L.A. Pautov; 7 — (Mikheev, 1957, № 704). Stellerite: 8 — A.E. Fersman outcrop, analyst L.A. Pautov; 9 — Villanova, Monteleone, Sardinia, Italy (ASTM 25-124), it's composition is as follows (wt. %): SiO_2 59.15, Al_2O_3 14.21, CaO 7.45, H_2O 17.79; besides there are traces of Fe, Mg, Sr, Mn, Ba, Na and K (quantities are not given), absent in stellerite from A.E. Fersman outcrop.

$Mn^{2+}_3Al_2[SiO_4]_3$, solid solution series. It occurs as translucent bright red roundish grains up to 2 mm in size on which some faces may be visible. Microprobe analysis gave the following result (wt.%): MgO 0.42, Al_2O_3 19.66, SiO_2 36.34, CaO 2.91, MnO 27.82, FeO 12.42, total 99.57, which recalculates to the formula $[(Mn_{0.65}Ca_{0.08}Mg_{0.02}Fe_{0.25})_{1.00}]_3[(Fe_{0.05}Al_{0.96})_{1.01}]_2[SiO_4]_3$. The mineral was found in albite in association with quartz and pyroxene. An inclusion (~30 × 50 microns) with high reflection (Fig. 6) was discovered in the garnet. Its composition corresponds to the formula $(Y_{2.35}Dy_{0.15}Er_{0.11}Yb_{0.08}Gd_{0.05}Ho_{0.04})_{2.78}(Fe_{1.14}Ca_{0.33}Mn_{0.12}Si_{0.11})_{1.70}[SiO_4]_3$. This rare-earth mineral was not precisely identified, and requires further study.

As noted above, the rock-forming minerals of the Oshurkovskoe apatite deposit have been studied by many researchers. We have identified the following additional pyroxenes from the A.E. Fersman outcrop: augite (Tab. 3, An. 1, 2), pigeonite (Tab. 3, An. 3, 4), and minerals of the diopside-hedenbergite $CaMg[Si_2O_6]$ — $CaFe[Si_2O_6]$ series (Tab. 3, An. 5—10). In addition, the amphibole ferroedenite was found (Tab. 3, An. 11, 12). We also performed analyses of orthoclase, sphene and ilmenite, which are shown in Table 3.



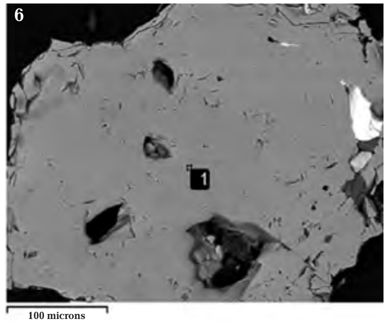


Fig. 5. Yugawaralite (tab. 1, point 1, an. 4), heulandite-Ca (tab. 2, point 2, an. 8), orthoclase (tab. 3, point 3, an. 13). Sample 6, area 1.

Fig. 6. A garnet group mineral (almandine – spessartite series) (gray) and an unidentified rare-earth silicate (bright white, ~ 50 x 30 microns). Sample 7, area 2.

Conclusions

1. Yugawaralite – a rare high-silicon zeolite with a Si/Al = 3 – was found for the first time in Russia at the A.E. Fersman outcrop in the Oshurkovskoe apatite deposit.

2. The zeolitic mineralization of this locality is described. Zeolitic veins occur in monzodiorite and as crusts on monzodiorite fragments. These contain stilbite, yugawaralite, laumontite, stellerite, and heulandite-Ca.

3. Newly recognized rock-forming minerals include: a member of almandine – spessartite solid solution series with composition $[(Mn_{0.65}Ca_{0.08}Mg_{0.02}Fe_{0.25})_{1.00}]_3[(Fe_{0.05}Al_{0.96})_{1.01}]_2[SiO_4]_3$ (25.2% of almandine and 74.8% of spessartite component), pyroxene group members (among them diopside-hedenbergite series minerals and pigeonite), and an amphibole group mineral corresponding to ferroedenite. A rare-earth phase was found as an inclusion in the garnet series mineral, which is close to $(Y,REE)_3(Fe,Ca,Mn)_2[SiO_4]_3$ in composition. The mineral requires additional investigation.

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