

THE NEW FINDS OF PERTSEVITE

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A revision of samples and thin sections collections of kotoitebearing rocks by optics and Electron Micro Probe methods has permitted to find two new occurrences of pertsevite $Mg_2(B,Si)(O,F,OH)_4$. In comparison with the pertsevite holotype having a rather broad meaning of B/Si the new finds of the mineral are more homogeneous in X_{Si} 0.12–0.20 in the sample from Titovskoye deposit, East Verkhoyansk region, and 0.24–0.32 from Gonochan deposit (Djugdjur Ridge, near Okhotsk Sea Coast). The last has the predominance of hydroxile over fluorine. The compositions of accompanied minerals – kotoite, ludwigite and humite group minerals have been studied and presented as well. Pertsevite was formed after kotoite and clinohumite with their reciprocal replacement owing to their chemical interaction.

2 tables, 1 figure, 7 references

After the approving of pertsevite as a new mineral species (Schreyer et al., 2003) the discoverer of it, outstanding mineralogist and petrologist Werner Schreyer decided prolongate the investigation. We have made attempts to find pertsevite in other occurrences, localities and regions. Thin sections of samples with kotoite mineralization collected by N.N. Pertsev and V.V. Rudnev from the 1950s to the 1990s at different localities in Russia were reexamined. The revision had allowed us to separate several samples with assumed pertsevite presence. Two of them have been studied in Ruhr University Bochum where the pertsevite holotype was investigated before using the same technique and equipment (EMP – CAMECA SX 50, etalons: synthetic pyrope, andradite, spessartite, TiO_2 , Cr_2O_3 , V_2O_5 , borosilicate glass and natural topaz; accelerating voltage 15 kV, beam current 15 nA). The results approved pertsevite presence. We finished the work after W. Schreyer left us in January, 2006.

The specimen from Titovskoye deposit (East Verkhoyansk region, Tas-Khayaktakh Ridge).

It is the sample VR-10 from V.V. Rudnev's collection. This locality is in the region east of Verkhoyansk, same to that of the initial find-

ing, or type locality of pertsevite (Schreyer et al., 2003; Pertsev et al., 2004) but from a different deposit distant about 30 km to east (Dorofeyev, 1979; Lisitsin et al., 1995). Kotoitite and kotoite marble zone occupy place between spinel-forsterite skarn zone and marble in which periclase has been replaced by typical brucite pseudomorphs.

The studied part of the sample is a small chip (about 3 x 3 x 1 cm) of a dense, massive, light-grey rock containing some black patches of about 5 mm in diameter. Using a hand lens, the latter can be identified to be made up of numerous prisms and needles of what looks like opaque members of the ludwigite-vonsenite series. Except for these, the rock is transparent in thin section and consists of a regular, non-oriented fabric of interlocking mineral grains with generally medium refringence as well as medium birefringence. Average grain size is about 1 to 2 mm. In very few cases of favorable orientation, grains having a higher birefringence can be recognized as pertsevite, which is but a minor constituent of the rock. Otherwise, pertsevite is hard to distinguish from the main constituent kotoite, if it were not for BSE images, in which pertsevite is just slightly brighter than kotoite. The whole rock, best named as kotoitite, is irregularly dissected by a multitude of veins and cracks, up to half a millimeter wide, which contain extreme-

Table 1. EMP (Electron microprobe) analyses of minerals in the kotoite (sample VR-10)

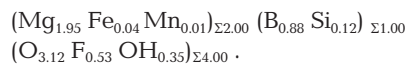
Mine	Perts.1 ¹	Perts.6	Perts.5	Koto3	Koto. id	Ludw.7	Alter.9 ¹	aib.id	ral
SiO ₂	5.41	7.81	8.82	0.31	—	0.04	0.24	—	
B ₂ O ₃ ²	22.36	21.88	20.93	36.79	36.79	15.31 ³	n.d.	41.38	
Al ₂ O ₃	0.01	0.00	0.00	0.00	—	1.01	0.00	—	
MgO	59.98	59.66	58.94	58.32	63.21	28.93	48.13	47.91	
FeO	2.18	2.38	2.05	4.22	—	47.93	1.07	—	
MnO	0.27	0.25	0.28	0.34	—	0.18	0.36	—	
CaO	0.03	0.02	0.08	0.01	—	0.04	0.08	—	
F	7.65	6.93	6.10	0.02	—	0.18	0.00	—	
P ₂ O ₅	n.d.	n.d.	n.d.	n.d.	—	n.d.	0.00	—	
Total	98.89	98.93	97.20	100.01	100.00	93.62	49.88	—	
-O=F ₂	3.22	2.92	2.57	0.01	—	0.08	0.00	—	
H ₂ O	2.43	2.38	2.53	n.d.	—	n.d.	n.d.	10.71	
Total	(wt.%)	98.10	98.39	97.16	100.00	100.00	93.54	49.88	100.00
Recalculations of ions per formula units (for details see text)									
Si	0.118	0.171	0.196	0.010	—	0.001	—	—	
Al	0.000	0.000	0.000	0.000	—	0.042	—	—	
B	0.881	0.828	0.804	2.041	2.000	1.000	—	1.000	
Sum 1	0.999	0.999	1.000	—	2.000	—	—	1.000	
Mg	1.954	1.951	1.955	2.795	3.000	1.528	—	1.000	
Fe ²⁺	0.040	0.044	0.038	0.113	—	0.464 ³	—	—	
Fe ³⁺				—	—	0.957 ³			
Mn	0.005	0.005	0.005	0.009	—	0.005	—	—	
Ca	0.001	0.001	0.002	0.000	—	0.001	—	—	
Sum 2	2.000	2.001	2.000	2.918	3.000	—	—	1.000	
F	0.529	0.481	0.429	—	—	0.020	—	—	
O ²	3.117	3.170	3.195	—	6.000	—	—	2.000	
OH ²	0.354	0.349	0.375	—	—	—	—	1.000	
Sum 3	4.000	4.000	3.999	—	—	—	—	3.000	

Note: ¹original numbers of analyses; ²calculated (see text) or as in ideal formula; ³calculated by distribution Fe²⁺ and Fe³⁺; id = ideal; Alter. = bulk of finegrained alteration products within veins; n.d. = not determined.

ly finegrained secondary alteration products and make up some 40 volume percent. No doubt, these finegrained vein materials contribute to the megascopically dense character of the rock.

Electron microprobe (EMP) analyses on sample VR-10 yield a rather restricted compositional range of pertsevit with SiO₂ varying from 5.4 to 8.2 wt%, FeO from 1.92 to 2.38 wt% and F from 6.10 to 8.20 wt%. This is well within the range found for the original pertsevit locality (Schreyer *et al.*, 2003), but clearly on the low side regarding SiO₂ and FeO.

Table 1 lists the analytical results obtained on some pertsevit crystals, one each on kotoite and ludwigite as well as one on the finegrained alteration product. For the recalculation on formula units for pertsevit, the experiences with the first occurrence (Schreyer *et al.*, 2003) were employed. These are expressed by the ideal general formula (Mg + Fe + Mn + Ca)₂(B + Si + Al)₁(O + F + OH)₄. Relative to the silicon-free pertsevit phase, Mg₂BO₃(F,OH), the substitution introducing Si is: Si + O for B + (F,OH). Thus excess-oxygen beyond 3.0 must equal Si, and OH = 1 - Si - F or OH = B - F. The formula of pertsevit No.1 in Table 1 so becomes:



Because H₂O could not be determined, it was calculated following the above equation.

The kotoite analysis of Table 1 was recalculated on the basis of 12 anion valences (six oxygens) and lies close to that of the ideal formula Mg₃(BO₃)₂. It contains more Fe than coexisting pertsevit. The main uncertainty derives from the unknown amount of B₂O₃, which was calculated by difference.

The ludwigite analysis was recalculated with a glance of high content

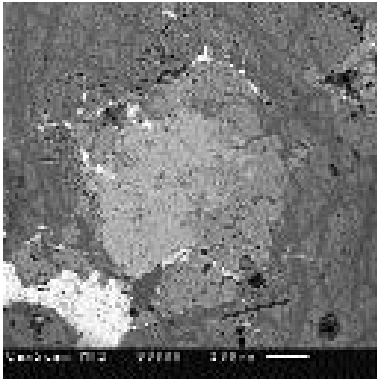


Fig. 1. BSE image of a part of the sample 900018. Pertsevitite forms the edge (grey) around the inclusion of clinohumite (light grey in the centrum) in kotoite (dark grey freaked by szaibelyite veinlets). Relics of kotoite and clinohumite in pertsevitite are distinctly visible. White crystals and grains – ludwigite. Scale 100 μm .

of Fe^{3+} using the formulae: $\Sigma\text{Fe} + \text{Al} + \text{Sn} + \text{Ti} + \text{Mg} = 3$; $\text{B} = 1$; $\text{O} = 5$.

No recalculation was attempted for the secondary alteration material analysed from one of the veins, because neither B_2O_3 nor H_2O could be determined. However, the composition of ideal szaibelyite, $\text{MgBO}_2(\text{OH})$, shown for comparison suggests that indeed szaibelyite is the main mineral within the veins, possibly with a small admixture of brucite, $\text{Mg}(\text{OH})_2$.

The specimen from Gonochan deposit, Djugdjur Ridge, Russian Far East

There are several localities of magnesian skarn boron mineralization in central part of Djugdjur Ridge in 60–70 km from Okhotsk Sea coast at $\sim 56^\circ 30' \text{N}$ and $136^\circ 20' \text{E}$. Here, platform sediments of Upper Precambrian have been subjected to strong Mesozoic tectono-magmatic activation. The magnesian skarns with boron mineralization developed in contacts of Upper Riphean dolomites with Cretaceous subalkaline hypabissal bodies of granitoids (Gramenitskii, 1969, Stepanov, 1973). Sample 90018 (Fersman Mineralogical Museum) was collected by N.N. Pertsev in 1964 in the small deposit Gonochan located in the bed of the small river of the same name. The rock was recognized as a very coarse grained kotoitite in the field analogy (in position and peculiarities of weather-

ing) with kotoitites of Tas-Khayakhtakh deposits (Pertsev, 1971, p. 131–132). Carbonate rocks (mainly dolomites) of Upper Riphean were cut by stocks Upper Cretaceous granites. The magmatic

rock in a band (up to several meters thick) along the contacts with skarns is represented by rather fine grained sub-alkaline (clinopyroxene facies) granite. The thickness of kotoite-containing lenticular bodies runs up to 1 m.

The studied part of the sample was also only a small chip (originally about $2 \times 3 \times 1 \text{ cm}$) of a light grey, dense rock with only minor amounts of small black prisms (ludwigite) aligned in parallel trails. In contrast to specimen VR-10, the thin section of the present rock is dominated by a medium grained fabric of carbonate minerals (calcite) forming a sort of matrix for the roundish, anhedral grains of the remaining transparent silicate and borate minerals. These show, as a function of orientation, low to medium to high birefringence and medium refringence, often without offering any characteristic optical features for their distinction. EMP work identified them as clinohumite, pertsevitite and kotoite. Only clinohumite is safe to recognize, when it exhibits characteristic polysynthetic twinning. Ludwigite has in thin edges strong pleochroism from very dark green (across to elongation) to dark brown (along).

Typically, it is only with the aid of BSE images that the mutual space relationships between clinohumite, pertsevitite and kotoite can be characterized (Fig.1). Clinohumite occupies the central portions of the three minerals complex aggregates and shows clear signs of corrosion. For example, it occurs as a multitude of small inclusions within the more peripheral mineral pertsevitite. This is in turn surrounded by often large crystals of kotoite, which are fractured by veins containing retrograde alteration products (szaibelyite, brucite). The intermediate textural position of pertsevitite – between clinohumite and kotoite – is also obvious when pertsevitite forms only small crystals or selvages around clinohumite. Thus, pertsevitite must have formed in the rock at a relatively late stage, probably by a reaction of kotoite with clinohumite. Such reaction was also envisaged for the original pertsevitite occurrence east of Verkhoyansk (Schreyer *et al.*, 2003). Altogether, the sample 90018 is a kotoite marble with very similar petrographic features as sample B-1048 studied previously.

EMP analyses of sample 90018, however, introduce some new mineral chemical features. In Table 2 are listed five analyses of pertsevitite, two of clinohumite and one of kotoite. SiO_2 in

Table 2. Electron microprobe analyses of minerals in the kotoite marble (sample 90018)

Mineral	Perts30 ¹	Perts45	Perts52	Perts53	Perts41	Clinoh28	Clinoh46 ⁴	Koto16
SiO ₂	13.55	13.14	12.49	11.39	10.86	35.69	36.92	0.31
B ₂ O ₃ ²	16.91	18.71	18.97	19.70	20.13	1.45	0.76	37.13 ³
Al ₂ O ₃	0.03	0.02	0.01	0.1	0.3	0.1	0.00	0.1
MgO	56.95	60.51	60.22	60.39	60.76	57.27	57.39	61.59
FeO	0.58	0.55	0.64	0.66	0.57	0.45	0.30	0.70
MnO	0.13	0.20	0.15	0.17	0.16	0.15	0.23	0.23
CaO	0.07	0.09	0.08	0.08	0.12	0.05	0.05	0.03
F	4.34	5.10	4.85	4.86	4.98	4.15	2.66	0.00
Total	92.56	98.32	97.41	97.26	97.61	99.22	98.31	100.00
-O=F ₂	1.83	2.15	2.04	2.05	2.10	1.75	1.12	–
H ₂ O ²	2.33	2.44	2.62	2.80	2.86	1.27	1.80	n.d.
Total (wt.%)	93.06	98.61	97.99	98.01	98.37	98.74	98.99	100.00
Recalculations of ions per formula unit (for details see text)								
Si	0.317	0.289	0.276	0.251	0.238	3.738	3.862	0.010
Al	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.000
B	0.682	0.710	0.724	0.749	0.761	0.262	0.138	2.030
Sum 1	1.000	0.999	1.000	1.000	1.000	4.001	4.000	–
Mg	1.984	1.984	1.983	1.983	1.984	8.940	8.948	2.909
Fe	0.011	0.010	0.012	0.012	0.010	0.040	0.026	0.018
Mn	0.003	0.004	0.003	0.003	0.003	0.013	0.021	0.006
Ca	0.002	0.002	0.002	0.002	0.003	0.005	0.005	0.001
Sum 2	2.000	2.000	2.000	2.000	2.000	8.998	9.000	2.934
F	0.321	0.354	0.339	0.339	0.345	1.373	0.879	–
O ²	3.316	3.288	3.275	3.250	3.237	15.739	15.862	–
OH ²	0.364	0.357	0.386	0.412	0.418	0.887	1.258	–
Sum 3	4.001	3.999	4.000	4.001	4.000	17.999	17.999	

Notes: ¹original numbers of analyses; ²calculated as in table 1 (see text); ³calculated by difference to 100 wt%; ⁴hydroxyclichohumite (by calculated OH); n.d. = not determined

pertsevit ranges from 10.86 to 13.55 wt%, FeO from 0.36 to 0.66 wt% and F from 4.63 to 5.34 wt%. Thus, Si is much higher than in the pertsevit of sample VR-10, but also surpasses the highest Si-values measured in the type-pertsevit of Schreyer *et al.* (2003). On the other hand, FeO is much lower than in the pertsevites of the other two localities, so that the ones found here may truly be taken as the most magnesian pertsevites found thus far. Moreover, fluorine lies below all the values hitherto determined, so that these pertsevites also seem to be among the most hydrous ones ever investigated.

For the recalculations of the pertsevit analyses to formula unit, the same procedure was employed as described for sample VR-10. They indicate that pertsevit no.30 with 0.32 Si per formula unit of sample 90018 is now the most silicatian pertsevit ever analysed; its low

analytical totals cannot be explained but do not seem to influence this property. The Si-range extends down to as low as 0.24 *p.f.u.*, which is close to the upper Si limit in the pertsevites of sample B-1048. So, considering all three pertsevit occurrences known thus far, there is now a full range of solid solution from 0.10 to 0.32 Si *p.f.u.* Contrary to the situation found in sample B-1048, no correlation could be made out here between Si content and the proximity of the pertsevit to either clinohumite or kotoite. The pertsevites are much more homogeneous here than in B-1048. Despite the considerable variations of Si in sample 90018, there is surprisingly little, or even no, variation in the ferromagnesian elements. Likewise F remains rather constant, and the calculated values for OH always exceed those of F. Thus, these pertsevites are indeed the first ones with

OH/F > 1 and could deserve a new mineral name ("hydroxy-pertsevite"). We abstain from this procedure, however, because OH values are only calculated. The structural formulae of Table 2 confirm that the pertsevites from sample 90018 are indeed the most magnesian ones.

Concerning the clinohumite grains analysed in the sample, the main difficulty arises from their unknown contents of B₂O₃. With the experience of the kotoite marble of sample B-1048 (Schreyer *et al.*, 2003) it seems clear that clinohumite coexisting with pertsevite must contain boron; that sample had about 1.5 wt% B₂O₃. As evidenced in B-1048, the boron is incorporated in the tetrahedra partly replacing silicon. Therefore, we used in Table 2 a similar recalculation scheme as for pertsevite, calculating B as 4.0 – Si *p.f.u.* The results for two analyses (Table 2) are very reasonable clinohumite structural formulae, that are comparable to those of the earlier study. As in pertsevite, there is very little Fe and Mn so that the clinohumite grains of sample 90018 are nearly Mg end members. Fluorine is quite variable: the two analyses nos. 28 and 46 represent the highest and the lowest F values, respectively, that were analysed. But they are quite similar to those of the clinohumite in B-1048 as well. The lower fluorine contents correspond to predomination of hydroxycclinohumite end member and appears to witness of reequilibration of clinohumite mineral during overprinting of enriched with hydroxyl pertsevite.

The kotoite analysis of Table 2 is very close to ideal composition (compare Table 1), although B₂O₃ was only calculated as difference of the measured oxides to a total of 100 wt.%. Notable is the very high Mg/Fe ratio like in all other minerals of sample 90018.

No analyses were performed on ludwigite, but from its pleochroism in thin section it is presumably quite magnesian as well.

Altogether, sample 90018 is probably among the Mg-richest, pertsevite-bearing contact skarns (kotoite marbles and kotoitites) that can be found.

In conclusion we have to point to pertsevite appears to be rather wide spread in kotoite-containing rocks where paragenesis of

kotoite with the minerals of humite group is quite usual. The modern diagnostics of pertsevite is simple enough by using BSE images. Larger pertsevite crystals seem to be found to precise the ranges of optical properties and compositions of the mineral species.

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