

## NEW MINERALS OF THE GROUP OF IRON ANTIMONIDES AND ARSENIDES FROM SEINÄJOKI DEPOSIT, FINLAND

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This article gives pertinent data of two minerals, previously unknown in nature, seinäjokite —  $(\text{Fe}_{0.8}\text{Ni}_{0.2})(\text{Sb}_{1.7}\text{As}_{0.3})_2$  and the antimony westerveldite —  $\text{Fe}(\text{As}_{0.95}\text{Sb}_{0.05})$ ; also described is the mineral association in which they occur.

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Two minerals unknown to date were found in the Seinäjoki deposit in a specimen of native antimony\*).

In chemical composition and structure one of these new minerals is close to the antimony analog of löllingite and to the phase  $\text{FeSb}_2$  in alloy. This is the first time that such a compound has been found in nature and therefore it is described as a new mineral species. The name, taken from the Seinäjoki deposit, was affirmed by the Commission on New Minerals and Mineral Names of the

International Mineralogical Association on 28-II-1976.

Seinäjokite occurs as irregular grains, more rarely idiomorphic crystals with rhombic sections, from 0.2 to 0.3 mm in size (Fig. 1). The chemical composition was determined by JXA-5 electron microprobe (Table 1). The abundances of the elements vary only slightly; the variations of Fe and Ni, as well as Sb and As exhibit reverse relation. These facts are evidence of the variation in composition of the mineral and the isomorphism between these elements. The average formula is  $(\text{Fe}_{0.78}\text{Ni}_{0.19}\text{Co}_{0.03})_{1.00} \cdot \text{Sb}_{1.71}\text{As}_{0.26}\text{Fe}_{0.03})_{2.00}$  or in generalized form —  $(\text{Fe}_{0.3}\text{Ni}_{0.2}) \cdot (\text{Sb}_{1.7}\text{As}_{0.3})_2$ . The X-ray powder pattern of seinäjokite (Table 2) is closed to that of the

\*) More data on these minerals can be found in the paper Mozgova et al., 1976. The geology and mineralogy of the deposit were described in the monography by V. Pääkkönen (1966).

Table 1. Results of microprobe analyses of seinäjokite, Sb-westerveldite and associated minerals (Wt. %).

Mineral	Fe	Ni	Co	Au	Pb	Sb	As	Fe	S	Total	Formula
Seinäjokite	16.0	3.4	0.6	—	—	72.9	7.6	1.0	—	101.5	(Fe <sub>0.81</sub> Ni <sub>0.16</sub> Co <sub>0.03</sub> ) <sub>1.00</sub> (Sb <sub>1.69</sub> As <sub>0.20</sub> Fe <sub>0.02</sub> ) <sub>2.00</sub>
	15.8	3.8	0.6	—	—	71.6	7.8	1.0	—	100.6	(Fe <sub>0.80</sub> Ni <sub>0.19</sub> Co <sub>0.03</sub> ) <sub>1.02</sub> (Sb <sub>1.67</sub> As <sub>0.20</sub> Fe <sub>0.02</sub> ) <sub>1.98</sub>
	15.7	3.6	0.6	—	—	74.4	7.0	1.0	—	102.3	(Fe <sub>0.79</sub> Ni <sub>0.18</sub> Co <sub>0.03</sub> ) <sub>1.00</sub> (Sb <sub>1.72</sub> As <sub>0.26</sub> Fe <sub>0.02</sub> ) <sub>2.00</sub>
	15.1	3.9	0.6	—	—	75.4	5.7	1.1	—	101.8	(Fe <sub>0.77</sub> Ni <sub>0.19</sub> Co <sub>0.03</sub> ) <sub>0.99</sub> (Sb <sub>1.77</sub> As <sub>0.25</sub> Fe <sub>0.02</sub> ) <sub>2.01</sub>
	15.2	4.2	0.6	—	—	73.9	7.2	1.4	—	102.5	(Fe <sub>0.76</sub> Ni <sub>0.20</sub> Co <sub>0.03</sub> ) <sub>0.99</sub> (Sb <sub>1.71</sub> As <sub>0.27</sub> Fe <sub>0.03</sub> ) <sub>2.01</sub>
Average	14.7	5.4	0.3	—	—	73.0	6.4	1.6	—	101.4	(Fe <sub>0.75</sub> Ni <sub>0.26</sub> Co <sub>0.02</sub> ) <sub>1.03</sub> (Sb <sub>1.70</sub> As <sub>0.24</sub> Fe <sub>0.03</sub> ) <sub>1.97</sub>
	15.4	4.0	0.6	—	—	73.5	6.9	1.2	—	101.6	(Fe <sub>0.75</sub> Ni <sub>0.19</sub> Co <sub>0.03</sub> ) <sub>1.00</sub> (Sb <sub>1.71</sub> As <sub>0.26</sub> Fe <sub>0.03</sub> ) <sub>2.00</sub>
Sb-westerveldite	42.4	—	—	—	—	4.7	53.7	—	1.0	101.8	Fe(As <sub>0.94</sub> Sb <sub>0.05</sub> S <sub>0.04</sub> ) <sub>1.03</sub>
Löllingite	25.0	2.4	—	—	—	—	73.3	—	0.6	101.3	(Fe <sub>0.90</sub> Ni <sub>0.08</sub> ) <sub>0.98</sub> (As <sub>1.98</sub> S <sub>0.04</sub> ) <sub>2.02</sub>
Gudmundite	27.8	—	—	—	—	58.9	—	—	14.7	101.4	Fe <sub>1.03</sub> SbS <sub>0.95</sub>
Stibarsen	—	—	—	—	—	64.5	36.9	—	—	101.4	Sb <sub>1.04</sub> As <sub>0.96</sub>
Aurostibite	—	—	—	43.2	—	54.2	—	—	—	97.4	Au <sub>0.99</sub> Sb <sub>2.01</sub>
Altaitte	—	—	—	—	55.3	0.5	—	37.4	0.1	93.3	Pb <sub>0.94</sub> (Te <sub>1.03</sub> Sb <sub>0.02</sub> S <sub>0.01</sub> ) <sub>1.06</sub>

Note. Analyses were performed with a JXA-5 electron microprobe; accelerating voltage 25 kv; standards were pure metals (Fe, Ni, Co, Sb, Te), natural PbS and synthetic GaAs.

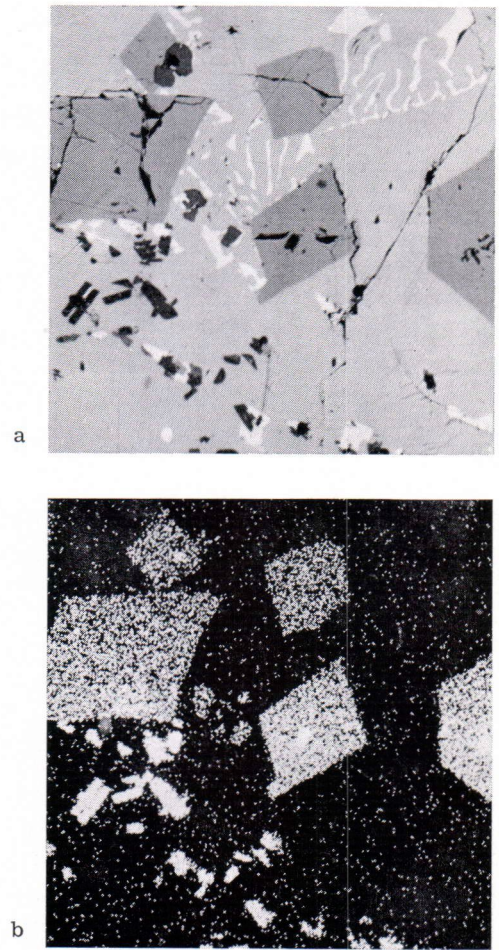


Fig. 1. Crystals of seinäjokite (grey) and Sb-westerveldite (black) in native antimony (light grey). Altaitte (white) forms graphic intergrowths with antimony. Magn. 170x. a — back-scattered electron image; b — FeK<sub>α1</sub> X-ray image.

synthetic phase FeSb<sub>2</sub>. The unit cell of the mineral may be orthorhombic or pseudo-orthorhombic. The calculated density is 7.938 (with  $a_0 = 3.189$ ,  $b_0 = 5.819$ ,  $c_0 = 6.520\text{Å}$  and  $Z = 2$ ).

In reflected light, seinäjokite is grey with a pinkish tint. Reflectance is high, and dispersion of reflectivity is insignificant (Table 3). Bireflectance is unnoticeable in air, whereas anisotropy is distinct with a coloured effect — from brownish to bluish. It polishes well.

Table 2. X-ray diffraction pattern of seinäjokite ( $a_0 = 3.19 \pm 0.01\text{\AA}$ ,  $b_0 = 5.81 \pm 0.01\text{\AA}$ ,  $c_0 = 6.49 \pm 0.015\text{\AA}$ )

I	d meas.	hkl	d calc.
10	2.81	{ 012 110	2.83 2.80
9	2.59	111	2.57
0,5	2.12	112	2.12
8	2.03	{ 121 013	2.04 2.03
1	1.818*		
6	1.790	{ 103 122	1.791 1.791
1	1.710	113	1.711
2	1.626	004	1.624
2	1.523	123	1.524
1	1.407	{ 041 212	1.417 1.390
3	1.212	231	1.210
3	1.174	115	1.177
1	1.153	232	1.151
1	1.077	151	1.077
1	1.053	301	1.049

Note. RKD camera, D = 57.3 mm,  $\text{CuK}\alpha$  radiation, 40 kv-5 ma. Absorption correction was not effected because of the small size of the rubber ball with the sample.

\* — the line is not indicated.

Seinäjokite is less bright but with higher relief than native antimony. The microhardness is 330 kg/mm<sup>2</sup> (with the load of 30 g). The impression is quadrate and slightly concave with cracks. The mineral is transparent in near infra-red light ( $\lambda$  — up to 1.2 micron).

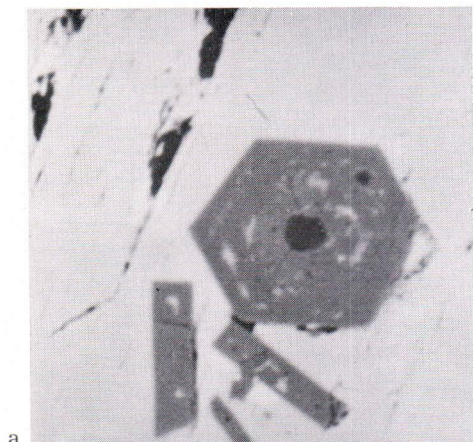
It has been suggested that the name seinäjokite be used for natural solid solutions having orthorhombic symmetry and the composition  $\text{Fe}(\text{As}, \text{Sb})_2$  (when  $\text{Sb} \gg \text{As}$ ).

The other mineral,  $\text{Fe}(\text{As}_{0.95}\text{Sb}_{0.5})$ , has likewise gone undetected in nature until now. In samples of chromite-nicolite ore from La Gallega (Spain), I.S. Den *et al.* (1972) recently discovered a new mineral, westerveldite ( $\text{Fe}, \text{Ni}, \text{Co}$ )As, containing from 13.4 to 17.4 % Ni. The authors proposed the name westerveldite for the orthorhombic  $\text{FeAs}$  —  $(\text{Fe}, \text{Ni})\text{As}$  solid solution series. Later, westerveldite of a similar composition was found in an assemblage of disseminated arsenides in serpentinized

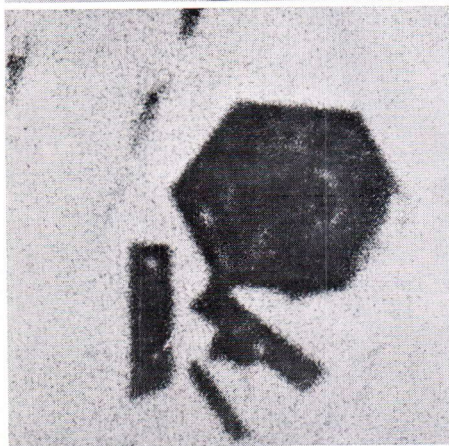
Table 3. Reflectivity dispersion (R) of seinäjokite, Sb — westerveldite and native antimony from Seinäjokite deposit

Mineral	R (in %) for different wave lengths (in nm)															
	440	460	480	500	520	540	560	580	600	620	640	660	680	700	720	740
Seinäjokite	63.8	62.4	61.4	60.8	60.8	60.8	60.8	61.0	61.4	61.9	62.7	63.4	64.3	65.3	66.2	67.1
Sb-westerveldite	59.5	56.3	54.1	53.0	52.6	52.4	52.4	52.6	53.1	53.8	54.8	56.0	57.0	58.1	59.6	61.0
Native antimony	75.0	75.2	75.5	76.0	76.5	76.0	75.4	75.3	75.2	75.2	75.4	75.5	75.5	75.7	76.0	76.5

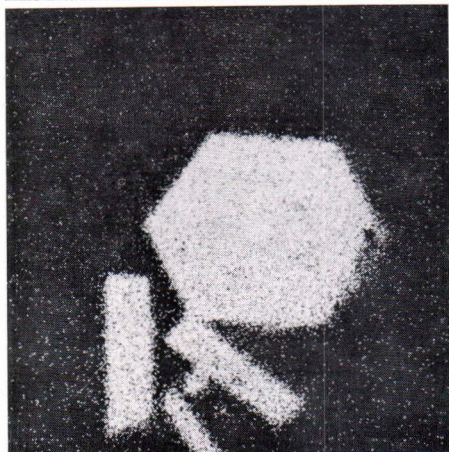
Note. Reflectivity was measured on a Pyor-type device, equipped with an automatic register. (See publication by L. N. Vjalsov 1973, for a detailed description of the apparatus and conditions of measurements).



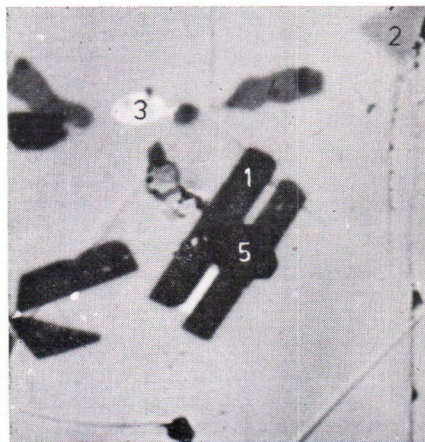
a



b



c



a



b



c

Fig. 2. Crystals of Sb-westerveldite in native antimony. Sb-westerveldite has inclusions of pyrrhotite (black) and antimony (white). Black spots in the field of native antimony are defects in polishing. Magn. 680x. a — back-scattered electron image; b —  $SbL_{\alpha_1}$  X-ray image; c —  $FeK_{\alpha_1}$  X-ray image.

Fig. 3. Sb-westerveldite (1), seinäjokite (2) and tellurides in native antimony. 3-altaite; 4-non-determined telluride; 5-pyrrhotite. Magn. 700x. a — back-scattered electron image; b —  $SbL_{\alpha_1}$  X-ray image; c —  $FeK_{\alpha_1}$  X-ray image.

peridotite near Birchtree mine in Canada (Sizgoric and Duesing, 1973).

The Fe -arsenide that we discovered at Seinäjoki does not contain Ni and is the first find of a wholly nickel-free member of this series. The mineral contains about 5 % Sb (Table 1) and we propose that this mineral be considered as an antimony variety of westerveldite (Sb -westerveldite). Sb-westerveldite occurs as isometric grains, up to 0.1 mm in diameter, with characteristic hexagonal, rectangular and trapezoidal sections (Fig. 2).

The composition of the mineral corresponds to the formula  $\text{Fe}(\text{As}_{0.94}\text{Sb}_{0.05}\text{S}_{0.4})_{1.03}$  (Table 1). Its d-values and line intensities (the powder pattern was obtained only for the mixture of this mineral and native antimony — see Table 4) are closer to those of the synthetic compound FeAs than of the westerveldite from La Gallega. The calculated density (taking into account the parameters of FeAs) is 7.907. In reflected light it is pinkish grey, darker than native antimony and shows a higher relief than the native mineral. In comparison with seinäjokite it is pinkish brown, and exhibits less reflectance and a higher relief. Sb-westerveldite contains inclusions of pyrrhotite (often in the centre of grains) and native antimony (Fig. 2 and 3).

Both minerals replace native antimony and associate with altaite and other non-determined tellurides (Fig. 3). The latter minerals were discovered in ores of the Seinäjoki deposit for the first time. Near this association native antimony contains 0.3 to 0.4 % As, but at some distance the content of As increases to 7 %. In other parts of the same specimen, stibarsen (SbAs) and aurostibite ( $\text{AuSb}_2$ ) were found for the first time in the Seinäjoki deposit. Stibarsen forms chains of small crystals and irregular grains. In reflected light it is pinkish white, distinguished from native antimony with difficulty and

Table 4. X-ray diffraction pattern of Sb-westerveldite.

Mixture of Sb-westerveldite and native antimony, Seinäjoki deposit		Sb-westerveldite, Seinäjoki deposit; (corrected for native antimony)	
I	d Å meas.	hkl	d Å correct.
10	3.13		
0.5	2.96 *)	110	2.92
2	2.66 *)	021	2.64
6	2.61 *)	111	2.59
2	2.50 *)	012	2.48
6	2.26		
6	2.16		
3	2.10 *)	102	2.08
4 w	2.02 *)	022	2.01
1	1.939		
1	1.891		
4	1.775		
4	1.739 *)	013	1.736
1	1.704 *)	200	1.700
0.5	1.633 *)	032	1.630
4	1.559 **)		
2	1.422 **)	221	1.422
4	1.373		
1	1.265 **)	231	1.265
0.5	1.241		
0.5	1.217 **)	114	1.217
0.5	1.127 **)	223	1.127
0.5	1.076 **)	311	1.076

Note. RKD camera, D = 57,3 mm,  $\text{CuK}\alpha$  radiation (Ni filter), 40kv-5ma. \*) — the lines of westerveldite; \*\*) — the lines common for westerveldite and native antimony.

situated on grain boundaries of this mineral. Aurostibite was encountered in antimony at the contact with quartz as a single isometric crystal, 0.15 mm in diameter. It shows less reflectance than antimony and has a pinkish yellow tint.

The established mineral association — arsenides, antimonides tellurides — is characterized by a distinct deficiency in sulphide sulphur. Hence, solutions from which early native antimony and the above-mentioned minerals were formed contained only insignificant amounts of dissociated  $\text{H}_2\text{S}$ . The role of the latter becomes marked only during the final stages of deposition when antimonite is formed. The antimonides and arsenides described evidently obtained arsenic and antimony from native antimony.

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