Arseniopleite from the Gozaisho Mine, Fukushima Prefecture, Japan

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Abstract   Arseniopleite is found in metamorphosed manganese ore from the Gozaisho mine, Fukushima Prefecture, Japan. It is reddish brown in color and forms aggregates composed of platy crystals in rhodonite-braunite ore in association with sarkinite, brandtite, Ce-bearing romeite, quartz, barite, aegirine, K-feldspar, and albite. The representative chemical analysis by EDS indicates Na_2O 6.39, CaO 5.45, PbO 0.87, MgO 2.84, MnO 25.61, Fe_2O_3 3.52, As_2O_5 55.22, total 99.90 wt.%, and leads to the empirical formula, $(Na_{0.91}Pb_{0.03})_{\Sigma0.94}(Ca_{0.61}Na_{0.39})_{\Sigma1.00}Mn_{1.00}(Mn_{1.28} Mg_{0.44}Fe_{0.28})_{\Sigma2.00}As_{3.03}O_{12}$, on the basis of O=12. The strongest lines in the X-ray powder diffraction pattern are 6.54 (19) (020), 3.28 (22) (040), 3.00 (21) (311), 2.83 (100) (330), 2.80 (30) (400), 2.68 (26) (13$\bar{2}$), and 2.19 (17) (251). The calculated cell parameters from the X-ray powder diffraction data are: a=11.320 (7), b=13.118 (7), c=6.872 (6) Å, β=98.85 (5)°, V=1008 (1) Å^3 in a setting of the space group $P2_1/c$.

Key words :   arseniopleite, arsenate, Gozaisho mine, X-ray, chemical data.

Introduction

The name of arseniopleite has been known since over a hundred year ago. Arseniopleite was found as veinlets and nodules in dolomitic marble of the Sjö mine, Grythytte Parish, Örebro, Sweden (Igelström, 1888). However, it was identical with carynite described by Lundström (1874) until the study by Dunn and Peacor (1987). Now arseniopleite is recognized as a Mn-analogue of carynite, that is, their ideal formulae are $NaCaMnMn_2(AsO_4)_3$ for arseniopleite and $NaCaCaMn_2(AsO_4)_3$ for carynite. Also both species are considered to be members of alluaudite group. The space group of caryinite was determined as $P2_1/c$ by Boström (1958), but Ercit (1993) proposed $I2/a$ by the crystal structure analysis. Dunn and Peacor (1987) examined the space groups of caryinite and arseniopleite by the Weissenberg method and concluded that both are $C2/c$ as same as that of alluaudite (Moore, 1971).

Although three localities of arseniopleite (Sjö and Långban mines, Sweden; Canteloube, France) are known (Gaines *et al.*, 1997), it is still a rare mineral. During the study of manganese arsenates from the Gozaisho mine, we found reddish brown platy crystals resembling brownish aegirine in rhodonite-braunite ore. X-ray powder diffraction study and chemical analysis indicated that it is arseniopleite as the first occurrence in Japan. The Gozaisho mine is unique locality in Japan of many rare manganese arsenates such as sterlinghillite (Matsubara *et al.*, 2000) and wallkilldellite (Matsubara *et al.*, 2001). This paper is for the description of Gozaisho's arseniopleite and the discussion to the space group on the basis of the indexing X-ray powder diffraction data.

Occurrence

The mode of occurrence of manganese arsenates and the location and geology of the Gozaisho mine (36°59.7′N, 140°42.4′E) are already reported in some papers (e.g. Matsubara *et al.*, 1996; Matsubara *et al.*, 2001).

The aggregates of arseniopleite occur as small lenses under 15 mm in length and 5 mm in thickness forming vein-like units in rhodonite-braunite ore. The aggregates are composed of minute platy crystals under 0.2 mm in length (Fig. 1). Distinct cleavage of one direction parallel to *c*-axis is observed. The examined rhodonite-braunite ore includes sarkinite, brandtite, Ce-bearing romeite, quartz, barite, aegirine, K-feldspar, and albite besides arseniopleite. Arseniopleite is frequently replaced by
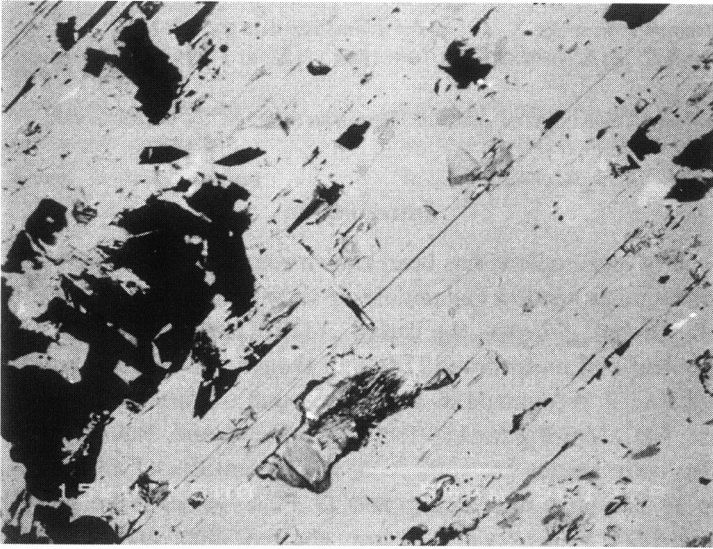

Fig. 1. Back-scattered electron image (BEI) of arseniopleite (light) in association with rhodonite (dark). A bar indicates 50 μm.

brandtite (Fig. 2). The euhedral cerian romeite crystal is included in rhodonite and the chemical zoning with strongly heterogeneous margin is observed (Fig. 3).

Arseniopleite is reddish brown with a pale brown streak resembling the appear-

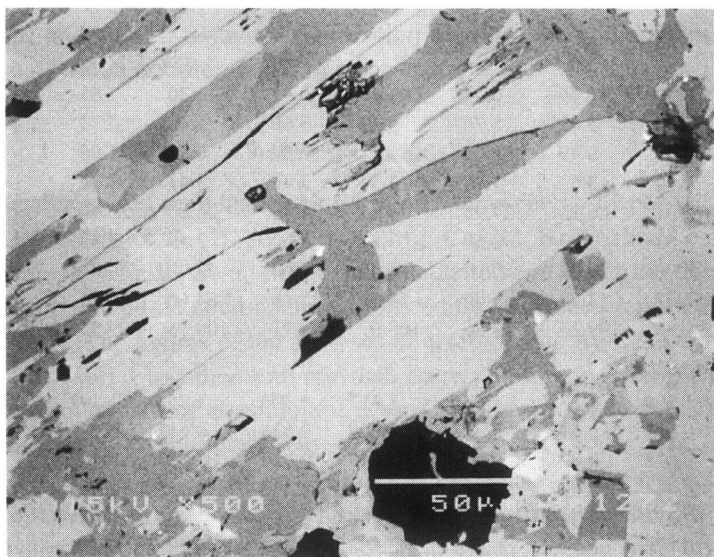

Fig. 2.   Back-scattered electron image (BEI) of arseniopleite (light) and brandite (gray) replacing the margin of arseniopleite. A bar indicates 50 μm.
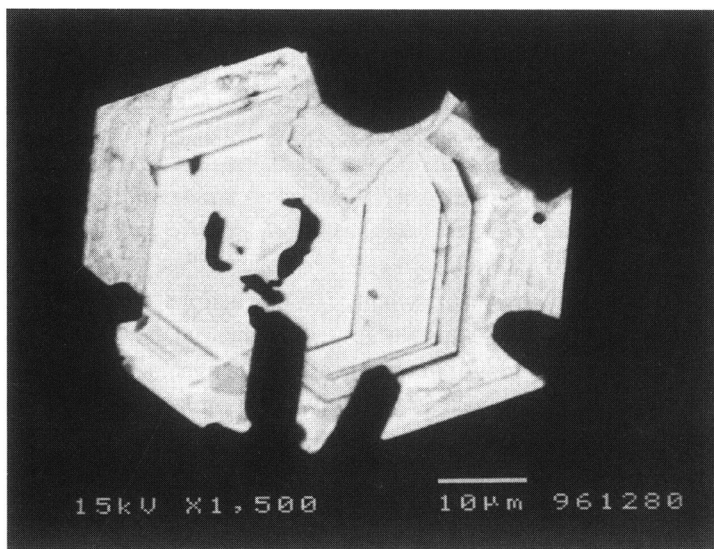

Fig. 3.   Back-scattered electron image (BEI) of Ce-bearing romeite crystal in rhodonite (dark). The chemical zoning is mainly due to Ce content.

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Table 1. Chemical analyses of arseniopleite from the Gozaisyo mine.

	Arseniopleite							"Caryinite"
	1	2	3	4	5	6	7	8
Wt. %								
Na_2O	6.39	6.26	6.34	6.48	6.41	6.20	5.85	4.25
CaO	5.45	5.42	5.76	5.42	5.66	5.45	5.73	18.43
PbO	0.87	0.99	1.06	1.08	0.87	0.84	1.00	1.50
MgO	2.84	3.63	3.06	3.34	3.41	3.41	3.22	2.01
MnO	25.61	26.13	24.95	25.34	24.80	26.00	26.40	17.13
Fe_2O_3	3.52	2.93	3.59	3.86	3.60	3.59	2.82	2.45
Al_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
As_2O_5	55.22	53.90	55.00	54.55	55.16	54.66	54.51	54.03
Total	99.90	99.26	99.76	100.07	99.91	100.15	99.53	99.80
Cations par 12 oxygens								
Na	1.300	1.284	1.291	1.317	1.300	1.258	1.197	0.859
Ca	0.613	0.614	0.648	0.609	0.634	0.611	0.648	2.057
Pb	0.025	0.028	0.030	0.030	0.024	0.024	0.028	0.042
Mg	0.444	0.572	0.479	0.522	0.532	0.532	0.507	0.312
Mn	2.277	2.341	2.220	2.250	2.197	2.304	2.361	1.512
Fe	0.278	0.233	0.283	0.305	0.283	0.282	0.224	0.192
Al	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
As	3.030	2.981	3.021	2.989	3.016	2.991	3.009	2.943
Total cations	4.936	5.073	4.952	5.033	4.969	5.011	4.965	4.974

Table 2. Chemical analyses for rhodonite, brandtite, sarkinite, and Ce-bearing romeite.

Wt. %	Rhodonite	Brandtite	Brandtite	Sarkinite	Romeite	Romeite
SiO_2	47.30	n.d.	n.d.	n.d.	n.d.	n.d.
TiO_2	n.d.	n.d.	n.d.	n.d.	13.03	13.07
Al_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.	0.40
FeO	n.d.	n.d.	n.d.	n.d.	1.74	1.51
MnO	47.59	14.74	15.55	52.88	9.31	8.88
MgO	2.43	0.95	n.d.	n.d.	n.d.	n.d.
CaO	2.75	25.29	25.03	0.37	11.21	11.25
PbO	n.d.	n.d.	0.79	n.d.	n.d.	n.d.
Ce_2O_3	n.d.	n.d.	n.d.	n.d.	13.65	13.66
Sb_2O_5	n.d.	n.d.	n.d.	n.d.	47.46	49.08
As_2O_5	n.d.	52.75	52.01	43.47	n.d.	n.d.
Total	100.07	93.73	93.38	96.72	97.02	97.85

n.d.: not detected

ance of Mn-bearing aegirine at this locality. However, the color of arseniopleite is rather darker than that of aegirine, and also both are easily distinguishable in thin section by the distinct difference of the refractive indices, that is, those of arseniopleite are higher than aegirine. The refractive indices of the present arseniopleite are $\alpha=1.780$ (5) and $\gamma\gg1.810$ by the immersion method. Moh's hardness of arseniopleite is 3 to 4, which is softer than 7 of aegirine.

Chemical Composition

Chemical analyses were made using Link Systems energy dispersive X-ray spectrometer (QX-2000) for Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, As, Sb, Ce and Pb. The contents of Si, Al, Mg, K, Sb and Ce in arseniopleite were under the detection limit. Standard materials and detailed analytical procedure have been reported by Yokoyama *et al.* (1993). The figures of the analyses of arseniopleite from the Gozaisho mine is presented in Table 1 together with one data corresponding to caryinite composition (Ca>Mn) in limited part of arseniopleite crystal. The empirical formula of the representative analysis of arseniopleite (No. 1) is $(Na_{0.91}Pb_{0.03})_{\Sigma0.94}(Ca_{0.61}Na_{0.39})_{\Sigma1.00}Mn_{1.00}$ $(Mn_{1.28}Mg_{0.44}Fe_{0.28})_{\Sigma2.00}As_{3.03}O_{12}$ on the basis of O=12 and total Fe=Fe$_2$O$_3$. The present arseniopleite shows excess Na which partially replaces Ca site. So we estimate Fe to be trivalent in order to balance the total charge. It is reasonable from the result of the original analysis (Fe$_2$O$_3$ 3.68%) by the wet method (Igelström, 1888). Pb is assigned at X2 site as like as caryinite (Ercit, 1993).

While, the empirical formula of No. 8 in Table 1 is $(Na_{0.86}Ca_{0.07}Pb_{0.04})_{\Sigma0.97}Ca_{1.00}$ $(Ca_{0.99}Mn_{0.01})_{\Sigma1.00}(Mn_{1.50}Mg_{0.31}Fe_{0.19})_{\Sigma2.00}As_{2.94}O_{12}$ on the basis of O=12. In comparison with the theoretical formula of caryinite, the result shows obvious excess of Ca. Although there is no example of Ca being assigned at X2 site, no other sites accept the excess Ca. Here, it is referred to as "caryinite".

The representative chemical analyses of the associate rhodonite, brandtite, sarkinite, and romeite are presented in Table 2. The composition of brandtite and sarkinite are nearly close to that of each ideal formula. The empirical formula of romeite is $(Ca_{0.88}Mn_{0.58}Ce_{0.36}Fe_{0.11}Na_{0.09})_{\Sigma2.02}(Sb_{1.29}Ti_{0.71})_{\Sigma2.00}O_6[O_{0.26}(OH)_{0.74}]$ on the basis of $Sb^{5+}+Ti^{4+}=2$ and the estimated OH calculated charge balance. Matsubara *et al.* (1996) already reported the occurrence of romeite from rhodonite-braunite ore excluding manganese arsenates at the Gozaisho mine, but Ce, Mn and Ti were not detected. Some Mn contents are generally known. It is worthy to mention that the present romeite includes significant amounts of Ce and Ti. No REE except Ce were under the detected limit.

X-ray Study

The X-ray powder diffraction data were obtained by a diffractometer using

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Table 3. X-ray powder data for arseniopleite by setting $P2_1/c$.

Gozaisho mine				Sjö mine	
d_{obs}	I	d_{calc}	$h\ k\ l$	d	I
6.54	19	6.56	0 2 0	6.52	40
5.60	6	5.59	2 0 0	5.58	20
4.45	2	4.41	2 1 $\bar{1}$	4.42	30
4.25	4	4.26	2 2 0	4.27	10
4.16	2	4.19	1 2 1	4.13	35
3.81	4	3.81	2 2 $\bar{1}$	3.80	20
3.67	7	3.68	0 3 1	3.65	30
3.590	12	3.586	3 1 0	3.58	30
3.280	22	3.280	0 4 0	3.27	40
3.200	9	3.197	2 3 $\bar{1}$	3.20	20
3.134	6	3.147	1 4 0	3.13	20
2.996	21	2.994	3 1 1	2.993	45
2.903	8	2.904	1 4 $\bar{1}$	2.896	20
2.828	100	2.837	3 3 0	2.825	100
2.799	30	2.796	4 0 0	2.793	40
2.685	26	2.683	1 3 $\bar{2}$	2.676	60
2.574	6	2.572	4 2 0	2.571	20
2.486	3	2.462	3 4 0		
			3 4 $\bar{1}$	2.391	10
2.206	12	2.206	4 2 $\bar{2}$	2.204	25
2.194	17	2.198	2 5 1		
2.144	6	2.140	0 2 3	2.134	20
2.072	2	2.065	4 3 $\bar{2}$	2.063	20
2.043	6	2.047	1 2 3	2.036	30
1.994	10	1.992	5 1 $\bar{2}$	1.991	35
1.933	1	1.933	1 3 3		
1.896	8	1.904	3 4 2	1.895	20
1.871	3	1.864	6 0 0	1.864	20
1.842	12	1.844	5 4 $\bar{1}$	1.841	30
1.803	4	1.806	0 7 1	1.798	20
1.741	1	1.740	2 7 $\bar{1}$		
1.731	1	1.733	5 1 2	1.729	10
1.702	12	1.702	5 5 0		
1.698	13	1.698	0 0 4	1.693	45
1.639	2	1.640	0 8 0	1.631	10
1.621	10	1.621	6 4 0	1.618	25
1.599	3	1.598	7 0 0	1.596	20
1.586	2	1.586	7 1 0		
1.548	13	1.546	4 7 $\bar{1}$	1.542	30
a	11.320 (Å)			11.31 (Å)	
b	13.118			13.06	
c	6.872			6.86	
β	98.85 (°)			99.0 (°)	
				"ICDD 20-224 (Moore, 1968)"	

Table 4.   X-ray powder data for arseniopleite by setting $C2/c$.

Gozaisho mine				Sjö mine	
d_{obs}	I	d_{calc}	$h\ k\ l$	d	I
6.54	19	6.56	0 2 0	6.52	40
5.60	6	5.60	2 0 0	5.58	20
4.45	2	4.42	0 2 1	4.42	30
4.25	4	4.26	2 2 0	4.27	10
4.16	2	4.16	2 2 $\bar{1}$	4.13	35
3.808	4	3.839	3 1 $\bar{1}$	3.80	20
3.666	7	3.637	1 3 $\bar{1}$	3.65	30
3.590	12	3.589	3 1 0	3.58	30
3.280	22	3.280	0 4 0	3.27	40
3.200	9	3.161	1 1 $\bar{2}$	3.20	20
3.134	6	3.152	1 3 1	3.13	20
2.996	21	2.996	0 0 2	2.993	45
2.903	8	2.877	0 4 1	2.896	20
2.828	100	2.830	2 4 0	2.825	100
2.799	30	2.799	4 0 0	2.793	40
		2.799	2 4 $\bar{1}$		
2.685	26	2.685	4 0 $\bar{2}$	2.676	60
2.574	6	2.574	4 2 0	2.571	20
2.486	3	2.485	4 2 $\bar{2}$		
			2 4 1	2.391	10
2.206	12	2.207	5 1 0	2.204	25
2.194	17	2.196	3 5 $\bar{1}$		
2.144	6	2.146	3 5 0	2.134	20
2.072	2	2.077	4 4 $\bar{2}$	2.063	20
2.043	6	2.043	1 5 $\bar{2}$	2.036	30
1.994	10	1.993	5 3 0	1.991	35
1.933	1	1.932	5 1 $\bar{3}$		
1.896	8	1.911	0 2 3	1.895	20
1.871	3	1.869	2 4 2	1.864	20
		1.866	6 0 0		
1.842	12	1.844	2 6 1	1.841	30
		1.839	5 1 1		
1.803	4	1.802	1 7 $\bar{1}$	1.798	20
		1.795	6 2 0		
1.741	1	1.739	5 5 $\bar{2}$		
1.731	1	1.733	6 4 $\bar{1}$	1.729	10
1.702	12	1.703	5 5 0		
1.698	13	1.698	3 7 $\bar{1}$	1.693	45
		1.695	4 6 $\bar{2}$		
1.639	2	1.640	0 8 0	1.631	10
1.621	10	1.622	6 4 0	1.618	25
1.599	3	1.596	3 7 $\bar{2}$	1.596	20
1.586	2	1.588	7 1 0		
1.548	13	1.553	4 6 1	1.542	30
a	12.339 (Å)			* 12.36 (Å)	
b	13.118			13.06	
c	6.605			6.68	
β	114.87 (°)			114.0 (°)	

*: recalculated from ICDD 20-224

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Table 5.   Cell parameters of arseniopleite.

	S.G.	a (Å)	b (Å)	c (Å)	β (°)	V (Å^3)	Method
Gozaisho mine	$P2_1/c$	11.320	13.118	6.872	98.85	1008.3	diffractometer
Gozaisho mine	$P2_1/c$	11.288	13.026	6.840	98.97	993.4	gandolfi camera
Sjö mine	$P2_1/c$	11.31	13.06	6.86	99.0	1000.8	Debye-Scherrer camera (ICDD 20-224)
Gozaisho mine	$C2/c$	12.339	13.118	6.605	114.87	970.1	diffractometer
Gozaisho mine	$C2/c$	12.281	13.026	6.563	114.67	954.0	gandolfi camera
Sjö mine	$C2/c$	12.36	13.06	6.68	114.0	985.1	Debye-Scherrer camera (ICDD 20-224)

Table 6.   X-ray diffraction data for arseniopleite from the Gozaisho mine by a Gandolfi camera.

	$P2_1/c$			$C2/c$	
I	d_{obs}	d_{calc}	$h\ k\ l$	d_{calc}	$h\ k\ l$
s	6.53	6.51	0 2 0	6.51	0 2 0
w	5.57	5.58	2 0 0	5.58	2 0 0
vvw	5.10	5.13	2 1 0	5.13	2 1 0*
vw	4.43	4.40	2 1 $\bar{1}$	4.40	0 2 1
w	4.24	4.24	2 2 0	4.24	2 2 0
m	4.13	4.16	1 2 1	4.13	2 2 $\bar{1}$
m	3.79	3.80	2 2 $\bar{1}$	3.82	3 1 $\bar{1}$
m	3.63	3.65	0 3 1	3.61	1 3 $\bar{1}$
ms	3.58	3.57	3 1 0	3.58	3 1 0
s	3.27	3.26	0 4 0	3.26	0 4 0
w	3.18	3.18	2 3 $\bar{1}$	3.16	2 1 $\bar{2}$ *
mb	3.12	3.13	1 4 0	3.14	1 1 $\bar{2}$
					1 3 1
vs	2.98	2.98	3 1 1	2.98	0 0 2
m	2.89	2.89	1 4 $\bar{1}$	2.86	0 4 1
vvs	2.82	2.82	3 3 0	2.81	2 4 0
s	2.79	2.79	4 0 0	2.79	4 0 0
					2 4 $\bar{1}$
vw	2.73	2.73	4 1 0	2.71	0 2 2
vs	2.67	2.67	1 3 $\bar{2}$	2.67	4 0 $\bar{2}$
w	2.56	2.56	4 2 0	2.56	4 2 0
w	2.47	2.50	2 2 2	2.47	4 2 $\bar{2}$
		2.45	3 4 0		
vw	2.38	2.38	3 4 $\bar{1}$	2.36	2 4 1
vw	2.32	2.31	4 3 $\bar{1}$	2.30	2 4 $\bar{2}$
m	2.20	2.20	4 2 $\bar{2}$	2.20	5 1 0
w	2.13	2.13	0 2 3	2.13	3 5 0
w	2.06	2.06	4 3 $\bar{2}$	2.06	4 4 $\bar{2}$

Table 6.   (continued).

I	$P2_1/c$			$C2/c$	
	d_{obs}	d_{calc}	$h\ k\ l$	d_{calc}	$h\ k\ l$
m	2.02	2.04	1 2 3	2.03	1 5 $\bar{2}$
m	1.980	1.987	5 1 $\bar{2}$	1.985	5 3 0
vvw	1.919	1.922	1 3 3	1.919	5 1 $\bar{3}$
m	1.884	1.893	3 4 2	1.878	3 2 2*
vw	1.860	1.858	6 0 0	1.860	2 4 2
					6 0 0
m	1.836	1.836	5 4 $\bar{1}$	1.834	5 1 1
vw	1.792	1.794	0 7 1	1.789	1 7 $\bar{1}$
s	1.689	1.689	0 0 4	1.687	3 7 $\bar{1}$
vvw	1.628	1.628	0 8 0	1.628	0 8 0
w	1.614	1.614	6 4 0	1.614	2 2 3
vw	1.590	1.590	4 6 $\bar{2}$	1.591	3 2 4
			3 7 1		4 7 $\bar{1}$*
m	1.539	1.540	6 4 $\bar{2}$	1.539	2 6 $\bar{3}$
		1.538	2 8 $\bar{1}$		
w	1.513	1.514	4 2 $\bar{4}$	1.514	7 3 $\bar{3}$
w	1.490	1.490	6 2 2	1.491	0 0 4
vw	1.475	1.476	3 8 $\bar{1}$	1.473	1 3 $\bar{4}$
w	1.423	1.424	2 7 $\bar{3}$	1.423	5 4 $\bar{4}$*
w	1.406	1.406	4 8 0	1.406	4 8 0
vw	1.390	1.389	7 4 $\bar{2}$	1.390	4 8 $\bar{2}$
w	1.372	1.370	5 7 1	1.373	7 5 $\bar{3}$
vvw	1.354	1.354	4 0 4	1.354	7 3 $\bar{4}$
vw	1.347	1.347	4 1 4	1.346	6 0 2
w	1.330	1.330	0 9 2	1.330	5 8 $\bar{2}$*
vvw	1.279	1.279	0 10 1	1.282	8 4 0
vw	1.265	1.265	4 6 $\bar{4}$	1.264	4 4 3
vw	1.256	1.255	7 1 $\bar{4}$	1.259	9 4 $\bar{2}$*
vvw	1.235	1.235	6 4 3	1.234	8 4 $\bar{4}$
vw	1.189	1.189	8 4 $\bar{3}$	1.189	7 8 $\bar{2}$*
vvw	1.148	1.149	4 6 4	1.148	2 8 $\bar{4}$
		1.147	0 6 $\bar{5}$		
vvw	1.135	1.135	7 5 $\bar{4}$	1.136	10 2 $\bar{4}$
vvw	1.125	1.125	4 8 $\bar{4}$	1.126	5 5 3
vvw	1.117	1.117	7 8 $\bar{2}$	1.118	10 4 $\bar{1}$
vvw	1.107	1.107	8 5 2	1.108	6 8 $\bar{4}$
vvw	1.088	1.089	2 10 3	1.089	8 8 $\bar{3}$
a	11.288 (Å)			12.281 (Å)	
b	13.026			13.026	
c	6.840			6.563	
β	98.97 (°)			114.67 (°)	

*: not permitted by space group.

Cu/Ni radiation. The diffraction data of arseniopleite are given in Tables 3 and 4, in which those of arseniopleite from the Sjö mine, Sweden (Moore, 1968) were compared. Table 3 and 4 show the indexing of ($h\,k\,l$) in setting of the space groups, $P2_1/c$ and $C2/c$, respectively. In Table 4 the data from the Sjö mine are recalculated from the original space group, $P2_1/c$. The calculated cell parameters for the present arseniopleite are $a=11.330$, $b=13.095$, $c=6.872$ Å, $\beta=98.85°$ for $P2_1/c$ setting, and $a=12.339$, $b=13.118$, $c=6.605$ Å, $\beta=114.87°$ for $C2/c$ setting. The reported cell parameters of arseniopleite are summarized in Table 5. Arseniopleite is generally considered to be isostructural with alluaudite with space group $C2/c$ (e.g. Dunn and Peacor, 1987; Gaines *et al.*, 1997). However, our X-ray powder data indicate that the space group fits to the previously known $P2_1/c$ rather than $C2/c$, because the difference between observed and calculated d-spacing in the case of $P2_1/c$ is smaller than $C2/c$. Also, the very weak reflections violating C-centering rule are observed in the long exposure X-ray diffraction photograph by a Gandolfi camera (Table 6).

Conclusions

The general formula for arseniopleite and caryinite is [X2][X1][M1][M2]$_2$As$_3$O$_{12}$, X2=Na, Pb; X1=Ca, Na; M1=Mn, Ca; M2=Mn, Mg, Fe. Arseniopleite dominates Mn in M1 site. The results of the chemical analyses are illustrated in Figures 4 and 5. Both indicate that the present analyses are good agreement with the general formula.

Although we consider the space group of Gozaisho material to be $P2_1/c$, $C2/c$ is realized in Sjö material as reported by Dunn and Peacor (1987). This may suggest that two different types of arseniopleite exist.
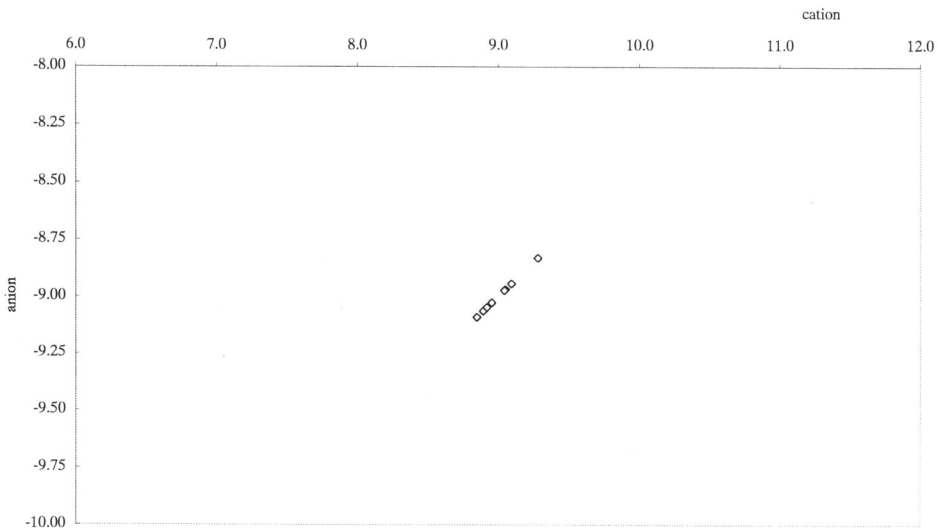

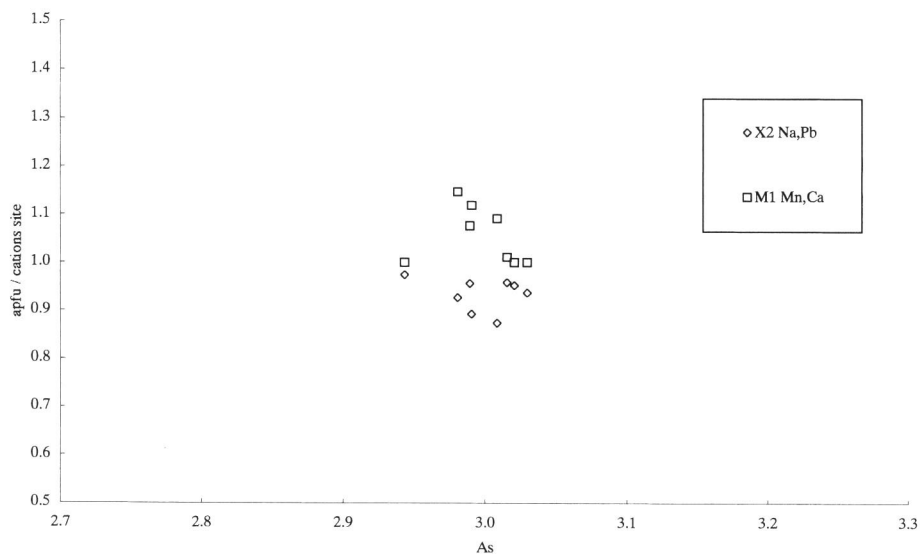Fig. 4.   The charge diagram between anion and cations. The ideal position is $(-9, 9)$.

Fig. 5. The apfu diagram between As and four cation sites. The ideal apfu are 3 for As, 1 for [X2] and 1 for [M1].

Arseniopleite might be formed prior to the formation of hydrous manganese arsenates such as brandtite and sarkinite during the latter stage of metamorphism.

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