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The Occurrence of Ferro-gedrite from the Kawai Mine, Ena, Gifu Prefecture, Japan

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Introduction

Ferro-gedrite is a rather uncommon amphibole and representatively known in FeO and Al_2O_3 rich hornfels from the western slope of Mt. Yakushi, Miyamori Village, Iwate Prefecture, Japan (SEKI & YAMASAKI, 1957), referred to as aluminian ferroanthophyllite at that time. The present report is for the new occurrence of this mineral in association with a high alumina annite, almandine and gahnite in the country rock of disseminated lead-zinc ore deposit of the Kawai Mine, Ena City, Gifu Prefecture, Japan.

Occurrence

The ore deposit of the Kawai Mine is located in the right side of the Kiso River and about 10 km WNW of Ena Station, Chūo Line, Japan National Railway (Fig. 1). The mine is said to have been worked for lead and zinc during the World War II and at present the access is only possible through the observation of dump rocks around the mining site where the studied materials were collected, and nearby the locality is exposed a quartz porphyry, which is a member of acidic intrusive and pyroclastic complex called Nohi Rhyolite (YAMADA *et al.*, 1971).

The dump consists of deep greenish black massive rocks in which at least four kinds of rocks are distinguished with the aid of microscopic observation. That is, in the decreasing order of appearance, 1) almandine–annite–quartz rock with minor gahnite, 2) ferro-gedrite–annite–almandine–quartz rock with minor gahnite, 3) annite–white mica–quartz rock with minor almandine and gahnite, and 4) diopside–anorthite–quartz rock comprising disseminated sphalerite, galena and minor chalcopyrite. Seeing from the existence of sulphide in the last kind of rock, these rocks can be dealt with as the country rocks in the ore deposit.

Macroscopically ferro-gedrite has deep greenish black colur in the fresh surface and a vitreous lustre. The streak is grey green. A perfect cleavage, possibly {110}, is

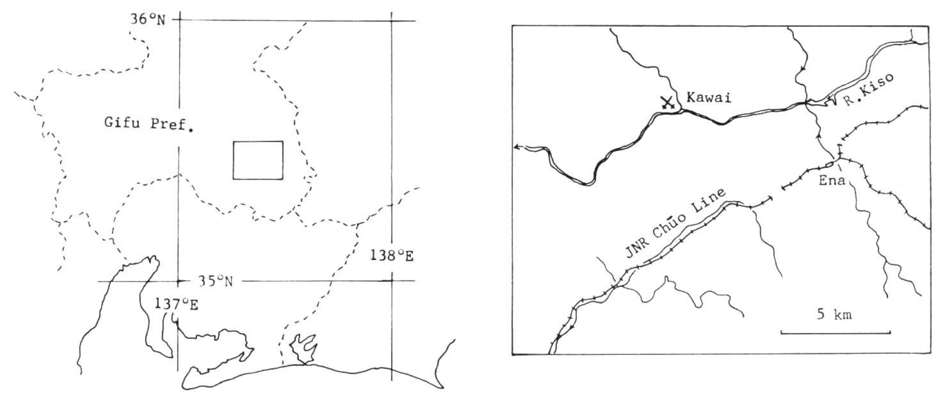

Fig. 1. Index map of the Kawai Mine (crossed hammar mark).

well developed. It forms subparallel aggregates composed of fibres reaching 10 mm long, and in the aggregates brownish red trapezohedral grains of almandine reaching 3 mm across are commonly disseminated. Quartz forms less greenish patches, but gahnite grains are too small to be macroscopically discerned. Besides them are observed white films of halloysite along fractures.

Under the microscope, fibrous ferro-gedrite and idiomorphic almandine, aggregate of annite flakes and subround quartz are the predominant constituents in the second kind of rock (Fig. 2). Besides them octahedral to subhedral gahnite grains less than 0.3 mm across are found (Fig. 3). A part of ferro-gedrite is replaced by non-oriented aggregates of minute annite flakes. The interstitial parts to almandine grains and ferro-gedrite fibre aggregates consist of aggregates of quartz and annite flakes, both being the order of 0.0n mm in size. Within almandine and ferro-gedrite crystals are found small amounts of ilmenite and zircon, the latter being accompanied by pleochroic halo. In the sample from which the analysed mineral grains were obtained, the mode of constituent minerals determined by measurements under the microscope is: Ferro-gedrite 33.1, annite 30.8, almandine 19.3, quartz 14.3, gahnite 1.9, others (principally ilmenite) 0.6%.

Ferro-gedrite is pleochroic from light straw yellow to bluish green through light brownish yellow green. Almandine is nearly colourless and neither colour zonation nor optical anomaly is observed. Annite is rather weakly pleochroic as compared with ordinary biotite and the axial colours are very light greyish brown and light

Table 1. Refractive indices and 2V of ferro-gedrite, almandine, annite and gahnite.

	Refractive indices	2V
ferro-gedrite	$\alpha=1.700$ (2), $\beta=1.715$ (5), $\gamma=1.725$ (5)	(−) 80～85°
almandine	n=1.83 (1)	
annite	$\alpha=1.618$ (2), $\beta\fallingdotseq\gamma=1.682$ (2)	(−) <5°
gahnite	n=1.815 (5)	

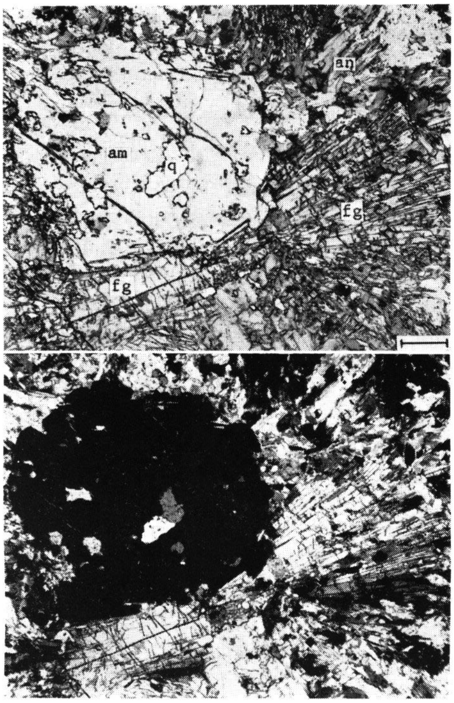

Fig. 2.

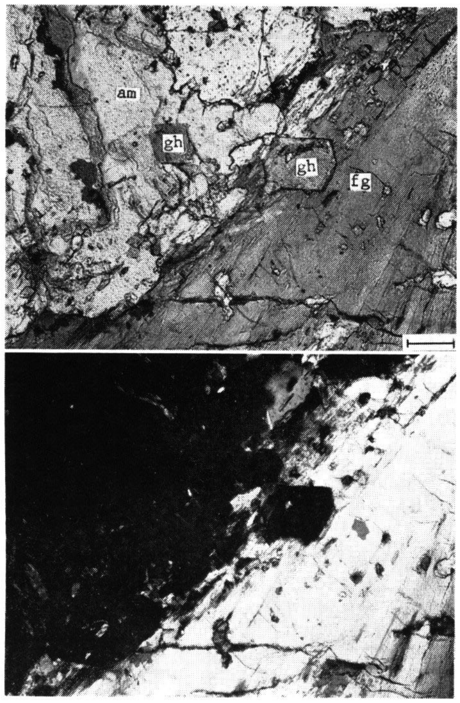

Fig. 3.

Fig. 2. Photomicrographs of fibrous ferro-gedrite (fg) and idiomorphic almandine (am) including quartz (q). Aggregates of annite (an) flakes are observed in the interstitial parts to ferro-gedrite and almandine. Bar indicates 0.2 mm. Above: one polar. Below: crossed polars.

Fig. 3. Photomicrographs of octahedral gahnite (gh) grains included in ferro-gedrite (fg) and almandine (am). Bar indicates 0.1 mm. Above: one polar. Below: crossed polars.

brown. Gahnite is pale bluish green in colour and more bluish than the associated ferro-gedrite even in the orientation with the most strongly bluish tint. The other optical data for these minerals are given in Table 1.

X-ray Powder Studies

The X-ray powder diffraction pattern of ferro-gedrite (NSM M–23272) is obtained by the diffractometer method using Co/Fe radiation as given in Table 2 in which that of the Miyamori material (Seki and Yamasaki, 1957) is compared. The unit cell parameters calculated from the pattern are: *a* 18.600, *b* 17.691, *c* 5.323 Å, all of which are somewhat larger than those of the Miyamori material, reflective of the compositional variation represented by the higher Na_2O content.

The X-ray powder studies were also made on annite, almandine and gahnite for their characterization. The figure of $c \cdot \sin\beta$ of the first material is 10.041 Å, which is

Table 2. X-ray powder diffraction pattern of ferro-gedrite.

	1		2				1		2		
hkl	d	I	$d_{obs.}$	$d_{calc.}$	I	hkl	d	I	$d_{obs.}$	$d_{calc.}$	I
020	9.06	12	8.99	8.98	8	560				2.332	
210	8.22	100	8.27	8.26	80	800			2.328	2.325	6
230	5.019	3	5.041	5.034	6	551	2.318	4		2.325	
400	4.629	10	4.650	4.650	18	830			2.167	2.167	4
040	4.483	6	4.490	4.490	5	502	2.159	5		2.165	
420	4.108	4	4.129	4.129	5	561	2.131	3	2.135	2.136	10
131	3.879	3	3.888	3.890	3	661	1.990	4	1.998	1.996	10
231	3.650	6	3.659	3.658	5	751	1.977	3	1.979	1.983	12
440	3.219	21	3.231	3.230	15	670	1.971	3		1.977	
610	3.041	76	3.056	3.055	100	702	1.874	4	1.882	1.881	4
521	2.879	5	2.887	2.887	8	552			1.855	1.854	6
260	2.845	3				931	1.827	4	1.834	1.834	8
251	2.833	6	2.835	2.836	4	$6\underline{10}0$			1.554	1.554	20
630	2.742	3	2.754	2.753	10	$\underline{12}00$			1.549	1.550	20
351	2.677	9	2.684	2.684	12	533				1.547	
161	2.580	9	2.582	2.584	10	772			1.517	1.517	10
202	2.554	8	2.559	2.559	6	$\underline{11}41$				1.517	
451	2.503	9	2.508	2.508	25	$0\underline{12}0$			1.498	1.497	4
302	2.440	3				$\underline{11}12$				1.423	
650	2.340	3	2.348	2.347	3	$\underline{12}50$			1.422	1.423	10
						$8\underline{10}0$				1.421	

1. Mt. Yakushi, Miyamori, Iwate Pref., Japan (SEKI & YAMASAKI, 1957).
2. Kawai Mine, Ena, Gifu Pref., Japan.

somewhat smaller than the those for ordinary biotites. The unit cell parameters of almandine and gahnite are 11.541 Å and 8.112 Å, respectively. The former is very close to that of synthetic $Fe_3^{2+}Al_2(SiO_4)_3$, 11.526 Å after SKINNER (1956), and the latter is reasonable when the unit cell parameters of synthetic $ZnAl_2O_4$ (8.0848 Å)(JCPDS Card No. 5–0672) and of $FeAl_2O_4$ (8.135 Å)(STRUNZ, 1970) are taken into consideration with respect to the chemical compositions given in the next chapter.

Chemical Analyses

Two microprobe analyses of ferro-gedrite (NSM M–23272) are given in Table 3. Seeing from the close co-existence of almandine, the total iron is taken as Fe^{2+}, and this interpretation does not deliver any unreasonable formulae of ferro-gedrite. Except for insignificant differences in Al_2O_3 and Na_2O contents, they represent the chemical compositions close to $Na_{0.5}Fe_{5.5}^{2+}Al_{1.5}Si_6Al_2O_{22}(OH)_2$ after additions of H_2O, which require 1.85% and 1.88% H_2O for them, respectively, giving totals, 99.32% and 100.34%, respectively. The analysed materials are intermediate members between ideal ferro-gedrite ($Fe_5Al_2Si_6Al_2O_{22}(OH)_2$) and 'sodium ferro-gedrite' ($NaFe_6AlSi_6Al_2O_{22}(OH)_2$), which is unknown to date, and close to the latter member. According to the nomenclature system of amphibole (LEAKE, 1978), the present material is termed as sodian ferro-gedrite.

The microprobe analyses of two annites and one gahnite are given in Table 4 and 5, respectively. The two analyses of the former demonstrate the lower SiO_2 and higher Al_2O_3 contents as compared with theoretical annite, specifying them as high alumina annites, as approximately given by the ideal formula $KFe^{2+}_{2.5}Al_{0.5}Si_{2.5}Al_{1.5}O_{10}(OH)_2$. The lower totals in the given analyses are obviously due to the neglect of watery com-

Table 3. Electron microprobe analyses of ferro-gedrite.

	Weight percent			Molecular numbers on the basis of O=23	
	1	2		1	2
SiO_2	36.53	37.28	Si	5.91	5.93
TiO_2	0.07	0.06	Ti	0.01	0.01
Al_2O_3	18.80	19.60	Al	3.59	3.68
FeO	39.18	38.79	Fe	5.30	5.16
MnO	0.42	0.33	Mn	0.06	0.04
MgO	0.30	0.35	Mg	0.07	0.08
CaO	0.11	0.09	Ca	0.02	0.02
Na_2O	2.06	1.74	Na	0.65	0.54
K_2O	0	0.22	K	0	0.04
Total	97.47	98.46			

Empirical formula

1. $Na_{0.61}(Fe_{5.30}Al_{1.50}Mg_{0.07}Mn_{0.06}Na_{0.04}Ca_{0.02}Ti_{0.01})_{\Sigma 7.00}(Si_{5.91}Al_{2.09})_{\Sigma 8.00}O_{23}$
2. $(Na_{0.46}K_{0.04})_{\Sigma 0.50}(Fe_{5.16}Al_{1.61}Mg_{0.08}Na_{0.08}Mn_{0.04}Ca_{0.02}Ti_{0.01})_{\Sigma 7.00}(Si_{5.93}Al_{2.07})_{\Sigma 8.00}O_{23}$

Table 4. Electron microprobe analyses of annite.

	Weight percent			Molecular numbers on the basis of O=11	
	1	2		1	2
SiO_2	32.56	32.57	Si	2.69	2.68
TiO_2	1.48	1.44	Ti	0.09	0.09
Al_2O_3	17.24	17.30	Al	1.68	1.68
FeO	34.25	34.43	Fe	2.36	2.37
MnO	0.03	0.03	Mn	0	0
MgO	0.86	0.89	Mg	0.11	0.11
CaO	0	0	Ca	—	—
Na_2O	0.28	0.32	Na	0.04	0.05
K_2O	8.20	8.06	K	0.86	0.85
Total	94.90	95.04			

Emirical formula

1. $(K_{0.86}Na_{0.04})_{\Sigma 0.90}(Fe_{2.36}Al_{0.37}Mg_{0.11}Ti_{0.09})_{\Sigma 2.93}(Si_{2.69}Al_{1.31})_{\Sigma 4.00}O_{11}$
2. $(K_{0.85}Na_{0.05})_{\Sigma 0.90}(Fe_{2.37}Al_{0.36}Mg_{0.11}Ti_{0.09})_{\Sigma 2.93}(Si_{2.68}Al_{1.32})_{\Sigma 4.00}O_{11}$

Table 5. Electron microprobe analysis of gahnite

	1	2	
TiO_2	0.05	0	1. Weight percent
Al_2O_3	56.66	1.98	2. Molecular numbers
FeO	19.41	0.48	on the basis of
MnO	0.09	0	O=4
MgO	0.06	0	
ZnO	24.68	0.54	
Total	100.94		

Table 6. Electron microprobe analysis of almandine

	1	2		
SiO_2	35.79	2.96	1. weight percent	
Al_2O_3	20.64	2.01	2. Molecular numbers	
TiO_2	0.04	0	on the basis of	
CaO	0.72	0.06	O=12	
Na_2O	0.03	0	almandine	96.4
FeO	42.61	2.95	grossular	2.0
MnO	0.62	0.04	spessartine	1.3
MgO	0.09	0.01	pyrope	0.3
Total	100.54			

ponents, which will ideally be H_2O 3.63% in the former and 3.64% in the latter, respectively, leading to the totals, 98.53% and 98.68%, respectively.

The chemical composition of gahnite (Table 5) is characterized by its very high FeO content, which allows the mineral to be specified as a ferroan gahnite.

Also the microprobe analysis of the associated almandine presents an interesting example, that is, the almandine closest to theoretical $Fe_3Al_2(SiO_4)_3$ than any other almandine hitherto described (Table 6). The re-calculation of analysis into end member molecules gives almandine 96.4, grossular 2.0, spessartine 1.3, and pyrope 0.3%.

Geochemical Interpretation

On account of absence of any material from which the genesis of described peculiar rock and ferro-gedrite can be deciphered, no discussion about the genesis is to be made. But seeing from the variation in grain size of the minerals in the ferro-gedrite-bearing rock and from the differences in the mineral components of the dump rocks, the described rock comprising ferro-gedrite may be of metasomatic origin, though the nature of original rock is unknown.

Orthoamphibole of such an assemblage has never been reported to date. The minerals in the described assemblage are all characterized by their higher FeO contents, suggesting the formation under a reducing condition. This might be responsible for the absence of magnetite in the observed dump rocks. Also the presence of gahnite might have been favoured by a condition with lower sulphur fugacity at the time of formation of gahnite-bearing rocks. As far as observed, no sulphides are found in the gahnite-bearing rocks.

Alike to the case of ferro-gedrite from Miyamori, the mineral assemblage of the present ferro-gedrite includes quartz. This suggests the stable formation of ferro-gedrite under a silica saturated condition despite its low silica composition. The presence of quartz should also be referred to as to the formation of high alumina annite. Its approximate composition $KFe^{2+}_{2.5}Al_{0.5}Si_{2.5}Al_{1.5}O_{10}(OH)_2$ contains excess Al in the form of $Al^{[6]}_{0.5}+Al^{[4]}_{0.5}$ as the result of a coupled diadochy AlAl for $Fe^{2+}Si$, which is not uncommon in micas. It is thus worth mentioning that the formation of such an alumina excess and low silica mica is found in the assemblage including quartz.

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