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Ferroan Gahnite from Quartz-Biotite-Almandine Schist, Wind River Mountains, Wyoming

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Abstract

Ferroan gahnite, with compositions ranging from gahnite$_{60}$-hercynite$_{30}$-Mg spinel$_{10}$ to hercynite$_{49}$-gahnite$_{38}$-Mg spinel$_{13}$, have been found in quartz-biotite-almandine metasedimentary rocks from the Double Lake area of the Wind River mountains of Wyoming. It is believed that the large amount of zinc in these spinels, which seems to have been provided by desulfurization of nearby ore minerals, stabilized them in the presence of quartz.

Introduction

Ferroan gahnite, occurring with quartz, biotite, and almandine, has been found in several rocks from the Double Lake area in the northeastern Wind River Mountains, Fremont County, Wyoming. The locality is 24 kilometers by trail southwest of the nearest trailhead, Trail Lake Ranch, which itself is 19 kilometers by dirt road from the nearest town, Dubois.

The area is underlain by a Precambrian gneiss complex, which has undergone middle-to-upper amphibolite facies metamorphism. The complex shows two periods of igneous intrusion and migmatization; one event is synmetamorphic, the other, post-metamorphic. The pre-migmatitic rocks can be divided into two types, a hornblende-calcic andesine amphibolite, and a metasedimentary schist (Frost, 1971). The amphibolite body, the western margin of which is cut by a post-metamorphic batholith, is exposed over an area of about five square kilometers. The eastern contact of the body is locally discordant to the foliation of the metasedimentary schist and is commonly marked by a three-meter-wide zone of red-weathering metasedimentary schist. Many parts of this red-weathering zone contain as much as 15 percent opaque minerals. The major opaque mineral is magnetite. Pyrite is fairly common, usually rimmed by hematite. Chalcopyrite and sphalerite are rare.

Four of the seven samples found to contain ferroan gahnite were collected from such a red-weathering zone over a distance of a kilometer. The other three samples did not show the distinctive red weathering, but also came from within a hundred meters of the amphibolite-metasediment contact. Three samples containing the spinel were selected for microprobe analysis. Two, ZS-1 and ZS-2, came from the red-weathering metasedimentary schist. They both contain about 15 percent garnet, in crystals up to 1 cm in diameter. They also contain 20 percent biotite and 60 percent quartz. In sample ZS-1 the spinel occurs throughout the sample, but in sample ZS-2 it is restricted to a centimeter-wide quartz-rich layer. Sample ZS-3 does not show the distinctive red weathering. It displays a compositional layering with one layer enriched in quartz and containing green biotite, garnet, and rare spinel, and with the other layer enriched in brown biotite and containing quartz, spinel, and minor garnet. Such compositional layering may exist in ZS-1 and ZS-2 also, as spinel occurring with biotite differs in composition from that occurring with garnet in all three samples (Table 1). All three samples contain minor plagioclase, zircon, apatite, and opaque minerals. The major opaque mineral is ilmenite; pyrite is rare. Hematite is a common secondary mineral, causing the red stains. Masses of finely intergrown chlorite occur locally in some samples and may have formed from retrogressive breakdown of cordierite. However, no definite cordierite was found in any rock in the area.

In all occurrences, the spinel forms small, rounded to subhedral grains which are dark green in thin section. They show smooth, generally convex interfaces, with textures suggesting equilibrium with all phases in the rock, including quartz (Fig. 1). It was the apparent textural equilibrium with quartz that prompted a closer inspection of the spinel.

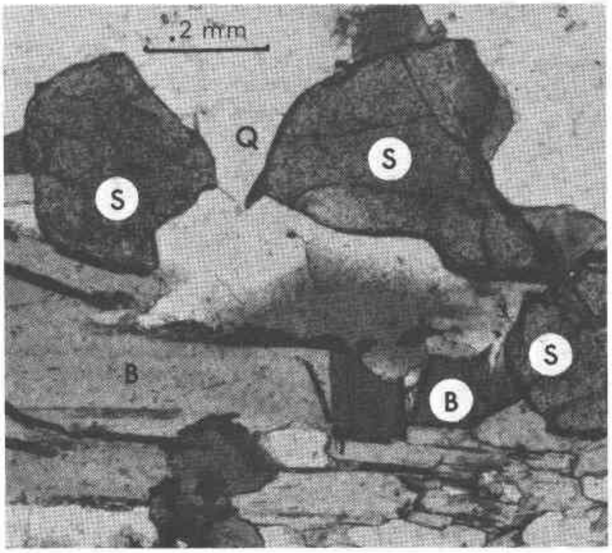

FIG. 1. Photomicrograph of sample ZS-1 showing stable association of green spinel and quartz. B = biotite; Q = quartz; S = spinel (PPL).

Methods of Analysis

Microprobe analyses of spinel, biotite, and garnet (Table 1) were conducted on carbon-coated polished thin sections. Five elements were measured simultaneously using an Applied Research Laboratories EMX-SM unit. Acceleration voltages of 15 kV for the major elements, and 20 kV for the minor elements, were used. Ten to twenty points were measured on each grain analyzed. No variations were noted either within grains or between grains of the same group. Full corrections were applied for X-ray absorption, characteristic fluorescence, atomic number effect, dead time, drift, and background. Standards used include an analyzed suite of garnets and biotites and, for the spinels, analyzed franklinite and synthetic $MgAl_2O_4$. In garnet and spinel FeO and Fe_2O_3 were computed from total iron assuming perfect stoichiometry.

Results

The ferroan gahnite is a mixture of gahnite, hercynite, and Mg-spinel with the R^{+++} site largely occupied by Al. Assuming that the minor Fe^{+++} is distributed evenly among the end members, compositions range from gahnite$_{60}$-hercynite$_{30}$-Mg Spinel$_{10}$ to hercynite$_{49}$-gahnite$_{39}$-Mg Spinel$_{13}$. These spinels contain considerably more of the hercynite molecule than gahnites reported by Winchell (1941) and the ferroan gahnites reported by Gandhi (1971). They are similar to spinel reported by Hutton (1957) from river gravel in New Zealand.

The analyses show that zinc is preferentially in-

TABLE 1. Analyses of Spinel, Biotite, and Garnet from the Double Lake Area, Wind River Mountains, Fremont County, Wyoming

SPINEL	ZS-1 with Biotite	ZS-1 with Garnet	ZS-2 with Biotite	ZS-2 with Garnet	ZS-3 with Biotite	ZS-3 with Garnet
Al_2O_3	56.3	56.2	56.7	56.7	55.4	56.3
Fe_2O_3*	1.34	1.76	2.77	2.42	2.42	2.04
FeO	13.7	15.0	20.0	16.4	12.1	13.1
MgO	1.87	2.36	2.96	3.27	2.25	2.33
MnO	.02	.02	.04	.02	.22	.19
ZnO	26.3	24.0	18.0	21.3	26.9	26.2
TOTAL	99.53	99.34	100.47	100.11	99.29	100.16
CATION PROPORTIONS	on the basis of 32 Oxygens					
Al	15.760	15.687	15.515	15.576	15.566	15.638
Fe^{+3}	.240	.313	.485	.424	.434	.362
Fe^{+2}	2.721	2.966	3.882	3.194	2.421	2.584
Mg	.662	.833	1.024	1.136	.800	.818
Mn	.004	.004	.008	.004	.044	.038
Zn	4.613	4.197	3.086	3.666	4.735	4.559
ΣR^{+2}	8.000	8.000	8.000	8.000	8.000	7.999
Fe / Fe+Mg	.804	.781	.791	.738	.751	.760

All have less than .02 % Cr_2O_3, TiO_2

* = Fe_2O_3 calculated assuming perfect stochiometry

BIOTITE	ZS-1	ZS-2	ZS-3
SiO_2	34.3	34.0	34.3
TiO_2	1.54	1.16	1.25
Al_2O_3	18.2	19.1	19.1
FeO	21.0	19.6	19.1
MgO	10.0	10.5	10.4
MnO	.04	.05	.16
ZnO	.20	.52	.28
K_2O	8.70	8.36	9.48
Na_2O	.45	.55	.19
TOTAL	94.43	93.84	94.26
CATION PROPORTIONS	basis of 22 Oxygens		
Si	5.324	5.273	5.303
Al IV	2.676	2.727	2.697
Al VI	.654	.764	.783
Ti	.180	.135	.145
FeO_{tot}	2.726	2.542	2.470
Mg	2.314	2.427	2.397
Mn	.005	.007	.021
Zn	.023	.060	.032
Total Y ions	5.902	5.935	5.848
K	1.723	1.654	1.870
Na	.135	.165	.057
Total X ions	1.858	1.819	1.927
Fe / Fe+Mg	.541	.512	.507

GARNET	ZS-1	ZS-2	ZS-3
SiO_2	37.2	37.9	37.8
Al_2O_3	19.7	19.9	19.9
Fe_2O_3	1.77	2.00	1.74
FeO	35.5	34.7	30.3
MgO	3.22	4.26	3.48
MnO	1.40	1.39	6.20
CaO	1.07	.84	1.24
ZnO	*	*	*
TOTAL	99.86	100.99	100.66
CATION PROPORTIONS	basis of 24 Oxygens		
Si	6.030	6.036	6.052
Al	3.764	3.736	3.755
Fe^{+3}	.216	.240	.210
Fe^{+2}	4.814	4.621	4.064
Mg	.825	1.011	.830
Mn	.180	.187	.841
Ca	.199	.143	.213
Zn	.000	.000	.000
Total R^{+2}	6.018	5.962	5.948
Fe / Fe+Mg	.854	.820	.830

* = below detection

cluded in the spinel and almost completely excluded from the garnet. The ZnO content of the garnet is below a detection limit of 0.03 percent. This is in agreement with Knorring (1946) who found that a garnet coexisting with sphalerite contained less than 0.01 percent ZnO.

The biotite coexisting with the spinel contains up to 0.5 percent ZnO. It is apparent that micas can accept fairly large amounts of zinc, *e.g.* see analyses of zinc micas from Franklin Furnace, New Jersey (Frondel and Ito, 1966). Sample ZS-3 contains two types of biotite. The brown biotite from the spinel-bearing layers contains more TiO_2 than the green biotite from the garnet-bearing layers. The biotites from the other samples are more nearly homogeneous, although those coexisting with the spinel are slightly richer in iron and poorer in magnesium than those coexisting with the garnet.

The $Fe^{2+}/(Fe^{2+} + Mg)$ ratios (Tables 2 and 3) indicate that the order of preference for Fe^{2+} over Mg is garnet > spinel > biotite. The preference of iron for spinel over coexisting biotite can also be seen in analyses by Stewart (1942). The distribution of iron and magnesium between garnet and spinel (Table 2), however, differs from the results of Stewart (1942), Knorring and Dearnley (1960), and Abraham and Schreyer (1971).

Discussion

Green spinel in pelitic metamorphic rocks is ordinarily considered to be indicative of silica undersaturation, *e.g.*, Friedman (1954). For Mg-spinel-hercynite solid solutions at metamorphic temperatures, the presence of quartz stabilizes the right hand side of the following equilibria (*cf* Richardson, 1968, Fig. 6):

$$3\ \underset{\text{hercynite}}{FeAl_2O_4} + 5\ \underset{\text{quartz}}{SiO_2} = \underset{\text{almandine}}{Fe_3Al_2Si_3O_{12}} + 2\ \underset{\text{sillimanite}}{Al_2SiO_5}$$

$$2\ \underset{\text{spinel}}{MgAl_2O_4} + 5\ \underset{\text{quartz}}{SiO_2} = \underset{\text{cordierite}}{Mg_2Al_4Si_5O_{18}}$$

One would expect, therefore, that spinel in quartzose metasediments would not be greatly enriched in either iron or magnesium. However, as shown above, zinc is preferentially included in spinel and almost totally excluded from garnet. This indicates that in zinc-rich environments spinel and quartz would be stabilized relative to almandine and sillimanite, or to cordierite.

TABLE 2. $Fe^{+2}/(Fe^{+2} + Mg)$ for Coexisting Spinel and Garnet

Reference	Spinel	Garnet	Remarks
Stewart, 1942	.895	.826	Hercynite from Hornfels
Knorring, 1946 Pehrman, 1948	.950	.999	Gahnite-Spessartine from pegmatite
Knorring and Dearnley (1960)	.975	.945	Gahnite-Spessartine from pegmatite
Abraham and Schreyer, 1971	.89	.87	from ironstone hornfels
This paper:			
ZS-1	.781	.854	ferroan gahnite-
ZS-2	.738	.820	almandine pair
ZS-3	.760	.830	from schist

TABLE 3. $Fe^{+2}/(Fe^{+2} + Mg)$ for Coexisting Spinel and Biotite

Reference	Spinel	Biotite	Remarks
Stewart, 1942	.895	.574	from Hornfels
Abraham and Schreyer, 1971	.895	.621	from ironstone hornfels
This paper:			
ZS-1	.804	.541	ferroan gahnite-
ZS-2	.791	.512	almandine pair
ZS-3	.751	.507	from schist

The red-weathering zone, near which these spinels occur, represents a minor concentration of ore minerals at the margins of what may have been a mafic intrusion (now represented by amphibolite). It is postulated that the regional metamorphism caused desulfurization of these rocks, allowing the zinc to be incorporated into the oxide phases. A similar mode of formation for gahnite at the margin of a metamorphosed sulfide deposit has been described by Juve (1967).

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