Crystal chemistry and petrology of coexisting galaxite and jacobsite and other spinel solutions and solvi[1]

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Abstract

Galaxite (Gx:$MnAl_2O_4$) and jacobsite (Jb:$MnFe_2O_4$)-rich spinels occur together in the metamorphosed manganese deposit near Bald Knob, North Carolina. They show limited mutual solubility with 12–19% Jb in Gx and 19–22% Gx in Jb. The implied solvus is consistent with syntheses of Ishida *et al.* (1977) along the Gx–Jb pseudobinary. Refinement of the structure of one galaxite ($Gx_{85}Jb_{10}Sp_4Gh_1$) reveals that Mn is located on tetrahedral sites and Al on octahedral sites and that galaxite is therefore a normal spinel. All available data suggest that jacobsite is also a normal spinel at low temperatures, and the solvus between galaxite and jacobsite does not seem to be caused by differences in normality/inverseness. Chemical and experimental data available for $(Mg,Zn,Mg,Fe^{2+})(Fe^{3+},Al)_2O_4$ spinels suggest that the ferrites (jacobsite, franklinite, magnesioferrite and magnetite) show extensive solid solution and are separated from aluminate solid solutions (galaxite, gahnite, spinel (*s.s.*) and hercynite) by wide solvi at metamorphic temperatures.

Introduction

The manganese deposit near Bald Knob, North Carolina contains a wide range of unusual manganese minerals which have equilibrated under amphibolite facies metamorphic conditions (Winter *et al.*, 1981). The deposit was originally described by Ross and Kerr (1932). We have subsequently carried out extensive mineralogical–petrological studies of the several mineral groups occurring there (Peacor *et al.*, 1974; Winter *et al.*, 1981, in prep.; Simmons *et al.*, 1981). The spinel group minerals (galaxite and jacobsite) found at Bald Knob are relatively simple in composition and therefore serve as a source of insights into the crystal-chemical and phase relations of spinels. This paper is a description of the mineralogy and petrology of those manganese spinels.

Only a limited amount of experimental data are available regarding the nature of solvi among spinels at low to moderate temperatures. Turnock and Eugster (1962) experimentally determined the magnetite–hercynite solvus showing complete solid solution above 870°C and a wide miscibility gap below 600°C. These two spinels are largely inverse and normal, respectively. The area of complete solution probably represents a continuum of cation distributions, but the occurrence of the solvus must be related in part to ordering into the inverse versus the normal cation distribution. Experiments on the binaries

Fe_3O_4–Fe_2TiO_4 (Vincent *et al.*, 1957; Price, 1981; Lindsley, 1981) and Fe_3O_4–$ZnFe_2O_4$ (Valentino and Sclar, 1982) suggest that the solvus observed in natural materials must form below 500–600°C. Experiments in the systems $MnFe_2O_4$–$MnAl_2O_4$ (Ishida *et al.*, 1977) and $ZnFe_2O_4$–$ZnAl_2O_4$ (Carvalho, 1978) reveal extensive miscibility gaps at metamorphic temperatures of 500–700°C with the crest of the solvi located at 900–1100°C. Experiments of Muan *et al.* (1972) on the ternaries $FeAl_2O_4$–Fe_2TiO_4–$FeCr_2O_4$ and $MgAl_2O_4$–Mg_2TiO_4–$MgCr_2O_4$ show solvi extending to more than 1300°C between the aluminate and titanate species but with complete solution at $T > 1000$°C engendered with addition of 30–40% of the chromites. There are no experiments on the join $MgAl_2O_4$–Fe_3O_4 and one must turn to natural occurrences to estimate the form of this solvus.

Surprisingly few examples exist of observations on naturally occurring two-phase spinels despite the fact that such observations may have the advantage of demonstrating equilibrium cation distributions at relatively low temperatures. Studies of minerals in lunar basalts have revealed high-temperature solvi in the system $(Mg, Fe^{2+})Al_2O_4$–$(Mg,Fe^{2+})Cr_2O_4$–$(Mg,Fe^{2+})_2TiO_4$ (Haggerty, 1971, 1972a,b,c; El Goresy *et al.*, 1972, 1976; Nehru *et al.*, 1974). Muir and Naldrett (1973) and Berg (1976) analyzed coexisting spinels and magnetites from igneous rocks, finding a wide miscibility gap in the system Fe_3O_4–$MgAl_2O_4$ which contracts with increasing Cr in solid solution. Plaksenko (1980) describes incipient exsolution in chrome spinels from ultramafic rocks. Kuno

Table 2. Structure factors for galaxite

H	K	L	F(OBS)	F(CALC)		H	K	L	F(OBS)	F(CALC)
0	0	2	148.6	0.0		3	7	9	64.6	64.2
0	2	6	89.0	87.9		3	5	11	45.5	46.2
0	6	6	91.7	90.0		3	9	9	62.8	63.0
0	4	8	44.8	44.8		3	7	11	31.6	30.4
0	2	10	65.9	65.9		4	0	0	137.3	140.0
0	8	8	119.1	126.8		4	4	4	72.0	72.2
0	6	10	34.4	33.2		4	4	6	5.8 *	8.1
0	0	12	16.4	16.6		4	6	6	50.5	51.0
0	4	12	100.3	102.7		4	4	8	152.1	159.4
1	1	3	155.5	162.7		4	5	8	9.9	10.5
1	3	3	57.9	57.3		4	4	10	6.5 *	3.7
1	1	5	171.0	175.4		4	8	8	20.3	19.2
1	3	5	5.0 *	5.6		4	6	10	62.2	61.1
1	1	7	31.3	32.3		4	4	12	15.0	10.4
1	5	5	20.9	21.8		4	8	10	9.0 *	5.6
1	3	7	78.8	75.6		5	5	5	127.1	124.3
1	5	7	86.9	85.6		5	5	7	8.5	9.0
1	1	9	14.4	14.6		5	7	7	56.9	57.1
1	3	9	95.3	95.5		5	5	9	16.3	16.4
1	7	7	31.1	32.1		5	7	9	59.5	59.5
1	5	9	96.1	96.5		5	5	11	43.1	44.4
1	1	11	48.7	49.2		6	6	6	37.9	35.5
1	3	11	29.0	28.2		6	6	8	58.0	58.0
1	7	9	7.0 *	5.5		6	8	8	16.4	15.5
1	5	11	20.1	19.1		6	5	10	26.4	29.3
1	9	9	5.4 *	9.5		7	7	7	37.9	37.0
1	7	11	36.1	35.9		7	7	9	12.1	7.1
2	2	2	21.4	20.8		8	0	0	195.5	210.2
2	2	4	113.5	113.3						
2	4	4	14.8	14.3						
2	2	6	37.4	31.9						
2	4	6	89.9	89.7						
2	2	8	73.5	74.2						
2	6	6	39.6	38.2						
2	4	8	15.1	15.1						
2	6	8	55.6	55.4						
2	2	10	37.2	37.1						
2	4	10	47.2	48.0						
2	8	8	24.1	20.7						
2	6	10	33.7	32.9						
2	2	12	45.6	46.1						
2	4	12	10.9	12.7						
2	8	10	49.0	47.4						
2	6	12	44.9	42.5						
3	3	3	91.1	90.1						
3	3	5	118.8	116.6						
3	5	5	120.6	119.7						
3	3	7	46.3	46.6						
3	5	7	19.0	18.6						
3	3	9	5.6 *	3.0						
3	7	7	42.7	42.3						
3	5	9	6.7 *	6.4						
3	3	11	35.5	37.0						