Manganian andalusite from Manbazar, Purulia District, West Bengal, India

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Abstract

Manganian andalusite occurs abundantly as porphyroblasts in manganiferous metasediments subjected to contact metamorphism under hornblende hornfels facies at the contact of a picrodolerite dyke near Manbazar, Purulia District, India. The Mn_2O_3 content of andalusite varies from 13.2% to 19.17%, corresponding to 14.8 and 21.14 mole per cent of 'Mn_2SiO_5' respectively. Based on the analysis showing maximum amount of Mn_2O_3 in andalusite, the mineral formula may be represented as follows:

$$(Mn^{3+}_{0.43}Al_{0.50}Fe^{3+}_{0.09})^{[6]}_{1.02}\,Al^{[5]}_{1.00}[O_{1.00}/Si_{0.98}O_{4.00}]$$

Other minerals in the assemblage are muscovite, manganophyllite, spessartine, piemontite, quartz, braunite, hematite and rutile. The manganian andalusite is completely fresh and appears to have formed at the expense of spessartine, piemontite and braunite during contact metamorphism. The manganian andalusite probably formed at about 600°C at around 3 kbar pressure. This is another rare example of andalusite with very high Mn_2O_3 (and Fe_2O_3) as well as that of an occurrence of abundant manganian andalusite.

KEYWORDS: andalusite, manganese, metasediments, Manbazar, India.

Introduction

MANGANIAN andalusite (nomenclature after Nickel and Mandarino, 1987) containing very high amounts of Mn_2O_3 occurs in profuse abundance in the manganiferous metasediments cut by a picrodolerite dyke in the area around Poradih, about 9km NNE of Manbazar (23°03'30"N, 86° 39'45"E), Purulia District, West Bengal, India. The purpose of this note is to describe the occurrence and the mineralogical properties of this unusual variety of andalusite.

General geology

The area around Manbazar forms a part of the granite gneiss complex of the Chotanagpur plateau of Eastern India and is composed of Precambrian rocks. It has been recently investigated by Acharyya (1984), the main litho-units being granite gneisses and massive granites, amphibolites, and a group of psammo-pelitic metasediments sporadically rich in manganese and iron. The minor rock units are basic dykes and numerous veins of quartz, aplite and pegmatite. The oldest rocks exposed in this area are the metasediments, whose basement is not exposed. The metasediments were followed by basic intrusions. The next important phase was the emplacement of mesozonal, sub-solvus granite which affected the older rocks. Intrusion of quartz veins, aplites, pegmatites and a group of younger dolerite dykes took place after granite emplacement.

Gonditic rocks from Manbazar show characteristic mineral assemblages: quartz–spessartine–

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piemontite–manganophyllite–braunite–hematite –oligoclase; other minerals occurring in these rocks, but not as a part of any assemblage, are microcline, titanite, muscovite, biotite, chlorite, epidote–zoisite, and mangano-stilpnomelane (Mukherjee and Bandyopadhyay, 1975). The low- to medium-grade regionally metamorphosed manganiferous sediments are never found to contain manganian andalusite in this area. The only place where this particular mineral occurs, and in abundance, is characterized by contact metamorphism.

The area has undergone three phases of deformation and four phases of metamorphism. The M_1 metamorphism has been overprinted by later pervasive regional metamorphic episode M_2 and as a result very few observable characteristics of M_1 episode have been preserved. M_1 is syn-kinematic with D_1 during which the prevailing P–T conditions ranged between 325 and 365°C at $P_{H_2O} = 2$–3 kbar (greenschist facies). The pervasive prograde metamorphic episode M_2 is syn-kinematic with the D_2 deformation phase. Deduced P–T conditions during the M_2 metamorphic episode were 350–600°C at $P_{H_2O} = 3$–5 kbar corresponding to the lower amphibolite facies. The contact metamorphic episode M_3, late syn-kinematic with D_2, is marked by the development of andalusite hornfels at the contact of a picrodolerite dyke cutting across the manganiferous sediments. The dyke may have suffered autometamorphism during its emplacement. This was followed by a post-kinematic metamorphic episode of retrogression (M_4). Culmination of metamorphism and the main phase of deformation is marked by late syn- to post-kinematic granite intrusions (Acharyya, 1984).

The hornfels group. The dyke of picrodolerite which is now represented by a talc–tremolite–actinolite–chlorite–magnetite rock is about 30 m in width and 1.6 km in length trending WNW–ESE. On its southern side manganiferous metasediments occur in juxtaposition with the dyke and conspicuous development of manganian andalusite is observed within the metasediments at this contact. Near the contact the hornfels is prominently porphyroblastic and dark greenish grey in colour, a colour imparted by the numerous porphyroblasts of manganian andalusite. Away from the contact the texture of the rock becomes maculose with fine specks of andalusite distributed throughout the rock.

The manganiferous metasediments which have been only regionally metamorphosed are rich in garnet (spessartine), piemontite and braunite. But the andalusite-rich hornfelses contain none or very little of these minerals. Superheated steam generated by the intrusion of the basic dyke into the metasediments, which contained water, may be responsible for oxidation of Fe^{2+} and Mn^{2+} to Fe^{3+} and Mn^{3+} respectively in the hornfels. It appears that during contact metamorphism andalusite consumed all the manganese derived from the breakdown of the above-mentioned minerals. The almandine molecule of the garnet, and possibly some biotite and hematite contributed the Fe_2O_3. Only biotite containing about 2.7 percent MnO coexists with the manganian andalusite. Even braunite, which is very common in the gondites, is rare in the hornfelses. The opaque minerals commonly observed in them are hematite and rutile. The mineral assemblage in these hornfelses in the andalusite-rich parts is muscovite–biotite (manganophyllite)–quartz–andalusite–apatite–hematite–rutile. Andalusite-poor parts contain garnet (spessartine-rich), piemontite and braunite in addition to the other minerals mentioned above. Possible oxidation reactions are:

$$\text{a)}\quad \underset{\text{Braunite}}{4(Mn^{2+}Mn_6^{3+}SiO_{12})} + O_2 + 10SiO_2 = 14(Mn_2^{3+}SiO_5)$$

$$\text{b)}\ \underset{\text{Spessartine}}{4(Mn_3^{2+}Al_2Si_3O_{12})} + 3O_2 \rightarrow 10\,|\,(Mn^{3+}, A1)_2SiO_5\,| + 2SiO_2$$

$$\text{c)}\ \underset{\text{Alamandine}}{4(Fe_3^{2+}Al_2Si_3O_{14})} + 3O_2 = 6Fe_2O_3 + 4Al_2O_3 + 12SiO_2 \rightarrow 10\,|\,(Fe^{3+}, Al)_2SiO_5\,| + 2SiO_2$$

Cordierite is completely absent from the hornfelses of the present area. We believe that crystallization of manganocordierite in this manganese-rich environment was hindered mainly by high f_{O_2}, and perhaps higher P–T conditions (Dasgupta *et al.*, 1974; Abraham and Schreyer, 1975). Pyrolusite, a phase expected to occur with andalusite very rich in manganese (Abs-Wurmbach and Langer, 1975), is also absent from the present assemblage.

The manganian andalusite in the present hornfelses occurs as irregular grains often with slight elongation parallel to the crystallographic *c*-axis. A crude foliation is defined by the parallel alignment of these grains. Development of crystal faces is absent. The grains vary in size from extremely small (≈10 μm) to as coarse as 5 mm in length (Fig.1). However, in thin sections they appear more as clots of smaller grains than as single large grains with optical continuity; in this respect this occurrence is similar to the one described by Abraham and Schreyer (1975). The grains are almost always perfectly fresh. The tiny crystals show a tendency to occupy the interstitial spaces

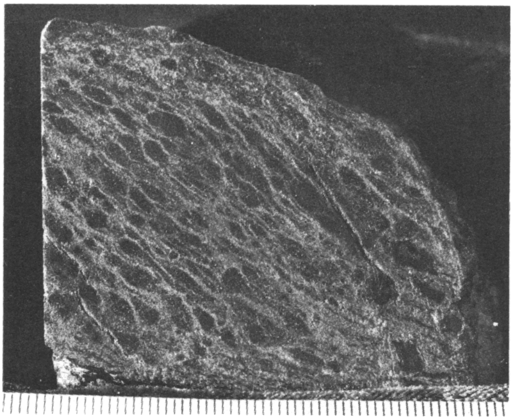

FIG. 1. Augen-shaped porphyroblasts of manganian andalusite defining a schistocity in the hornfels. Scale in mm.

between the grains of other minerals. The larger ones, mostly in clots, always contain many inclusions of other minerals, rendering it impossible to liberate the inclusions and separate pure manganian andalusite completely from its associates. Further, our analyses show that there is considerable variation in the total Mn_2O_3 and Fe_2O_3 content in different grains. Hence, the bulk specific gravity of the mineral (D = 3.27) determined in the laboratory is not completely reliable.

The manganian andalusite shows conspicuous pleochroism in the following shades:

X = yellowish green; Y = emerald green;
Z = golden yellow

Refractive indices of these crystals are much higher than those of common andalusite:

$$\alpha = 1.695;\ \beta = 1.715;\ \gamma = 1.750;\ (\pm\ 0.002)$$
$$\gamma - \alpha = 0.055;\ 2V_\gamma = 65°$$

α and γ values are slightly higher than those reported for crystals with similar Mn_2O_3 content (Vrana *et al.*, 1978, Fig. 4; Gunter and Bloss, 1982). It is likely that Fe^{3+} enhances the increase in α and γ much more than Mn^{3+} is capable of doing.

Powder diffraction and cell refinement analyses show that the unit cell size is also much larger than common andalusite:

$a = 7.93$, $b = 7.96$, $c = 5.60$Å (error <0.01Å in a, b, or c); $V = 353$Å^3

However, these are compatible with the cell edges for a manganian andalusite with 13.6% Mn_2O_3 and 3.6% Fe_2O_3 reported by Gunter and Bloss (1982):

$a = 7.8906$, $b = 7.9870$, $c = 5.5999$Å;
and $V = 358.98$Å^3

Microprobe analyses of eight grains of manganian andalusite are given in Table 1, and those of biotite, rutile and hematite closely associated with the manganian andalusite are given in Table 2. The average Mn_2O_3 content of the andalusite is quite high (16.7%) and is comparable to those reported by Abraham and Schreyer (1975) and Abs-Wurmbach *et al.* (1981). Very few manganian andalusite grains have been discovered that contain more Mn_2O_3 than the highest Mn_2O_3 (19.2%) reported here (cf. Gunter and Bloss, 1982). The abundance of Fe_2O_3 is, however, slightly less than that found in the crystals from Darmstadt by Abraham and Schreyer (1975). On the other hand, the biotites from the present rocks contain lesser amounts of Fe and Ti but higher Mg than those from Darmstadt, and are clearly in the phlogopite field. Hematite from the present rocks are also relatively more depleted in Ti than those from Darmstadt despite being otherwise similar.

Discussion

The chemical composition of the mafic dyke (Table 3) corresponds to that of picrodolerite, the mineralogical composition of which has been converted to an amphibole–chlorite–talc–magnetite rock under greenschist facies metamorphism. The composition and the mineral assemblages indicate that there is a close similarity between the manganian andalusite, biotites, and hematite from the present area and those described by Abraham and Schreyer (1975) from Darmstadt. Therefore, the conditions of metamorphism producing manganian andalusite in these two areas may be similar. The presence of both rutile and hematite is an indication of contact metamorphism under high f_{O_2} condition. Complete absence of kyanite and sillimanite in the hornfelses along the contact of the picrodolerite dyke suggests that the thermal metamorphism operated under hornblende hornfels facies conditions.

The geologic context of the picrodolerite dyke emplacement itself is also important. The *P–T* condition of intrusion of the partly crystalline hydrous magma probably suggests a bastite–peridotite mineral facies as described by O'Hara (1967; his fig. 1.4). The mafic-ultramafic intrusives at Red Hill in New Zealand are thought to indicate a temperature of 800°C (or a little lower) at the contact and a magma temperature of about 1200°C (Challis, 1965). If so, the Red Hill ultramafic body induced metamorphism under conditions of pyroxene hornfels facies. Green (1964,

Table 1. Microprobe analyses of manganian andalusite from Manbazar hornfels

	1	2	3	4	5	6	7	8	Average
SiO_2	35.41	33.84	34.12	34.30	34.28	34.15	33.58	33.82	34.19
TiO_2	-	0.46	-	-	-	0.18	0.12	0.09	0.11
Al_2O_3	45.83	46.25	45.07	45.41	48.30	44.31	43.62	45.13	45.49
^{a} Fe_2O_3	3.27	3.93	3.68	3.76	3.73	3.79	4.01	3.93	3.76
^{b} Mn_2O_3	15.89	15.88	17.35	16.82	13.66	17.35	19.17	17.08	16.65
Cr_2O_3	0.07	0.06	0.08	-	0.02	0.06	-	0.01	0.04
MgO	0.04	0.10	0.09	0.10	0.09	0.08	0.07	0.11	0.08
CaO	0.02	0.05	-	0.03	-	0.02	-	0.03	0.02
K_2O	-	0.01	0.04	0.04	-	-	0.01	0.01	0.01
Na_2O	-	-	0.03	0.05	-	-	-	-	0.01
Total	100.55	100.58	100.46	100.51	100.08	99.94	100.58	100.21	100.36
				Number of cations on the basis of 20 oxygens					
Si	4.073	3.912	3.963	3.974	3.942	3.989	3.928	3.939	3.965
Al	6.214	6.303	6.172	6.203	6.547	6.101	6.015	6.196	6.219
Fe^{3+}	0.285	0.342	0.322	0.328	0.323	0.333	0.353	0.344	0.328
Mn^{3+}	1.391	1.397	1.534	1.484	1.196	1.543	1.707	1.514	1.470
Cr^{3+}	0.006	0.005	0.007	-	0.002	0.006	-	0.001	0.004
Ti	-	0.040	-	-	-	0.016	0.011	0.008	0.010
Mg	0.007	0.017	0.016	0.017	0.015	0.014	0.012	0.019	0.014
Ca	0.003	0.006	-	0.004	-	0.003	-	0.003	0.003
K	-	0.002	0.006	0.006	-	-	0.001	0.001	0.001
Na	-	-	0.007	0.011	-	-	-	-	0.001
Total	11.979	12.024	12.027	12.027	12.025	12.005	12.027	12.025	12.015
				End member (mole %)					
Al_2SiO_5	78.76	78.38	76.88	77.39	81.17	76.48	74.49	76.93	77.57
Fe_2SiO_5	3.61	4.25	4.01	4.09	4.00	4.18	4.37	4.27	4.09
Mn_2SiO_5	17.63	17.37	19.11	18.52	14.83	19.34	21.14	18.80	18.34

^{a}Total Fe as Fe_2O_3 ^{b}Total Mn as Mn_2O_3

1967) suggested that ultramafic magmas are capable of imparting even higher temperatures at their contact as observed in Cornwall.

Winkler (1976) has listed common mineral associations in the contact aureoles of intrusive bodies and has also indicated the temperatures in the different zones (after Jaeger, 1957). The temperature of a gabbroic magma has been assumed to be around 1200 °C but the solidus temperature of the same magma comes down to 1050°C. Hence the temperature of intrusion of a predominantly crystalline, thin picrodolerite dyke may be assumed to be no more than 1100°C. The mineral assemblages in the hornfelses are compatible with this temperature estimate. At higher temperatures (pyroxene hornfels facies) muscovite and quartz react to give rise to K-feldspar and sillimanite (Turner, 1981). This has not taken place in the present area. It is likely that the flow of water from the surrounding rocks to the intrusive body further lowered its temperature and the temperature of contact metamorphism by such a thin dyke may be as low as 600°C. It has been experimentally shown by Abs-Wurmbach and Langer (1975) that manganian andalusite remains stable under much higher *P–T* conditions. But in the present area the mineral assemblages in the hornfelses do not indicate metamorphism under pyroxene hornfels facies.

Incorporation of Fe^{3+} and Mn^{3+} in coexisting

Table 2. Microprobe analyses of other minerals associated with the manganian andalusite from Manbazar hornfels.

	Biotite[c]	Rutile	Hematite[d]
SiO_2	38.52	0.25	0.41
TiO_2	0.23	98.42	0.20
Al_2O_3	17.68	0.12	0.29
Fe_2O_3	-	-	95.98
Mn_2O_3	-	-	3.22
Cr_2O_3	0.08	0.12	0.10
FeO	1.52	1.14	-
MnO	2.67	0.51	-
MgO	22.68	0.04	0.09
CaO	0.02	0.04	-
Na_2O	0.31	-	-
K_2O	10.39	-	-
Total	94.10	100.64	100.29

[c] Total Fe and Mn as FeO and MnO for biotite and rutile.

[d] Total Fe and Mn as Fe_2O_3 and Mn_2O_3.

Table 3. Composition of the picrodolerite dyke from Manbazar

	Major Elements wt%		Trace Elements ppm		CIPW Norms
SiO_2	46.70	Ba	30	Or	6.12
TiO_2	2.26	Sr	100	Ab	13.10
Al_2O_3	9.90	Cr	500	An	13.90
Fe_2O_3	5.22	V	50	Ne	3.12
FeO	4.66	Sc	40	Di	41.60
MnO	0.15	Ni	300	Ol	7.97
MgO	11.95	Co	50	Ap	1.01
CaO	14.13	Cu	70	Mt	7.66
Na_2O	2.22	Zr	60	Il	4.26
K_2O	1.00	Li	16		
P_2O_5	0.48	Rb	20		
H_2O^+	1.51				
Total	100.18				

Al_2SiO_5 phases adds additional degrees of freedom and invalidates any invariant points or reaction curves determined for pure phases (Gunter and Bloss, 1982; Abs-Wurmbach *et al.*, 1983; Grambling and Williams, 1985). If andalusite in the hornfels were to coexist with either kyanite or sillimanite, or both, and if the compositions of these phases were to be known, it would be possible to calculate the shift of the invariant point experimentally determined by Holdaway (1971), as shown by Grambling and Williams (1985). However, manganian andalusites described here occur only in contact aureoles without either kyanite or sillimanite. Therefore, the P–T conditions of their crystallization cannot be estimated from compositions of coexisting Al_2SiO_5 phases. Independent but rather poorly constrained evidence suggests that the P_{H_2O} in the sediments during the dyke emplacement may have been about 3 kbar (Acharyya, 1984). The andalusites appear to be saturated in $(FeAl)SiO_5$ and contain high Mn; the presence of rutile and hematite indicates high oxygen fugacity; and, crystallization during contact metamorphism of the manganiferous metapelites under hornblende hornfels facies condition (when the interstitial water of the metasediments was possibly converted into superheated steam) at about 600 °C at $\approx$3 kbar or less seems reasonable.

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