Manganese silicate minerals from Chikla, Bhandara District, India.

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Summary.—Blanfordite (a manganiferous aegirine), rhodonite, alurgite, manganophyllite, and piemontite are described from a pegmatite that cuts a manganese ore band in the Sitasaongi mine, Chikla, Bhandara district, India. In addition, rhodonite and piemontite are described from gneiss and schist areas. Chemical analyses and optical properties of all these minerals are given and their possible origin suggested.

THE minerals described in this paper were collected during the summer of 1950 from Sitasaongi mine, Chikla area, Bhandara district, India, which produces high-grade manganese ore. The ore band is 8 to 18 feet thick and is strongly folded and faulted. The associated rock types are calc-granulites, calc-gneisses, mica-schists, quartzites, gondite (quartz-spessartine rock), injection gneisses, and pegmatites. The pegmatites are the youngest and cut through the ore band as well as the country rocks. All are of Archaean age.

Previous work. The first detailed reference to the occurrence of manganese silicate minerals in India was made by Fermor (1909). He carried out preliminary optical work on these minerals and in a few cases chemical analyses were also undertaken. Blanfordite was first named and described by him on the basis of physical and optical properties and was analysed by Banerji (Hayden, 1916); Krishnan (1937) also reported the occurrence of the mineral in Gangpur State, India, but no detailed optical work was undertaken. A preliminary description of the mineral was given by the present writer in 1953.

The only work on the Indian piemontites is that of Fermor (1909), who has described the mineral from nine different localities from varying rock types. He gave comparisons of pleochroic schemes of the mineral from different localities but no other optical work was undertaken. A chemical analysis of the mineral from Kachi Dhana manganese mine, India, was given by Pascoe (1930).

Occurrence. At the 60-foot level of the Sitasaongi mine the ore band

and the mica-schist (which forms the foot-wall and the hanging-wall sides of the ore band) are cut by a pegmatite about 4 feet thick. The minerals described here occur irregularly distributed in the pegmatite, with a large number of braunite xenoliths. Here the minerals are associated with manganese amphiboles (Bilgrami, 1955), quartz, oligoclase, microcline, braunite, and a little baryte. Blanfordite occurs as brown crystals measuring up to $\frac{1}{2}$ inch in length; most of the crystals show well-developed faces and can be easily distinguished by their habit from other minerals of the pegmatite. Rhodonite occurs in small lumps of pink colour and sugary texture. Alurgite and manganophyllite attain large dimensions and books measuring up to 3 inches across can be found. Piemontite is developed in chocolate-brown crystal masses, some of them measuring up to 3 inches by 2·5 inches by 1·6 inches. Rhodonite and piemontite also occur in the schist and the gneiss areas, where rhodonite forms veins and patches in rhodonite-quartz-spessartine rock, while the piemontite-bearing bands, which are 1 to 2 inches thick, are composed of piemontite, quartz, manganese ore, sphene, biotite, and apatite.

Description and chemistry of the minerals.

Blanfordite is a monoclinic pyroxene the colour of which varies from lavender-blue to brown in the hand-specimen; the specific gravity is 3·28 and the hardness is $6\frac{1}{2}$–7. In thin section the mineral is deep pink in colour but occasionally shows a bleached appearance in different parts of the same plate. It is pleochroic from pink to blue according to the scheme given in table I, and has a high birefringence and patchy polarization colours. Schiller inclusions of brown colour arranged parallel to the prismatic cleavages are present and alteration to a dense brown material, probably limonite, is common (fig. 1). The mineral does not show variation from the type specimen from Kacherwahi, India.

The chemical analyses of the mineral from Sitasaongi and Kachi Dhana manganese mines are given in table I. The two analyses are very similar and the formula calculated on the basis of 6 oxygen atoms can be expressed as $(Na,Ca)_{0.89}(Al,Ti,Fe,Mn)_{1.08}(Si,Al)_{2.00}O_6$, which corresponds closely to the ideal formula $XYSi_2O_6$, and is near the boundary suggested for aegirine by Sabine (1950); blanfordite could therefore be classed as a manganiferous aegirine.

Rhodonite from the pegmatite is rose-pink in colour, has sugary texture and vitreous lustre; the specific gravity is 3·66 and the hardness is $6\frac{1}{2}$. In thin section the mineral shows granular texture, consisting of
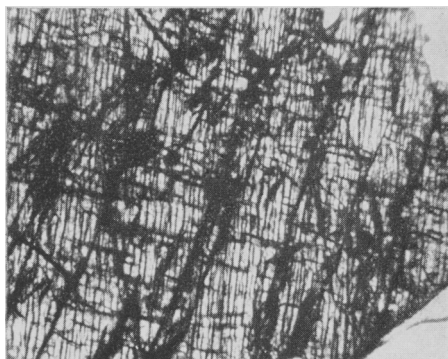
FIG. 1. Blanfordite showing veins of alteration product. ×70.

TABLE I. Chemical analyses and optical properties of blanfordites and rhodonites.

1–4, percentage compositions, 1a–4a, same analyses calculated to a basis of 6 oxygen atoms. Al^{iv} and Al^{vi}, Al in fourfold and sixfold coordination respectively.

	1.	2.	3.	4.		1a.	2a.	3a.	4a.
SiO$_2$ ...	52·52	52·18	45·46	48·38	Si ...	1·96	1·95	1·98	2·01
Al$_2$O$_3$ ...	5·88	5·89	0·27	0·09	Al^{iv} ...	0·04	0·05	0·01	0·00
TiO$_2$ ...	0·59	—	nil	0·02	Al^{vi} ...	0·20	0·21	nil	0·00
Fe$_2$O$_3$ ...	18·15	20·26	nil	0·21	Ti ...	0·01	nil	nil	0·00
FeO ...	1·11	—	0·96	11·31	Fe''' ...	0·51	0·57	nil	0·00
MgO ...	3·26	3·25	0·55	1·87	Fe'' ...	0·03	nil	0·04	0·39
MnO ...	4·72	3·60	50·54	31·54	Mg ...	0·19	0·18	0·00	0·11
CaO ...	4·38	4·37	2·25	6·62	Mn ...	0·14	0·11	1·86	1·19
K$_2$O ...	nil	nil	nil	0·02	Ca ...	0·18	0·17	0·10	0·30
Na$_2$O ...	9·75	10·12	nil	nil	K ...	nil	nil	nil	0·00
H$_2$O + ...	nil	—	nil	0·07	Na ...	0·71	0·75	nil	0·00
H$_2$O − ...	nil	—	nil	0·02	OH ...	nil	nil	nil	0·02
	100·36	99·67	100·03	100·15	X + Y*	1·97	1·99	2·00	1·99
α ...	1·732	—	1·725	1·722					
β ...	1·756	—	1·728	1·725					
γ ...	1·770	—	1·736	1·734					
γ − α ...	0·038	—	0·011	0·012					
γ : c ...	9°	—	36°	35°					
2V ...	80°	—	74°	71°					
Sp. gr.	3·28	—	3·66	3·64					

* Sum of cations other than Si and Al^{iv}.

1. Blanfordite, Chikla, India. Analyst, R. K. Phillips. Pleochroism, α rose-pink, β pale blue, γ blue.

2. Blanfordite, Kachi Dhana, India. Analyst, A. K. Banerji (Hayden, 1916). Pleochroism, α rose-pink, β bluish-lilac, γ sky-blue.

3. Rhodonite from pegmatite, Chikla, India. Analyst, R. K. Phillips. Pleochroism, α pale pink, β pale pink, γ pink.

4. Rhodonite from gneiss, Chikla, India. Analyst, S. A. Bilgrami. Colourless.

pale pink to colourless, rounded crystals. Most of the sections show one set of prismatic cleavages but occasionally two sets almost at right angles are observed. In grains and thick sections the mineral is pleochroic from pale pink to colourless. It is often altered along cracks and cleavages to a dirty brown material, possibly psilomelane.

Rhodonite from the gneiss does not show much difference from the above in thin section but polysynthetic twinning on (010) is occasionally observed; the twin lamellae are of equal thickness and are regularly spaced. Alteration to a dense brown mass is more marked here than in the pegmatite specimen, and may go so far that the hand-specimen is dark brown. The alteration usually seems to start along the cleavages and then spreads in all directions leaving small areas of clear unaltered mineral surrounded by dense brown manganese ore, possibly psilomelane; in some cases the alteration does not seem to start from the cleavages but spreads all over the mineral in moss-like form clouding the whole crystal. The alteration product is not of uniform colour but is often dark and light brown in patches. The associated minerals in the gneiss are lemon-yellow spessartine and quartz. The garnet is clear and seems to alter less readily than the rhodonite. In the much altered specimens the garnet also shows areas of dark brown alteration product and it appears that the alteration products of the two minerals are alike.

The chemical analyses and optical properties of rhodonites are given in table I. The atomic ratios have been calculated on the basis of 6 oxygen atoms to illustrate the relationship with the pyroxene group. It will be seen that the pegmatite mineral shows lower Si, Fe″, and Ca content but much higher Mn; in fact rhodonites with such high Mn content are very rare. These differences in the chemistry of the two specimens are reflected in their optics, the rhodonite with higher Mn + Fe″ content having higher refractive indices.

Alurgite occurs as books up to 3 inches broad in the pegmatite. It is dark reddish-brown in colour and splits easily into thin smoky brown flakes along the cleavages. Under the microscope thin plates of the mineral are pale brown with a pinkish tint and pleochroic from pale brownish-yellow to reddish-brown.

The chemical analyses and optical properties of the Chikla alurgite are given in table II. The two analyses of the mineral from Sitasaongi mine show general similarity but some important differences in detail, thus the earlier analysis shows higher SiO_2, Al_2O_3, and lower MgO; TiO_2 and Na_2O are not recorded in the earlier analysis but are present in

substantial amounts in the present analysis. Penfield's analysis of the mineral from the type locality shows very high SiO_2 compared with the two Sitasaongi specimens. The atomic ratios calculated on the basis of 12(O,OH) are included in table II and give the composition: $(K,Na,Ca)_{1.09}(Al,Ti,Fe,Mg,Mn)_{2.30}(Si,Al)_{4.00}O_{10.06}(OH)_{1.94}$. The alurgite

TABLE II. Chemical analyses and optical properties of alurgites and mangano-phyllites.

1–5, percentage compositions; 1a and 4a recalculated to a basis of 12(O,OH). Al^{iv} and Al^{vi}, Al in fourfold and sixfold coordination respectively. $X = Na+K+Ca$, $Y = Al^{vi}+Ti+Fe'''+Mg+Fe''+Mn$.

	1.	2.	3.	4.	5.			1a.	4a.
SiO_2 ...	40·60	45·6	53·22	38·32	40·6	Si	...	2·84	2·79
Al_2O_3 ...	26·37	29·6	21·19	16·51	16·7	Al^{iv} ...		1·16	1·21
TiO_2 ...	1·40	—	—	1·54	1·0	Al^{vi} ...		1·02	0·20
Fe_2O_3 ...	6·38	5·8	1·22	5·76	5·1	Ti	...	0·07	0·08
FeO ...	0·22	—	—	1·20	—	Fe'''	...	0·34	0·31
MgO ...	7·42	2·23	6·02	14·82	20·33	Fe''	...	0·01	0·07
Mn_2O_3 ...	nil ⎱	1·07	0·87	nil	—	Mg	...	0·77	1·60
MnO ...	1·53 ⎰		0·18	6·24	5·58	Mn	...	0·09	0·39
CaO ...	0·21	0·98	—	0·95	0·78	Ca	...	0·02	0·07
K_2O ...	9·46	9·5	11·20	9·23	8·40	K	...	0·84	0·86
Na_2O ...	1·66	—	0·34	1·37	—	Na	...	0·23	0·19
H_2O+ ...	4·15	4·4	5·75	4·22	2·2	OH	...	1·94	2·04
H_2O- ...	0·31	—	—	0·25	—				
	99·71	99·18	99·99	100·41	100·69	Y	...	2·30	2·65
						X	...	1·09	1·12

1. Alurgite, Chikla, India. Analyst, S. A. Bilgrami. α 1·588, β 1·636, γ 1·636, $\gamma-\alpha$ 0·048, 2V 3°, Sp. gr. 2·98.

2. Alurgite, Chikla, India. Analysts, Sahu and Dave (Kilpady and Dave, 1954). β 1·62–1·63, $\gamma-\alpha$ 0·038–0·04, 2V 29° 15′.

3. Alurgite, Piemont, Italy. Analyst, S. L. Penfield (Penfield, 1893).

4. Manganophyllite, Chikla, India. Analyst, S. A. Bilgrami. α 1·575, β 1·617, γ 1·621, $\gamma-\alpha$ 0·046, 2V 30°, Sp. gr. 2·98.

5. Manganophyllite, Chikla, India. Analysts, Sahu and Dave (Kilpady and Dave, 1954). β 1·60–1·61, $\gamma-\beta$ 0·0056, 2V 35° 30′.

analyses show more cations than are appropriate for a dioctahedral mica (2·30 instead of 2). Winchell (1951) has classified alurgite as a manganiferous phengite but pending a new study of the mineral from the type locality it would be better not to attempt to classify it.

Manganophyllite has the same mode of occurrence as alurgite with which it can easily be confused. In thin section it is pleochroic from pale yellowish-brown to dark brown and is occasionally partially replaced by a colourless tremolite.

The two manganophyllites from the Sitasaongi mine show close similarity in their chemical composition (table II) except for much higher MgO and lower MnO, K_2O, and H_2O, and the absence of Na_2O in the earlier analysis. The atomic ratios of the mineral calculated on the basis of 12(O,OH) give the formula:

$$(K,Na,Ca)_{1.12}(Al,Ti,Fe,Mg,Mn)_{2.65}(Si,Al)_{4.00}O_{9.96}(OH)_{2.04},$$

which is in general agreement with the structural formula for the ferro-magnesian micas. The high magnesia content of the mineral suggests a close relationship with phlogopite. The manganophyllite described by Jakob (1925) is classified by Winchell (1951) as a ferric iron equivalent of phlogopite, but both would be more precisely named manganiferous biotite.

Piemontite. The piemontite from the schist is granular in form, ruby red, and has pearly lustre. In thin section the mineral is pink or lemon-yellow in colour, idioblastic in form and encloses grains of braunite, quartz, and sphene. Areal analyses of the schist show that the mineral forms between 43 and 45 % of the rock, the other minerals present being quartz, manganese ore, sphene, biotite, and apatite. The pegmatite specimen is dark brown in colour, striated in the zone [001], and has a metallic lustre. In thin section piemontite is seen to occur as large plates often peppered with manganese ore grains and showing perfect basal cleavages. It is deeply coloured and strongly pleochroic according to the scheme given in table III. Occasional inclusions of a pink-coloured idiomorphic mineral with lower refractive index may be thulite.

The chemical analyses of the two piemontites with comparisons are given in table III. The three piemontites from India show exceptionally high Mn content, while the piemontite from St. Marcel shows very high Mn''' content but is well below the piemontite from the Sitasaongi pegmatite. The formulae of the Chikla piemontites calculated on the basis of 13(O,OH) are given in table III; it will be seen that the two specimens show close similarity except that the pegmatite specimen has higher Mn''', Al, and Ca, and lower Mg. The piemontite from the schist shows some noteworthy features, particularly its high alkali content and the presence of Cu in small amounts; a search of the literature has failed to disclose a piemontite with comparable alkali content. In order to conform to the usually accepted structural formula for the epidote group it is necessary to distribute Mn''' between the X and the Y positions.

TABLE III. Chemical analyses and optical properties of piemontites.

1–4, percentage compositions; 1a and 2a, analyses 1 and 2 recalculated to a basis of 13(O,OH). X = (sum of all cations)−(cations in sixfold coordination). Al^{iv} and Al^{vi}, Al in fourfold and sixfold coordination respectively.

		1.	2.	3.	4.			1a.	2a.	
SiO_2	...	36·60	36·63	35·57	38·64	Si	...	2·92	2·89	⎫ 3·00
Al_2O_3	...	15·24	17·21	18·27	15·03	Al^{iv}	...	0·08	0·11	⎬
TiO_2	...	0·60	0·21	—	——	Al^{vi}	...	1·37	1·49	⎫
Fe_2O_3	...	7·04	6·85	7·06	8·38	Ti	...	0·03	0·01	⎪
Mn_2O_3	...	14·93	17·78	12·43	15·00	Fe'''	...	0·42	0·41	⎬ 3·00
MnO	...	nil	nil	2·94	—	Mg	...	0·35	0·10	⎪
MgO	...	2·92	0·85	0·96	—	Cu	...	0·01	nil	⎭
CaO	...	17·47	18·98	19·53	22·19 ⎱	Mn'''	...	⎰ 0·82	0·99	⎭
Na_2O	...	2·41	nil	1·14	— ⎰			⎱ 0·31	0·35	
K_2O	...	0·95	nil	0·87	—	Ca	...	1·48	1·60	
H_2O+	.	1·95	1·75	0·85	1·78	Na	...	0·37	nil	
H_2O-	...	——	—	0·38	—	K	...	0·09	nil	
CuO	...	0·31	—	—	——	OH	...	1·01	0·91	
		100·42	100·26	100·00	101·02	X	...	2·26	1·95	

1. Piemontite from schist, Chikla, India. Analyst, R. K. Phillips. Analysis on powder dried at 105° C. α 1·785, β 1·796, γ 1·808, $\gamma-\alpha$ 0·023, $\gamma:c$ −7°, 2V 74°. Twinned on {100}. Pleochroism, α yellow, β pale pink, γ deep pink.

2. Piemontite from pegmatite, Chikla, India. Analyst, R. K. Phillips. Analysis on powder dried at 105° C. α 1·794, β 1·807, γ 1·819, $\gamma-\alpha$ 0·025, $\gamma:c$ −9°, 2V 79°. Pleochroism, α brownish-yellow, β violet-pink, γ ruby-red, violet.

3. Piemontite from Kajlidongri, India. Analyst not stated. Pascoe, 1930.

4. Piemontite from St. Marcel. Analyst, Rammelsberg, 1875.

Relation between chemical composition and optical properties.

A brief review of the literature on the subject has been made in a previous paper (Bilgrami, 1955) and only a short reference to some important points will be made here. Sabine (1950) has discussed in detail the relationship of the chemical composition and the optical properties in the acmitic pyroxenes. He states that, 'The range of composition shown by minerals having similar optical properties appears to arise principally from replacement of Mg″ and Fe″ by each other.' Specific gravity, extinction angle, and refractive index (β) vary irregularly within limited ranges. In the case of blanfordite, as in aegirine, the high Fe‴ and Na content will have considerable influence on the optical properties of these minerals. Sundius (1931) has published graphs showing relations between refractive indices, optic axial angle, and $(Ca,Mg)SiO_3$ and $(Mn,Fe)SiO_3$ in rhodonites. He has shown that with an increase in $(Mn,Fe)SiO_3$ indices of refraction and optic axial angles increase. Also in his opinion $MgSiO_3$ reduces refractive indices, optic axial angle, and specific gravities. On the other hand, $FeSiO_3$ is said to counteract the

effect of $MgSiO_3$. It may be pointed out that in most rhodonites the amount of $MgSiO_3$ is too small to have any significant influence on the optical properties and it is likely that the combined influence of $MgSiO_3$ and $CaSiO_3$ is more significant. In the two rhodonites under discussion here it is seen that a substantial decrease in the Mn content of the rhodonite from gneiss is accompanied by a decrease in the γ value even though this specimen has a higher Fe″ content than the pegmatite specimen.

The relationship between the chemical composition and optical properties of epidotes is not well known. Short (1933) has published a diagram plotting the optical properties against the Mn‴ contents of the piemontites. His diagram shows that the specific gravity, the optic axial angle and $\gamma:c$ all increase with an increasing content of Mn‴, while the refractive indices decrease. The highest γ value given by Short is for a piemontite with 10 % Mn‴. It is clear that the relationship of the optical properties and chemical composition has been oversimplified by Short, as other ions such as Al, Fe, and Ca which are present in substantial amounts will also affect the optical properties of the mineral. Johnston (1949) has shown that in clinozoisites the refractive indices and specific gravity increase with an increasing content of Fe_2O_3 but the optic axial angle and $\alpha:c$ vary irregularly when the Fe_2O_3 content of the mineral is below 5 %. He has suggested that when the iron content is low such factors as the pressure and temperature prevailing during the period of crystallization exert greater influence on the optical properties than does the chemical composition of the mineral. The two new analyses show that the specific gravity, refractive indices, 2V, and $\gamma:c$ all increase with an increasing content of Mn‴ in the piemontites.

Paragenesis.

In discussing the origin of rhodonite, Fermor (1909) advocated an igneous origin for this mineral. The absence of rhodonite from the typical kodurite rocks and those intrusive into gondites has been explained by him as due to the fact that 'rhodonite requires about 42 % of manganese for the formation of pure $MnSiO_3$ and when many other constituents are present in the rock so that the percentage of manganese is relatively low, the manganese naturally forms silicates that contain small percentages of manganese such as the other manganiferous pyroxenes and manganese garnets'. In the present case, however, rhodonite is found in the rocks intrusive into the gondite series. It appears that the formation of this mineral is due to the assimilation of

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manganese ore by the pegmatite that cuts through the ore band. Participation of other elements such as Al, Fe, Mg, and Ca would produce more complex manganese silicate minerals. As manganese was abundant a higher percentage of manganese in the minerals than is usual may be expected, this element replacing Ca, Fe, or Mg.

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