

Manganese amphiboles from Chikla, Bhandara district, India.

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INTRODUCTION.

THE four amphiboles described in this paper were collected during the summer of 1950 from the Sitasongi mine. This mine, which produces high-grade manganese ore, is situated in the Chikla area, Bhandara district, India. The ore band is 8 to 18 feet thick and is strongly

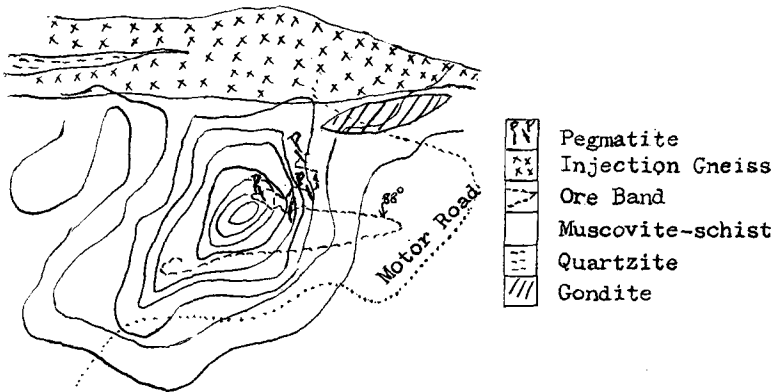


FIG. 1. Geological map of Sitasongi hill, Chikla, India. (Scale, $3\frac{1}{8}$ inches = 1 mile.)

folded and faulted at many places (fig. 1). The most common rock types in the area 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 manganese-ore band as well as the country-rocks. All are of Archaean age.

PREVIOUS WORK.

Of the four amphiboles described here, winchite and juddite were first described by Fermor (1909). Juddite was named on its optical properties, mainly pleochroism, while winchite was described in greater detail

and a chemical analysis of the mineral was given. Krishnan (1937) also reported the occurrence of winchite from Gangpur State, India, but no optical properties of the mineral were given. Tirodite, named after Tirodi mine, Balaghat district, India, was first described by Dunn and Roy (1938) and a chemical analysis of the mineral together with its

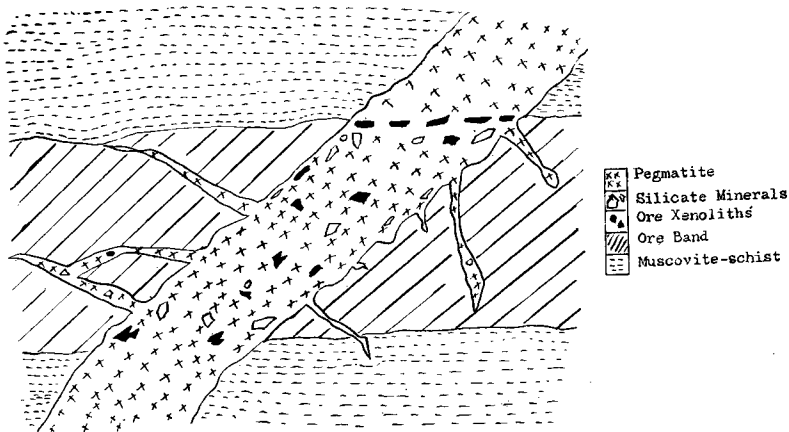


FIG. 2. Plan at the 60-foot level of the Sitasaongi mine, Chikla, India, showing the pegmatite cutting through the ore band.

physical and optical properties was presented. A preliminary description of these minerals from Chikla was given by Bilgrami (1953). Kilpady and Dave (1954) have also described manganese amphiboles from Balaghat district, India, and have given their optical properties and manganese contents. *Chiklita*, named after Chikla area, in which it is found, is here described for the first time, and its optical and chemical properties do not resemble closely any known amphibole.

OCCURRENCE.

Winchite, tirodite, juddite, and chiklita occur at Chikla in the pegmatite where it cuts the manganese-ore band and muscovite-schist at the 60-foot level of the Sitasaongi mine (fig. 2). Here the amphiboles are accompanied by other manganese-bearing minerals, blanfordite, alurgite, manganophyllite, piedmontite, and rhodonite. Other minerals present are quartz, oligoclase, microcline, and a little baryte. Some of the minerals attain large dimensions and measure up to 3 inches in length.

Winchite occurs in a band of medium-grained felspathic gneiss associated with mica-schist and when freshly broken shows numerous blue-coloured needles. It is associated with quartz, oligoclase, alurgite, rutile, and a little manganese ore, probably braunite. In thin sections it occurs as anhedral crystals showing perfect amphibole cleavages and pink to blue pleochroism. Inclusions of quartz, manganese ore, and rutile are common (fig. 3).

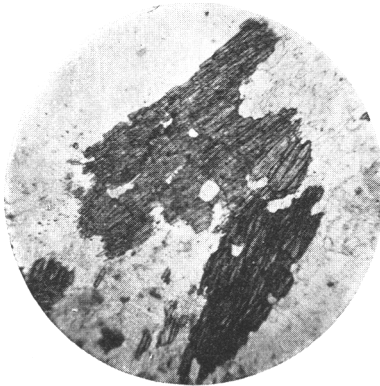


FIG. 3.



FIG. 4.

FIG. 3. Winchite with inclusions of quartz (white), rutile, and manganese ore (dark). $\times 20$.

FIG. 4. Tirodite with inclusions of apatite and alteration veins (black). $\times 20$.

Tirodite. Of the four amphiboles, tirodite is the simplest to recognize in the hand-specimen, due to its honey-yellow colour and stout prismatic habit; when crushed it breaks into fine asbestos-like silky fibres. In thin sections the mineral is straw-yellow in colour and shows perfect prismatic cleavages. Inclusions of euhedral apatite arranged roughly parallel to the cleavages are common (fig. 4). The mineral shows ultra-polarization colours due to high dispersion, and it is occasionally weakly zoned. Alteration of the mineral along the cleavages to a dense brown mass, probably psilomelane, is common.

A specimen of tirodite from manganese deposits of India was kindly presented by Mr. E. H. Shackleton of Whitehaven, Cumberland. The mineral is dark brown in colour, is less fibrous than the Chikla specimen, and under the microscope shows pale pink colour and a lower dispersion. The mineral is altered to a dense brown mass, probably psilomelane, and the brown colour of the hand-specimen is probably due to this mineral.

The MnO content of this specimen is 3.67 %, and γ (for Na-light) 1.649, and $2V \neq 41^\circ$. Another specimen of the mineral was found by the author on a dump of Indian manganese ore belonging to The General Iron and Steel Co. Ltd., Workington. In this specimen the tirodite occurs as plates flattened parallel to the prismatic cleavages and without systematic orientation, forming an encrustation on braunite. Under the

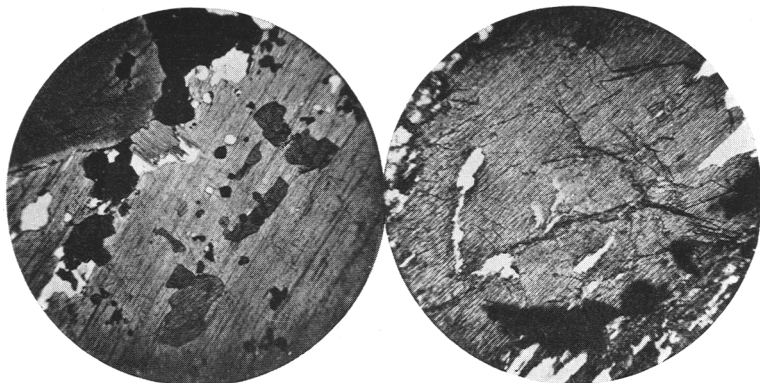


FIG. 5.

FIG. 6.

FIG. 5. Juddite with inclusions of manganese ore (black), baryte (white), and chiklite. $\times 20$.

FIG. 6. Chiklite showing prismatic cleavage and alteration veins. $\times 20$.

microscope the mineral is feebly pink to colourless and shows a lower dispersion than the Chikla specimen. The MnO content is 3.41, and γ 1.649 and $2V$ 42° .

Juddite shows anhedral form, rather poor prismatic cleavages and strong pleochroism. In thin sections and grains the mineral is pleochroic from carmine to red. Inclusions of manganese ore, baryte, and chiklite are common (fig. 5), and lie either parallel to the prismatic cleavages or are slightly inclined to them. Under crossed nicols the mineral shows strain effects round the inclusions, and in general large plates of the mineral show undulose extinction. Ultra-polarization colours due to very high dispersion are very characteristic.

Chiklite, by virtue of its deep violet colour and well-developed (100) and (110) forms, is quite distinct in the hand-specimen. It has pearly lustre on the cleavage faces, and the streak is very pale violet in colour. In thin sections the mineral resembles juddite, particularly in its pleochroic scheme, but the prismatic cleavages are better developed (fig. 6).

Faint zoning is occasionally present and patchy polarization is characteristic. Thin veins of a brown alteration product, probably limonite, are present.

SEPARATION OF THE MINERALS.

Separation of the minerals for chemical analysis did not present any special problems. Winchite, which is associated with manganese ore, quartz, feldspar, rutile, and a little mica, was separated by crushing the rock to 60-mesh British standard sieves and passing the powder through bromoform. From the heavy fraction winchite was separated from other heavy minerals by methylene iodide. The sample was further purified by crushing to 100-mesh followed by centrifuging in methylene iodide. The pegmatite amphiboles were separated by crushing the sample to $\frac{1}{8}$ -inch size and hand-picking under a binocular microscope. The majority of the composite grains and those containing inclusions were removed by further crushing to $\frac{1}{16}$ inch and hand-picking. The final purification was effected by crushing to 100-mesh and centrifuging in methylene iodide and Clerici's solutions.

CHEMICAL COMPOSITION.

The structural formula generally accepted for the amphibole group is $X_{2-3}Y_5Z_8O_{22}(OH,F,Cl)_2$ where the *X* group mainly consists of Na, Ca, K, Mn (in part), the *Y* group of Al, Ti, Cr, Fe^{''}, Mg, Li, Fe^{'''}, Zn, Mn (in part), and the *Z* group of Si, Al, and possibly of Ti. The ionic replacements in this group of minerals are still imperfectly understood and it is possible that Ca ions as well as Mn may occupy both *X* and *Y* positions in the structure. The replacements may be regarded as giving rise to two structural types: (*a*) such that the number of cations remains 7; and (*b*) where the vacant spaces are partially or completely occupied by Na or K, and the number of cations varies from 7 to 8. It was originally suggested by Warren (1930) that the occupation of vacant spaces in tremolite by Na and K was related to the replacement of Si by Al in the band framework.

The chemical composition of the amphiboles under review, and their structural formulae calculated on the basis of $24(O,OH,F)$, are given in tables I and II. They emphasize the extreme flexibility of the amphibole constitution, and the significance of substitution of cations in the *X*, *Y*, and *Z* groups. The low Al content of these amphiboles, all of which is in four-fold co-ordination, is noteworthy. Al occurs in increasing amounts in six-fold co-ordination with the increasing temperature, and in the

present case points to the relatively low-temperature paragenesis of these amphiboles. Harry (1950) has pointed out that the amount of tetrahedrally co-ordinated Al in the metamorphic calciferous amphiboles appears to be related to the temperature of crystallization. The relationships in these amphiboles of Ca and Mn is of interest. In general chemical characteristics winchite resembles imerinite (table I, 3) and tirodite resembles richterite (table I, 7), but juddite and chiklite show no close comparisons with other known amphiboles. In winchite and tirodite all the Ca and Mn occupy *X* or some of the vacant positions, while in juddite and chiklite the Mn is presumably restricted to the *Y* positions and the Ca in part or whole is located in the *Y* positions.

TABLE I. Chemical analyses of winchite and tirodite with comparisons.

	1.	2.	3.	4.	5.	6.
SiO ₂ ...	55.14	55.64	53.73	53.26	53.26	53.25
Al ₂ O ₃ ...	1.14	1.08	2.72	2.26	1.25	2.31
TiO ₂ ...	0.50	—	0.41	0.78	—	0.79
Fe ₂ O ₃ ...	4.59	—	4.72	2.60	2.63	1.81
FeO ...	1.25	6.35	4.70	1.12	1.06	1.62
MgO ...	22.16	22.09	20.60	29.16	31.26	28.42
MnO ...	1.38	0.77	—	6.24	8.25	4.66
CaO ...	7.37	7.64	2.73	1.10	1.11	3.42
Na ₂ O ...	2.88	2.89	7.42	1.39	1.56	1.25
K ₂ O ...	1.24	0.98	1.82	0.09	0.07	0.06
H ₂ O+	1.98	2.95	0.85	1.87	0.05	2.04
H ₂ O—	—	0.14	—	—	—	—
F ...	—	—	0.92	—	—	—
	99.63	100.53	100.62	99.87	100.50	99.63
Sp. gr. ...	2.970	2.959–3.024	—	3.252	3.312	3.248
α ...	1.636	—	—	1.629	1.629	1.629
β ...	1.646	—	—	—	1.639	—
γ ...	1.658	—	—	1.650	1.650	1.650
$\gamma-\alpha$...	0.020	0.020–0.030	—	0.021	0.021	0.021
$\gamma:c$...	18°	$\alpha:c$ 20–26°	—	17°	21°	18°
2V ...	82°	—	—	37°	88°	41°

1. Winchite, Chikla, India. Analyst, R. K. Phillips. Analysis on air-dried powder at 105° C.
2. Winchite, Kajlidongri, Central India. Analyst, T. R. Blyth (Fermor, 1909, p. 156).
3. Imerinite, Imeria, Madagascar. Analyst, F. Pisani (A. Lacroix, Min. France, 1910, vol. 4, p. 787).
4. Tirodite, Chikla, India. Analyst, R. K. Phillips. Analysis on air-dried powder at 105° C.
5. Tirodite, Tirodi mine, Central Provinces, India. Analyst, P. C. Roy (Dunn and Roy, 1938). [M.A. 7-317.]
6. Tirodite, Tirodi mine, Central Provinces, India. Analyst, S. A. Bilgrami. Analysis on air-dried powder at 105° C.

TABLE I (*contd.*). Chemical analyses of juddite and chiklite with comparisons.

	7.	8.	9.	10.	11.
SiO ₂ ...	57.74	51.21	57.10	52.66	48.51
Al ₂ O ₃ ...	0.37	2.82	6.19	1.75	1.08
TiO ₂ ...	trace	1.62	0.35	0.60	1.10
Fe ₂ O ₃ ...	0.29	9.15	8.01	18.44	17.53
FeO ...	trace	0.97	2.69	0.86	14.31
MgO ...	23.67	11.31	9.13	6.29	1.31
MnO ...	2.40	7.69	0.34	2.55	0.66
CaO ...	9.01	3.91	0.31	7.80	5.43
Na ₂ O ...	3.14	8.97	9.77	7.29	7.87
K ₂ O ...	0.64	0.22	2.38	nil	1.48
H ₂ O+ ...	2.39	1.89	0.50	1.88	1.48
H ₂ O- ...		—	0.08	—	0.17
F ...	0.37	—	2.69	—	—
	100.02	99.76	101.28*	100.12	100.93
Less O for F	0.16	—	1.13	—	—
	99.86	99.76	100.15	100.12	100.93
Sp. gr. ...	2.99	3.27	—	3.44	—
α ...	1.605	1.667	—	1.685	—
β ...	—	1.683	—	1.700	—
γ ...	1.627	1.692	—	1.712	—
γ-α ...	0.022	0.025	—	0.027	—
γ:c ...	17°	3°	—	8°	α:c 5-6°
2V ...	—	82°	—	82°	—

- Richterite, Långban, Sweden. Analyst, A. Bygdén (Sundius, 1945). [M.A. 9-271.]
- Juddite, Chikla, India. Analyst, R. K. Phillips. Analysis on air-dried powder at 105° C.
- Eckermannite, Norra Kärr, Sweden. Analyst, A. Bygdén (Sundius, 1946 a). Total* includes LiO₂ 1.15, ZnO 0.59. [M.A. 10-8.]
- Chiklite, Chikla, India. Analyst, R. K. Phillips. Analysis on air-dried powder at 105° C.
- Arfvedsonite, Morotu, Sakhalin. (K. Yagi, 1953.)

Winchite differs from ideal tremolite formula in containing 0.99 atom of Na and K and therefore is nearest to the end-member NaCa₂Mg₅AlSi₇O₂₂(OH)₂ of Sundius (1946b). The deficiency of Si-Al in the Z group shown both by these minerals from the type area and from Chikla is noteworthy.

The original analysis of tirodite shows some marked difference compared with both the analyses of the same mineral from the type locality, and also from the composition of the mineral from Chikla, the main difference being the absence of TiO₂ and the very low water content of the type material. The negligible amount of structural water reported in the earlier analysis suggests that it is inaccurate. The cell dimensions of the Chikla mineral were kindly determined by Dr. J. Zussman and

are a 9.80, b 17.97, c 5.30 Å., β 103° 9'. Measurements made on the specimen from the type area gave the same dimensions, within the limits of experimental error, as the Chikla specimen. The composition of tirodite shows a resemblance to that of winchite, the deficiency in the Z group of tirodite from the type area and the low Al and high Mg content being the common features. The main difference in the composition of the two minerals lies in their contrasted Ca and Mn contents, Ca being low and Mn high in tirodite, a reverse relationship being characteristic of winchite.

In juddite 2.5 atoms of Na are present in the formula unit. Thus, if juddite is considered as a derivative of tremolite, one Na atom occupies a vacant position and the remainder replaces Ca in the X positions. This, together with the replacement of 0.5 atom of Si by Al, necessitates the presence of a relatively high proportion of trivalent ions in the Y position, a requirement met by the high ferric iron content of the mineral. Juddite may be compared with eckermannite (table I, 9) except in its

TABLE II. Calculation of analyses (table I) on basis of 24(O,OH,F).

1. Winchite, Chikla.				2. Winchite, Kajlidongri.			
SiO ₂ ...	55.14	7.70	} 7.88	55.64	7.19	} 7.73	
Al ₂ O ₃ ...	1.14	0.18		1.08	0.54		
TiO ₂ ...	0.50	0.05	} 5.26	—	—	} 5.31	
Fe ₂ O ₃ ...	4.59	0.48		6.35	0.73		
FeO ...	1.25	0.14	} 2.30	22.09	4.58	} 2.16	
MgO ...	22.16	4.59		0.77	0.09		
MnO ...	1.38	0.15	} 2.89	7.64	1.13	} 2.16	
CaO ...	7.37	1.16		2.89	0.78		
Na ₂ O ...	2.88	0.78	} 1.84	0.98	0.16	} 1.37	
K ₂ O ...	1.24	0.21		3.09	1.37		
H ₂ O ...	1.98	1.84	1.84	3.09	1.37	1.37	
	99.63			100.53			
4. Tirodite, Chikla.				5. Tirodite, Tirodi.			
SiO ₂ ...	53.26	7.38	} 8.04	53.26	7.56	} 7.77	
Al ₂ O ₃ ...	2.26	0.66		1.25	0.21		
TiO ₂ ...	0.78	0.08	} 7.76	—	—	} 7.99	
Fe ₂ O ₃ ...	2.60	0.27		2.63	0.27		
FeO ...	1.12	0.12	} 7.76	1.06	0.12	} 7.99	
MgO ...	29.16	6.02		31.26	6.05		
MnO ...	6.24	0.73	} 1.72	8.25	0.98	} 1.37	
CaO ...	1.10	0.16		1.11	0.15		
Na ₂ O ...	1.39	0.37	} 1.87	1.56	0.41	} 1.37	
K ₂ O ...	0.09	0.01		0.07	0.01		
H ₂ O ...	1.87	1.72	1.72	0.05	0.00	0.00	
	99.87			100.50			

TABLE II (contd.)

6. Tirodite, Tirodi.				8. Juddite, Chikla.			
SiO ₂ ...	...	53.25	7.29	} 7.82	51.21	7.52	} 8.00
Al ₂ O ₃ ...	...	2.31	0.52		2.82	0.48	
TiO ₂ ...	...	0.79	0.16	} 7.77	1.62	0.17	} 5.00
Fe ₂ O ₃...	...	1.81	0.18		9.15	1.01	
FeO ...	...	1.62	0.18	11.31	2.49	} 0.28	} 2.91
MgO ...	...	28.42	5.88	7.69	0.95		
MnO ...	...	4.66	0.54	3.91	0.61	} 0.33	} 1.85
CaO ...	...	3.42	0.51	8.97	2.54		
Na ₂ O ...	...	1.25	0.32	0.22	0.04	} 1.89	} 1.85
K ₂ O ...	...	0.06	0.00	1.89	1.85		
H ₂ O ...	...	2.04	1.86	1.86	1.89	1.85	1.85
		99.63			99.76		
10. Chiklite, Chikla.							
SiO ₂ ...	...	52.66	7.70	} 8.00			
Al ₂ O ₃	1.75	0.30				
TiO ₂ ...	...	0.60	0.07	} 5.00			
Fe ₂ O ₃	18.44	2.05				
FeO ...	...	0.86	0.10				
MgO ...	...	6.29	1.37	} 1.17			
MnO	2.55	0.31				
CaO ...	...	7.80	1.21	} 0.04			
K ₂ O	nil	nil				
Na ₂ O ...	...	7.29	2.07				
H ₂ O ...	...	1.88	1.82				
		100.12					

high percentage of manganese atoms. When the composition of juddite is plotted on the cummingtonite-grunerite series composition-refractive index curves (Winchell, 1951), lower values for refractive indices than the determined values are obtained and this is probably related to the high content of manganese. Juddite may more appropriately be called ferririchterite.

Chiklite shows many of the chemical characteristics of juddite but is an amphibole of $X + Y = 7$ type. Considerations of the number of ions in the unit cell suggest that the X positions are occupied by Na atoms and that the whole of the Ca is located in the Y position. In this respect chiklite appears to be unique among known amphiboles. An arfvedsonite described by Yagi (1953, table I, 11) is similarly lacking in Y position atoms unless most of the Ca is assumed to occupy similar positions. This mineral differs from chiklite in being an amphibole of $X + Y = 8$ type. In both these amphiboles the high content of ferric iron and Na are noteworthy. Like juddite, lower refractive indices values are obtained from Winchell's curves compared with the determined values,

but here the discrepancy may be due to very high Fe^m content of the mineral.

DISTRIBUTION OF TRACE ELEMENTS.

The results of the spectrographic examination of the amphiboles under review are given in table III. It is interesting to note that win-

TABLE III. Spectrographic analyses of the amphiboles and muscovite-schist, showing the distribution of trace elements. (Parts per million ± 50 %.)

	Winchite.	Juddite.	Chiklite.	Tirodite (Chikla).	Tirodite (type).	Mica- schist.
Cr	500	20	20	50	0	70
Co	20	50	10	70	100	20
Ni	150	100	30	300	250	100
V	10	10	0	0	20	150
Cu	50	30	30	150	100	50
Ba	400	50	1000	300	200	600
Sr	600	1500	300	800	20	80
Zr	20	0	20	10	10	50
Li	3	3	1	1	0	2
Mo	1	0	$\frac{1}{2}$	$\frac{1}{2}$	1	0
Ga	1	0	0	2	1	3
Bi	2	0	0	2	0	0
Pb	0	1	2	0	0	1

chite, the amphibole from the gneiss, shows little difference from the pegmatite amphiboles, the most marked difference is the high concentration of Cr which is low in the other amphiboles. It will be seen that Ni follows Mg closely and those amphiboles high in Mg are also high in Ni. Another interesting feature is that Cr does not follow Fe, nor do Ba and Sr follow K and Ca. The two specimens of tirodite, one from the type area and the other from Chikla, show resemblances in most cases. The notable difference is that Cr, Ba, and Sr are high in the Chikla specimen and low in the specimen from the type area.

RELATION BETWEEN THE CHEMICAL COMPOSITION, COLOUR, AND OPTICAL PROPERTIES.

The problem of absorption colours in minerals is still imperfectly understood; a review of the literature on the subject brings out the following points:

- (1) Magnesia has the effect of diluting or masking the colour produced by Ti, but in the case of tourmalines it has no effect on the colours produced by Fe and Mn.
- (2) The colour produced by Ti dominates over that produced by Fe.

- (3) The colour in biotites is related to their Fe content.
- (4) The absolute proportion of any oxide responsible for a particular colour is less important than the proportion of the oxide to others present.
- (5) Ions in a higher state of oxidation exert greater influence than those in a lower state of oxidation.

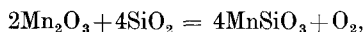
In the absence of specific data concerning the influence of a given element on the colour of the amphiboles, it is likely that points 4 and 5 are of greater importance. Thus, it is interesting to note that winchite, which has a lower magnesia content, is pleochroic in pinks and blues, while tirodite with higher magnesia is almost colourless. In the case of juddite and chiklite the very high ferric oxide content may be responsible for their colours.

No definite relationship between the chemical composition and optical properties is apparent except that the magnesia:iron ratio ($\text{FeO} + \text{Fe}_2\text{O}_3$, calculated as FeO) shows normal influence on the refractive indices. Winchite and tirodite with high magnesia:iron ratio show low refractive indices, while juddite and chiklite with low ratios show high refractive indices. It would appear from analyses 4 and 6 (table I) that the increase in MnO in tirodite tends to decrease the optic axial angle.

PARAGENESIS.

Fermor, when describing the manganiferous amphiboles from India, stated that 'all the known occurrences of amphiboles in Indian manganiferous rocks are the varieties that I look upon as metamorphic in origin, belonging always to the gondite series' (1909, p. 145). In another place, when discussing the origin of rhodonite, he again advocates a metamorphic origin, stating 'that the metamorphic mode of formation is the characteristic one is shown by the frequency with which this mineral occurs in the rocks of gondite series' (p. 141). The abundance of this mineral in the manganiferous rocks, he suggests, is due to 'the frequency with which the original sediments from which the gondite series were formed contained a high percentage of manganese' (p. 142). This explanation seems to hold in the case of winchite where it appears that the mineral was probably formed by the recrystallization of sediments which contained an appreciable amount of manganese. This explanation, however, does not hold in the case of pegmatite amphiboles. Here it is clear from the field evidence that assimilation of manganese ore and mica-schist by the pegmatite has taken place. Thus the formation of

rhodonite may be illustrated by the equation:



the oxygen liberated oxidizing the ferrous to ferric iron, thus explaining the high ferric iron content of chiklite and other pegmatite amphiboles.

In view of its paragenesis and the lack of an abnormal content of magnesium in the composition of the mica-schist (table IV) it is difficult to account for the very high content of magnesium in the tirodite.

TABLE IV. Analysis of mica-schist from 60-foot level, Sitasongi mine, Chikla.
(Analyst, S. A. Bilgrami.)

SiO ₂	60.99	CaO	trace
TiO ₂	1.21	Na ₂ O	0.75
Al ₂ O ₃	23.42	K ₂ O	3.97
Fe ₂ O ₃	1.49	P ₂ O ₅	0.05
FeO	0.56	H ₂ O+	3.49
MnO	0.82	H ₂ O-	0.21
MgO	3.35		
			100.31

It is, however, noteworthy that the tirodite is confined to the margins of the pegmatite, while other amphiboles are found in the core. Thus it is possible that on assimilation of the schist and ore band the magnesia was taken up early in the formation of tirodite and led to a relative concentration of iron and sodium which are characteristically high in both juddite and chiklite.

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