

CLINOHUMITE SAUSAR SERIES, BHANDARA DISTRICT, INDIA

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INTRODUCTION

THIS paper gives a mineralogical account of the humite mineral, clinohumite occurring in the dolomitic marbles of the Bichua stage of the Sausar series. This series—a member of the Archæan rocks of the Bhandara District, Madhya Pradesh, has been studied in great detail by Sir Lewis Fermor and the occurrence of the mineral has been reported by him (1921). However, so far there has not been any detailed study of any humite mineral occurring in India. The dolomitic marble specimens with the humite mineral were kindly made available by Dr. W. D. West from the collections he made with his student Mr. Manjrekar. The exact location is near Baoli, on the Bhawanthari river, about ten miles north-east of Deolapar.

GEOLOGICAL SETTING

The Archæan terrane has been subjected to intense folding. It is in this classic ground that West (1926) has recognised nappe structure. The regional metamorphism is obviously connected with the folding movements of the originally horizontal sediments. The associated granites and injection gneisses are a natural accompaniment of folding. The impure dolomitic rocks have been metamorphosed to schists with anthophyllite and cordierite and the pure limestones to marbles with forsterite. In this regenerative process, the pneumatolytic effect of fluorine, that usually accompanies acid intrusives, is observed in the partial and complete conversion of forsterite to humite minerals.

The marble is white to greyish white, equigranular showing no well defined foliation, with calcite, diopside forsterite, the humite mineral, phlogopite, tremolite and spinel. Weathered rocks show the harder minerals in relief, calcite and phlogopite having been leached away. The humite mineral occurs in isolated grains or aggregates, giving rise to a streaky or banded

character to the rock. Lenticular concentrations, with insets of blue spinel are fairly common.

MINERALOGY

Clinohumite is one of the four members of the humite group of minerals. The designation humite mineral refers to any one of the four minerals. The humites are neo-silicates of magnesium containing hydroxyl and fluorine. The general formula is $\text{Mg}(\text{OH}, \text{F})_2 - n\text{Mg}_2\text{SiO}_4$, where n may be 1, 2, 3 or 4, as shown below. Taylor and West (1928, 1929) have determined by X-ray studies, the structure of the humite minerals. They are made of interleaved slabs of $\text{Mg}(\text{OH}, \text{F})_2$ and Mg_2SiO_4 . The arrangement of the slabs is as follows: In norbergite n being 1, one slab of forsterite (Mg_2SiO_4) is interleaved with one of $\text{Mg}(\text{OH}, \text{F})_2$; in chondrodite n equals 2, resulting in two slabs of forsterite following one of $\text{Mg}(\text{OH}, \text{F})_2$; n is 3 in humite and 4 in clinohumite; hence every fourth slab in the former, and every fifth one in the latter, is forsterite.

It is a common feature of the humite minerals to show a diadochical replacement of Mg^{2+} by Fe^{2+} and Mn^{2+} ; also a part of OH^- by F^- . The ionic radii of Mg^{2+} , Fe^{2+} and Mn^{2+} are 0.78 Å, 0.83 Å and 0.91 Å respectively. No complete hydroxyl end member, corresponding to brucite, $\text{Mg}(\text{OH})_2$ seems to be present. Humite synthesis (1955), using hydrothermal techniques has been achieved. The hydroxyl end member has not resulted. Fluorine and hydroxyl are in the proper relationship to each other, as far as ionic size and charge are concerned, and hence efficiently exchange one for the other. Studies of anion exchange of $(\text{OH})^-$ by F^- , in silicate structures have been made by infra-red spectroscopy (1957) and these have confirmed the ionic substitution. If a complete replacement of OH^- by F^- results, the fluorine end member sellaite MgF_2 will result. But the structural pattern of the end member brucite $\text{Mg}(\text{OH})_2$, will be of the cadmium iodide type, while that of sellaite MgF_2 will be of the rutile type.

The slabs are arranged parallel to the basal pinacoid (1892, 1951); however some mineralogists take the arrangement as parallel to the \bar{a} pinacoid (1944, 1953); \bar{a} and b are essentially constant in absolute length. Since the slabs are packed in the direction of crystallographic c -axis, the length of this axis changes in a regular way, and is proportional to the number of Mg atoms in the mineral formula, which are 3, 5, 7 and 9.

The crystallographic and other data are given in Table I.

METHODS OF STUDY

The humite mineral was separated from dolomitic marble. The rock was crushed and ground to pass through sixty mesh. Grains in lots of

TABLE I
Crystallographic Data—Humite Minerals

Mineral	Crystal System and space-group	Slabs parallel to 001 Axial ratio and β				Value of c' in terms of 0.6287	Unit cell content			Stoichiometric ratio	
		a	b	c	β		Mg(OH, F) ₂	(Mg, Fe) ₂ SiO ₄	Mg(OH, F) ₂	(Mg, Fe) ₂ SiO ₄	
Norbergite ..	Orthorhombic P _{bnm}	1.0803	1	1.887	..	3 c	4	4	1	1	
Chondrodite ..	Monoclinic P _{21/c}	1.0863	1	3.1447	109°2'	5 c	2	4	1	2	
Humite ..	Orthorhombic P _{bnm}	1.0802	1	4.4033	..	7 c	4	12	1	3	
Clinohumite ..	Monoclinic P _{21/c}	1.0803	1	5.6588	100°50'	9 c	2	8	1	4	

3-5 were examined under the microscope; the strong pleochroism brought out vividly the contrast between clinohumite and any other foreign grain or impurity. Grain after grain was thus picked out for chemical analysis and X-ray powder pattern. The method, though laborious eliminated all foreign material excepting pigments. Sahama has advocated a preliminary X-ray analysis, to ensure the purity of the sample under study. Sahama who kindly gave his authoritative opinion on the mineral wrote* "The powder pattern is good, and I could not detect any other humite mineral with certainty. It is possible that a very small quantity of humite is admixed with the clinohumite sample. If present, the amount of humite is, however, extremely small, and as a matter of fact, I doubt its presence."

OPTICAL DETERMINATION

The refractive indices were determined by the immersion method. Grains were selected from microsections, some showing maximum interference colours to determine α and γ ; grains which under convergent light showed one isogyre splitting the field were selected for determining β . The cover slips were then removed by immersing the slides in xylol. The selected grains were transferred to separate slides, those showing maximum interference colours being kept separate, from those required to determine β .

The same grain was used to determine α and γ . Repeated washings by xylol and distilled water eliminated any trace of the liquid used. After careful wash the grain was removed to another slide by a match stick. Independent determinations were also made on individual grains. Grains so picked out from microsections bring out the Beckeline effect clearly, because of their being flat. The method though tedious is found very satisfactory to ensure good results. The R.I. of the liquid was immediately determined by the Billingham and Stanley refracto-meter.

SPECIFIC GRAVITY

The Specific Gravity was determined by a pycnometer and corrected to 20° C.

CHEMICAL ANALYSIS

This was kindly undertaken by Jun Ito of the Mineralogy Department of the Harvard University (Mass). Fluorine value was obtained by H_2O_2 and TiO_2 method and also by semiquantitative spectroscopic analysis for CaF band.

* Personal communication.

TABLE II
Composition of Clinohumite

Weight percent	M.O. ratio	Ratio of OH:F atoms	Ratio of metal atoms	Ratio of metal atoms to (O, OH, F)	Type formula clinohumite	Ratio ions	Electrical charges
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SiO ₂ ..	0.0197	1.2074	0.0087	16.1634 0.0226 3.92	4	Si ⁴⁺	0.0226 17.0993
Al ₂ O ₃ ..	..	..	..	..	..	..	..
Fe ₂ O ₃ ..	0.0036	0.0092	0.0031	0.0076	..	Fe ³⁺	0.0076 0.1128
FeO ..	0.0012	0.0013	0.0012	0.1275	..	Fe ²⁺	0.1275 0.3956
MnO ..	0.0005	0.0005	0.0007	0.0003 9.13	2	Mn ²⁺	0.0002 0.0064
MgO ..	1.3603	1.3603	1.3603	4.6623	..	Mg ²⁺	4.6623 16.2545
TiO ₂ ..	0.0065	0.0730	0.0060	0.0118	..	Ti ⁴⁺	0.0074 0.2256
H ₂ O*	1.30	0.0721	0.0315 1.662	1.5162	..	OH ⁻	0.2162 0.9762
F ..	0.0000	0.0000	0.0000	0.0000	2	F ⁻	0.0000 0.0000
H ₂ O*	0.25	..	..	..	..	..	..
Less O	10.44	..	..	..	..	..	..
For F	0.40	..	..	..	..	..	..
* Multiplication factor to build 16 OH, F atoms is 0.000134 = 2.54 = 6.34. Analysis 1.25. 100.06							
						17.7698	23.4550 34.6688

TABLE III
Clinohumites
 Chemical Analysis with Atomic Proportions

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO ₂	37.18	36.53	37.12	35.86	38.03	37.78	37.42	36.83	36.24	37.97	37.65	37.70	37.53	37.50	37.65
Al ₂ O ₃	..	0.22	0.77	..	..	..	..	0.07	0.37	..	..	0.06	0.06	..	..
Fe ₂ O ₃	0.49	0.56	0.32	0.22	..	..	0.46	0.42	4.69	..	..	..	..	..	..
FeO	2.24	5.04	3.44	14.25	4.83	5.64	1.27	4.90	6.20	1.12	1.29	2.51	1.57	3.84	3.41
MnO	0.04	0.34	0.15	1.19	..	..	0.10	0.28	0.30	..	0.44	0.03	1.39	0.23	0.50
MgO	55.09	54.16	54.85	44.66	54.00	53.05	56.32	51.53	46.05	56.60	55.00	54.10	53.76	52.55	51.74
TiO ₂	2.92	0.26	1.48	0.06	..	..	1.14	1.92	5.20	0.68	1.00	2.52	2.96	3.96	5.40
H ₃ O ⁺	1.30	1.52	0.88	1.58	1.94	1.33	0.56	3.04	1.23	2.20	2.25	2.56	1.82	1.76	1.57
F ..	0.95	2.74	1.70	4.16	2.06	3.58	5.04	0.03	..	0.93	0.90	0.08	0.86	0.68	0.06
H ₂ O ⁻	0.25	0.04	..	..	..	..	..	0.12	..	..	..	..	..	..	..
Cl	..	..	..	..	..	..	..	..	..	..	..	0.16	..	0.20	0.20
CO ₂	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CaO	..	..	..	Tr.	..	..	..	..	..	0.20	0.66	..	..	..	..
K ₂ O	..	..	..	0.15	..	..	..	..	..	0.30	0.85	0.13	0.76	..	0.10
Na ₂ O	..	..	..	0.29	..	..	..	0.12	..	..	..	..	..	..	..
Total	100.46	100.41	100.71	102.42	100.86	101.88	102.31	99.26	100.28	100.00	100.04	99.85	100.71	100.72	100.63
Loss O	0.40	1.15	0.72	1.75	0.86	1.50	2.12	..	..	0.43	0.88	0.07	0.36	0.33	0.08
Total	100.06	99.26	99.99	100.67	100.0	99.88	100.19	99.26	100.28	99.57	99.66	99.78	100.35	100.39	100.55

TABLE III (Contd.)

Atomic Proportions on Basis of 18 (O, OH, F) Atoms

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Si ..	3.92	3.79	3.90	3.80	3.94	3.89	3.74	3.94	3.97	3.94	3.97	3.98	3.95	3.95	4.00
Al ..	..	0.027	0.090	..	..	..	..	0.007	0.047	..	..	0.008	..	..	..
Fe ³⁺	0.038	0.044	0.025	0.018	..	..	0.035	0.034	0.385	..	..	..	..	..	..
Fe ²⁺	0.198	0.436	0.302	1.262	0.419	0.485	0.106	0.438	0.568	0.097	0.114	0.221	0.138	0.338	0.301
Mn	0.003	0.030	0.013	0.104	..	..	0.008	0.025	0.028	..	0.039	0.002	0.124	0.020	0.045
Mg ..	8.662	8.374	8.592	7.047	8.348	8.130	8.398	8.205	7.513	8.751	8.646	8.507	8.433	8.262	8.202
Ti ..	0.231	0.022	0.117	0.005	..	..	0.086	0.154	0.428	0.053	0.079	0.200	0.234	0.314	0.864
OH	0.914	1.053	0.616	1.115	1.341	0.912	0.373	2.166	0.90	1.524	1.582	1.801	1.276	1.239	1.114
F ..	0.317	0.900	0.565	1.393	0.675	1.164	1.594	1.010	..	0.305	0.300	0.027	0.287	0.227	0.020

X-RAY DATA

The powder diffractometer pattern of the sample was taken by Sahama with a Norolco diffractometer. A comparison with the pattern of his standard material (No. 865 + 9) Hameenkyla confirmed the identification. The data for the glancing angles 2θ , d spacings and intensities of the Sausar series mineral, and Sahama's standard were kindly given by R. Natarajan of Harvard University.

OPTIC AXIAL ANGLE

The determinations of $2V$ were made on the universal stage by direct rotation from one optic axis to another, as this is decidedly the best method to ensure accuracy. The optic axes positions are read on the outer east-west axis, for two settings of the readings, 90 degrees apart. The two readings for each axis are averaged. The difference between the two averages is recorded as $2V$, after necessary corrections. This procedure compensates for inaccuracies in the optic plane setting.

BIREFRINGENCE

The value was determined by Berek compensator.

The structural pattern of dehydrated clinohumite $MgF_2 \cdot 4Mg_2SiO_4$ has a basis of 16 O ions and 2 F ions or 17 O ions. The substitution of OH, by F does not alter the relation of Mg to Si-ions. The pure OH mineral has the composition $Mg_9Si_4O_{16}(OH)_2$. The sum of the charges on the MgSi ions is 34 to balance the 17 O ions. Hence the ratio of Mg to Si for clinohumite, and similarly for any other humite mineral will be constant. For clinohumite this ratio is 9 to 4. For the mineral under study this ratio is 9.13-3.92, well within the results of analytical errors.

Si: (O_{Ti}, OH, F) RATIO

Ti⁴⁺ is usually considered to replace Si⁴⁺. Geochemically, this replacement has been considered to be the most important one in silicates containing titanium. Kunitz (1936), as a result of intensive investigation considered that Ti-Si diadochy was common in garnets, amphiboles and micas. According to the recent trend of opinion in crystal chemistry, this mode of replacement is considered very limited because of the differences in the atomic radii of Si⁴⁺ (0.39 Å) and Ti⁴⁺ (0.64 Å). Ti³⁺ and Ti⁴⁺ favour substitution of Al³⁺ (0.67 Å) and Mg²⁺ (0.78 Å) in the structures. If then Ti³⁺ ions (0.69 Å) substitute Mg²⁺ (0.78 Å) of the brucite-sellaite slab, one should expect a similar substitution of the Mg²⁺ ions of the forsterite slabs

also of the humite mineral. However, there are evidences to indicate that the Ti-Mg diadochy is a restricted one confined to the brucite-sellaite slabs only. Firstly analysis of forsterite picked out from dolomitic marbles containing the humite mineral, shows an insignificant content of titanium, as recorded in the forsterite analysis from Ojama, Finland (1953). Secondly, as pointed out by Borneman-Starynkevitch and Mjasnikov (1950), analytical results agree better with the structural formula if titanium is not added to the magnesium of the forsterite slab. Thirdly, the crystal structure of TiO_2 is similar to that of MgF_2 ; OH, when present, is not so far known to alter the structure. Perhaps the water of the cell content, in the brucite-sellaite slab, acts as a catalyst to initiate and aid the atomic substitution.

If this assumption of restricted diadochy of Ti-Mg in the brucite-sellaite slab is accepted, this would also involve a substitution of F in the slab by the O associated with Ti. Thus F will decrease as O and OH increase; However, the atomic ratio of any humite mineral—Si to (O_{Ti} , OH, F) will be constant and prove a diagnostic feature. For clinohumite the average ratio of thirteen selected analyses is given as 8:4.20 (Table IV), while the theoretical value should be 8:4. The minimum for O_{Ti} , OH, F is 2.9 and the maximum is 5.3. In the clinohumite (this paper) this value is 3.45, well within the limits. In this connection, it may not be inappropriate to point out that the determination of H_2O is a difficult problem in mineral analysis, and particularly so in the humite minerals. Water is tenaciously adsorbed in the cell structure. It also contains 89 per cent. of oxygen—a percentage much higher than any other oxide; this will inevitably result in errors in the oxygen atoms per unit cell even for a small percentage error in the analysis. Further water has a low molecular weight compared to others, which will also affect the computation.

O_{Ti} , OH, F RATIO

The next mode of interpreting the analysis is to find out if an increase of O_{Ti} goes with a decrease of F, with the three variables O_{Ti} , OH and F. Sahama has plotted in a triangular diagram, the three anions of selected analyses (Fig. 1). There are eleven plots in the diagram of Sahama. That marked (1) is the O_{Ti} , OH, F ratio of the mineral under study of values 27, 54 and 19 (Table IV) respectively. Admittedly taken as a whole, the figure does not bring out the relationship it is intended to convey. Out of the twelve plots, seven are scattered far down below to formulate authoritatively that an increase in O_{Ti} , results in a decrease of F. But neglecting the plots with low titanium content, a tendency in the direction expected is observed. The real difficulty seems to be this. Crystal lattices attain the

TABLE IV

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
OTI+OH+F	3.45	4.13	2.9	5.3			4.57	5.08	3.53	3.93	4.11	4.48	4.11	4.23	3.99	..
Atomic ratio of silicon. Basis 8 to (OTI, OH and F)																
Average ratio Si to (O, OH, F) = 8 : 4.20																
%																
OTI	27	2	17	0.4	..	..	8	12	49	5	8	18	23	30	43	..
OH	54	53	43	44.1	..	..	17	87	51	79	77	81	63	59	56	..
F	19	45	40	55.5	..	..	75	1	..	16	15	1	14	11	1	..
OTI, OH, F—per cent.																
α	1.638	1.629	1.633	1.652	1.625	1.632	1.628	1.664	1.691							1.655
β	1.650	1.641	1.643	1.663	1.638	1.644	1.642	1.673	1.700							1.678
γ	1.670	1.662	1.674	..	1.653	1.664	..	1.698	1.724							1.700
$\bar{\alpha}\beta\gamma$	1.652	1.644	1.650	..	1.639	1.647	..	1.678	1.704							1.677
$\bar{2}\bar{V}\bar{\gamma}$	76°	73°	73°	76°27'	near 90°	74°	..	62°	58°							near 90°
Extinction $\alpha \wedge 001$	9°	11°	9°	12-15°	..	..	..	..	..							..
Specific Gravity	3.23	3.26	3.215	3.350	3.184	3.219	3.170	..	..	3.157	3.162	3.181	3.216	3.231	3.253	..
Optical data not reported																
Specific Gravity																

Index for the Tables III and IV—

1. This Paper—Sausar Series, India.
2. Th. G. Sahama (1953) Härneenkylä, Finland.
3. Th. G. Sahama (1953) Ojama, Lohja, Finland.
4. Sjogren (1894) } Nordmark.
- Larsen (1953) }
5. Penfield and Howe (1894) } Vesuvius Brush collection 2,064.
- Larsen (1928) }
6. Penfield and Howe (1894) } Vesuvius Yale 4,143.
- Larsen (1928) }
7. Walker and Parsons (1927) } Chaffey's Lake, Ontario.
- Larsen (1928) }
8. Zambonini (1919) } Piedmont.
- Larsen (1928) }
9. Quervain (1938) } Alpes, Canciano.
- 10-15. Borneman Staryn-Kevitch and Mjasnikov Achmatovsk 1-6.
16. Lindberg, M. L., 1946, *Bull. Geol. Soc. Am.*, p. 1213.

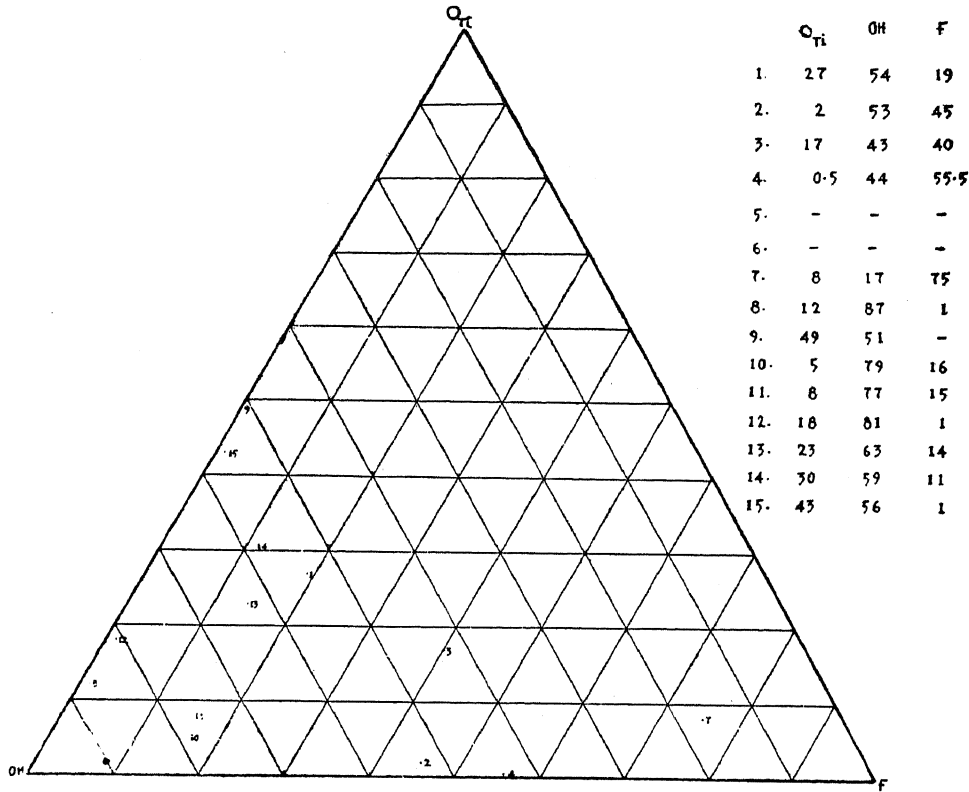


FIG. 1. Clinohumite (O_{ri}, OH, F) ratio.

ideal type only at the absolute zero of temperature. At all other temperatures, thermal vibrations produce defects either in the form of holes, or in some atoms not taking their legitimate positions. In the increased temperature of metamorphism the defects perhaps become much greater.

PHYSICAL AND OPTICAL CHARACTERS

Physical Characters

Crystal form absent; subhedral, Colour—of shades of yellow, brown to dark brown often violetish in weathered specimens. Cleavage poor. H 5.5–6, fracture subconchoidal to conchoidal. Lustre vitreous. Specific Gravity 3.2.

Twinned on 001, simple and polysynthetic—the bands of varying width; cracks usually present.

Optical Properties

Pleochroism	.. α = Golden yellow. β = Pale yellow. γ = Pale yellow.
Refractive indices	.. $\alpha = 1.638$ } $\beta = 1.658$ } ± 0.001 . $\gamma = 1.670$ }
Birefringence	.. Strong with middle second order interference colours.
Double refraction	.. .032.
2V	.. 76° (corrected for R.I. Segments).
Sign	.. Positive.

Extinction .. $\alpha \wedge 001 = 9^\circ$; symmetrical on either side of the trace of the composition plane 001, γ coinciding with the microscope axis. Random sections, orientated with the twinning line bisecting the angle $18-20^\circ$, between the extinction positions of α of two adjacent bands are noted. The adjacent lamellæ of such grains show equal illumination eight times on a complete rotation of the stage.

REFRACTIVE INDICES AND OPTIC AXIAL ANGLES

A reference to the refractive indices of 29 chondrodites (Table V), nine clinohumites (Table IV) and ten humites (Table VI) collected from literature indicates that there is considerable overlap in the R.I. values of α , β and γ . With reference to these three humite minerals, on the basis of the available data, it may be tentatively inferred that a humite mineral is chondrodite provided α is less than 1.607, or β less than 1.619 or γ less than 1.639. Also, if β is more than 1.655 or γ more than 1.675, it can be clinohumite. The identification of norbergite is best done by its optic axial angle $2V_\gamma = 44-50^\circ$. Only eight values of $2V_\gamma$ are available for humite and eight for clinohumite. The range in the former is $65-84^\circ$ while in the latter it is $58-90^\circ$. Out of the sixteen readings available for chondrodite the range is $70-90^\circ$.

OPTICAL PROPERTIES AND CHEMICAL COMPOSITION

The relation between the chemical composition and optical values for the humite mineral cannot be made out, as the available data are too scarce to draw a generalised conclusion. Further the refractive index is influenced by the chemical content of various constituents like FeO, MnO, TiO₂, F and H₂O. However, it may be mentioned that Thiele (1940) shows that

TABLE V
Chondrodite

Refractive Indices, 2V and Specific Gravity

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
α	1.592	1.593	1.594	1.600	1.601	1.601	1.602	1.604	1.605	1.607	1.607	1.607	1.608	1.638
β	..	1.606	1.607	1.609	1.616	..	1.611	1.613	1.616	1.617	1.619	1.620	1.620	1.619
γ	..	1.621	1.619	1.628	1.638	1.637	1.630	1.633	1.636	1.639	1.639	1.643	1.642	1.640
$\sqrt{a\beta}$	..	1.607	1.606	1.612	1.619	..	1.614	1.617	1.619	1.621	1.621	1.623	1.624	1.622
2V γ	..	..	Lge	72°	85-90°	..	72°	72°	73°	80°	..	72°14'	74°	77°
Extinction	..	..	..	26°	28°56'	27°2'	26°	22°	..	28°	30°	26°25'	..	27°
Specific Gravity	..	..	..	3.177	3.227	..	3.191	3.161	3.168	3.260	..	..	3.252	3.217
	15	16	17	18	19	20	21	22	23	24	25	26	27	28
α	1.609	1.609	1.610	1.611	1.612	1.613	1.613	1.615	1.619	1.619	1.621	1.631	1.635	1.643
β	..	1.622	1.623	1.622	1.619	1.625	1.623	1.627	1.632	1.630	1.632	1.640	1.645	1.655
γ	..	1.643	1.643	1.641	1.641	1.643	1.643	1.646	1.653	1.650	1.655	1.657	1.663	1.670
$\sqrt{a\beta}$	..	1.625	1.625	1.625	1.624	1.627	1.627	1.629	1.635	1.633	1.636	1.643	1.648	1.657
2V γ	..	79°	74°	..	73°	72°	70°	75°	79°40'	71°	..	med	Lge	Lge
Extinction	..	..	26°	27°	26°	26°34'	..	24°	27°30'	..	31°	..	26°	..
Specific Gravity	3.194	3.241	..	..	3.224	..	..	3.228	3.28	..	..	..	3.204	..
	3.215	..	..	..	..	..	..	..	..	..	..	..	3.231	..

Index—

- 1, 11, 12, 21, 24 and 28, Winchell, A. N. and Winchell, H. (1951).
- 2, 3, 5, 6, 9, 13, 15, 18, 23, 25, 26 and 27, Larsen, E. S. (1928).
- 4, 7, 8, 10, 14, 16, 19, and 22, Sahama, Th. G. (1953).
- 17, Sadasiviah and Ghosh (1953).
- 20, Eckeremann (1922), *Geol. For. Forh. Stockholm*.

TABLE VI
Humite

Refractive Indices, 2V and Specific Gravity

	1	2	3	4	5	6	7	8	9	10
α	..	1.607	1.621	1.621	1.623	1.624	1.625	1.632	1.641	1.643
β	..	1.619	1.627	1.629	1.634	1.633	1.635	1.643	1.649	1.653
γ	..	1.639	1.649	1.652	1.655	1.653	1.656	..	1.672	1.675
$\frac{2V}{\alpha\beta\gamma}$..	1.622	1.632	..	..	..	1.639	..	..	1.657
2V	..	76°	..	65°	69°	66°	70°	..	75°	68°
Specific Gravity	3.202	3.236	3.194 3.201	3.214	..	3.245	3.183 3.225	3.32	3.243	3.273

Index—

- 1, 2 and 10, Thiele (1940).
 3, 7 and 8, Larsen, E. S. (1928).
 4, 6 and 9, Sahama, Th. G. (1953).
 5, Rankama (1938).

TABLE VII*
Chondrodite

No.	Vorkommen	Fe ₂ O ₃	FeO	Fe'' + Fe'''	η_m	Analyst
5	Warwick	..	2.64	2.87	1.619	Penfield
9	Mansjo	..	3.67	4.08	1.623	Eckermann
2	Mt. Somma	0.54	3.85	4.80	1.623	Thiele
10	Hermala	1.86	4.16	6.48	1.626	Jernefelt
3	Tilly Forster	0.63	5.34	6.59	1.628	Thiele
14	Brewster	..	5.91	6.66	1.628	Penfield
15	Ristienne	0.30	8.70	9.97	1.628	Rankama
16	Nordmarken	0.54	10.54	11.97	1.635	Mauzelius

* From Thiele, *Chemie der Erde*, 13, p. 73.

TABLE VIII

*Clinohumite*Phillips Geiger Counter X-ray Spectrometer Cu/Ni-K α

Powder pattern data				Diffractometer data				
1		2		3		4		
Sahama's No. 865+9 Hameenkylä, Finland		This Paper—Sausar Series		Sahama's No. 865+9 Hameenkylä, Finland		This Paper—Sausar Series		
2θ	d	I	2θ	d	I	2θ	d	I
17.55	5.05	m	17.61	5.04	s	17.62*	5.02	s
19.89	4.46	w	20.03	4.43	m	19.96	4.44	w
22.95	3.88	w	23.00	3.86	w	22.96	3.86	w
24.02	3.70	ms	24.11	3.69	s	24.00	3.70	s
25.60	3.48	ms	25.62	3.47	m	25.50	3.48	w
..	..	..	..	..	..	25.80	3.44	w
26.50	3.36	w	26.58	3.35	vw	26.55	3.35	vw
27.50	3.34	ms	27.58	3.23	s	27.63	3.22	m
..	..	..	31.11	2.87	vw	30.58	2.91	vw
32.53	2.76	s	32.52	2.75	vs	32.33	2.76	s
..	..	..	..	..	..	32.68	2.73	m
..	..	..	..	..	..	33.85	2.68	vw
..
..	..	..	..	..	..	32.39	2.76	vs
..	..	..	..	..	..	32.70	2.74	m
..	..	..	..	..	..	33.45	2.68	w

Clinohumite Sausar Series, Bhandara District, India

34.35	2.61	m	34.53	2.60	w	34.38	2.60	w	34.45	2.60	m
35.34	2.54	m	35.28	2.53	vs	35.22*	2.54	s	35.30	2.54	m
35.94	2.50	m	35.84	2.50	vs	35.68	2.51	s	35.75	2.51	s
37.32	2.41	w	37.40	2.40	w	37.29	2.40	w	37.40	2.40	w
..	..	..	..	..	..	37.54	2.39	vW	37.64	2.39	m
38.16	2.36	w	38.15	2.36	w	38.07*	2.36	m	38.15	2.37	m
..	..	..	39.06	2.30	vW	38.98	2.30	vW	39.05	2.31	w
39.95	2.26	s	39.97	2.26	vs	39.77	2.26	s	39.87	2.26	s
..	..	..	42.13	2.14	vs	41.89	2.15	vW	..	..	..
52.41	1.75	s	52.45	1.745	vs	52.37	1.742	s	52.45	1.745	vs
..	..	..	52.95	1.728	vs	52.51	1.738	vs	52.60	1.740	vs
54.36	1.69	w	54.56	1.682	w	54.42	1.681	vW	54.48	1.680	w
56.45	1.63	w	..	..	..	56.49	1.624	vW	..	..	..
..	..	..	57.03	1.614	w	56.95	1.612	vW	57.05	1.610	w
60.13	1.54	w	60.35	1.534	w	60.02	1.537	vW	60.08	1.540	vW
..	..	..	..	..	..	62.20	1.488	vW	62.30	1.490	w
62.64	1.480	ms	62.82	1.479	s	62.61	1.479	m	62.78	1.480	w
66.83	1.400	m	67.14	1.394	m	66.84	1.398	vW	66.88	1.400	w
69.79	1.350	m	70.11	1.342	s	69.70	1.345	w	..	..	..

Courtesy of R. Natarajan,
Harvard (Mass.).

Dr. Fronde,
Harvard (Mass.).

Sahama (1953)
* Lines diagnostic.

R. Natarajan,
Harvard (Mass.).

the mean refractive index of chondrodite increases with increase in Fe^{2+} and Fe^{3+} , as shown in Table VII reproduced from Thiele.

Extinction $\alpha \wedge 001$

Though the determination of the refractive indices and optic axial angles are not useful in the specific identification of humite, chondrodite and clinohumite, the extinction value $\alpha \wedge 001$ is a useful criterion. The recognition of the morphological feature (001) depends on the crystal being twinned on (001). If the orientation of the grain is such that if a tilt on the N.S. axis in the U stage preferably does not exceed 15° , γ being made to coincide with the microscope axis, the symmetrical extinction (1951) for the humite minerals is as follows:

Humite	..	0° .
Clinohumite	..	$7-15^\circ$.
Titan clinohumite	..	20° .
Chondrodite	..	$26-30^\circ$.

For the mineral under study, the extinction is 9° ; indeed, grains with orientation exactly perpendicular to γ , giving symmetrical extinctions, without a need for investigation on the U stage, confirmed the correctness of the identification.

X-Ray Powder Data

In the absence therefore of twinning lamellæ, the specific determination of a humite mineral is practically impossible. The only method is to compare the X-ray powder pattern with a standard pattern of humite mineral. Here again the purity of the mineral for taking the standard should be rigidly ensured. Sahama's standard No. 865 + 9, of clinohumite Hameenkyla, Finland, serves the purpose of a standard.

Table VIII gives the X-ray data for glancing angles (2θ), d -spacings (d) and estimated intensities (I) of the lines for the Sausar series mineral and Sahama's standard. The patterns were obtained in both cases by Philips Geiger Counter X-ray spectrometer, using $\text{Cu-K}\alpha$ radiation and nickel filter. The asterisks in the column 2θ are recommended as diagnostic of clinohumite by Sahama. The identification is well established.

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Prof. Th. G. Sahama was kind enough to confirm the identification of the mineral by X-ray investigation and comparison with his standard material (No. 865 + 9). Thanks are due to Mr. R. Natarajan and Dr. Frondel, Harvard University, for letting me have the X-ray data. The chemical analysis was done by Jun Ito of the Mineralogical Department, Harvard University (Mass.). Prof. Percy Quensel, Stockholm University, was so kind as to supply the chemical analytical data of some of the comparable humite minerals, which could not be easily located in India. The micro-photographs were kindly prepared by Dr. West for publication.

The interest and help received from one and all, in writing this paper, is hereby gratefully acknowledged.

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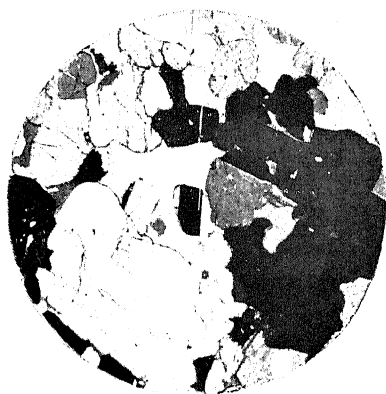


FIG. 1. Clinohumite—Symmetrical extinction.
× 12.

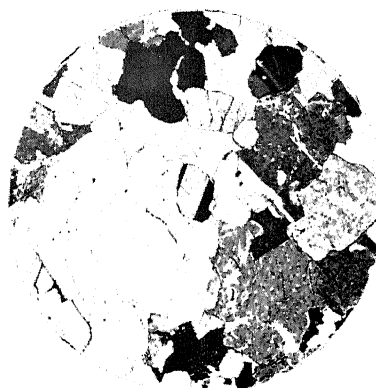


FIG. 2. Clinohumite—Symmetrical extinction.
× 12.

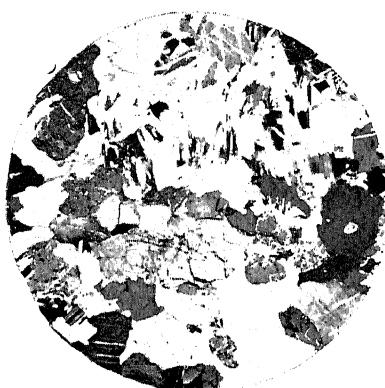


FIG. 3. Clinohumite with calcite, forsterite,
tremolite and spinel. × 12.



FIG. 4. Clinohumite—Polysynthetically twinned.
× 8.

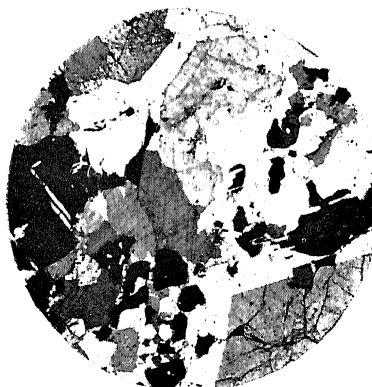


FIG. 5. Clinohumite with calcite, spinel
and phlogopite. × 12.

