On the relation of chamosite and daphnite to the chlorite group.[1]

(With Plates XVIII and XIX.)

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I. INTRODUCTION.

THERE is a close optical and chemical resemblance between chamosite, the chloritic mineral of the bedded ironstones, and daphnite, a low-temperature vein-chlorite common in some of the Cornish tin mines. New material has made it possible to undertake a fresh comparison of the two minerals: chemical analyses have been made by Mr. C. O. Harvey, chemist to H.M. Geological Survey, and a report on the X-ray measurements is contributed by Mr. F. A. Bannister, of the Mineral Department of the British Museum.

The new analysis of chamosite agrees with the simple formula previously assigned: X-ray examination of material from several localities has now established the distinctive crystalline nature of this fine-grained mineral, which differs structurally from ordinary chlorites such as clinochlore. Daphnite, on the other hand, has the ordinary chlorite structure, but the new analysis fully confirms Tschermak's original opinion that it cannot be represented chemically as a mixture of serpentine and amesite.

In attempting a comparison with chlorite analyses already published, great difficulty arises from the confused nomenclature. In order to ascertain the nearest chemically allied chlorites to those under discussion, a representative number of selected chlorite analyses have been plotted on a diagram with co-ordinates proportional to R_2O_3/SiO_2 and RO/SiO_2. This diagram illustrates clearly the relation of the several chlorites here mentioned to other similar minerals and to the formulae that have been proposed.

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As a result of the X-ray measurements it is found that the iron-ore chlorite, bavalite, is an orthochlorite resulting from the recrystallization of chamosite in an early stage of metamorphism.

II. DAPHNITE FROM THE TOLGUS MINE, CORNWALL.

The name daphnite was given by Tschermak (1891, p. 74) to material 'from Penzance' obtained in 1840. An analysis by R. Zeynek showed that the mineral was predominantly an iron-chlorite with low magnesia, and that its composition lay outside the main serpentine-amesite (Sp–At) series. Tschermak accordingly represented the composition by $At'_5At_5Sp_4$ (At' being $SiAl_2H_2O_7.MgOH.H$), and classed it in his leptochlorite division.

Several iron-chlorites have since been described under the name daphnite, which has been proposed by A. N. Winchell (1936, p. 649) as a varietal name to be used for a range of optically negative chlorites with high refractive index and negative birefringence (corresponding with a high iron content). The rest of the chlorite group was similarly divided by Winchell into varieties arbitrarily based on the optical properties. Although this procedure offers a convenient means of supplying a name for any chlorite, it will be evident (for example in the present case) that some chloritic minerals which are structurally different are too closely alike for it to be an adequate means of classification.

The original daphnite was a scaly vein-chlorite encrusting quartz and arsenopyrite. A specimen of similar chlorite from New Rosewarne mine (M.I. 3211x), cementing broken quartz and clay-slate, was purchased by the Museum of Practical Geology in 1873. Scaly iron-chlorite occurs in large quantities in many of the Cornish lodes, but has generally been termed simply chlorite. The specimen now to be described is typical of this vein-material. It was presented to the Museum (M.I. 16006) by Mr. R. H. Porter, and was obtained during the sinking of a new shaft at Tolgus mine, near Redruth, in 1926; it occurred in a vein penetrating killas, at a depth of about 1450 feet below the surface.

Daphnite (M.I. 16006).—Vein-stuff with one side attached to green chloritic killas. The vein-fissure contains prisms of milky quartz up to $1\frac{1}{2}$ inches in length; the interstices between these are filled with scaly, dark green chlorite, which forms coatings on the quartz about $\frac{1}{8}$ inch thick, composed of fan-like aggregates with their cleavage roughly normal to the quartz surface. The laminae are soft and flexible. Micro-section, E 13984, cut from the preceding (pl. xviii, fig. 1). The chloritic coatings are composed of fan-like tufts, with radial extinction. In a few

cases the outer ends extend as thin tabular crystals with no measurable external form, embedded in a later filling of vein-quartz. The chlorite is sensibly uniaxial, negative, with birefringence equal to that of the associated quartz (0·009). Pleochroic: ω green, ϵ pale greenish-yellow. Between the vein and the killas is a layer of earlier granular vein-material, composed of sutured quartz and orthoclase, with nests of chlorite, prisms of brown tourmaline, and white mica, sometimes chloritized.

The green coatings were readily separated by hand and broken up for analysis, yielding a flaky powder. The separated mineral was analysed by C. O. Harvey by the usual methods, with slight modification on account of the rather small quantity. The results are shown below, with earlier analyses for comparison.

TABLE I. Analyses of daphnite.

Analyst	...C. O. Harvey*	R. Zeynek (Tschermak, 1891)	E. S. Simpson (1936)	E. S. Simpson (1937)
Locality	... Tolgus mine, Cornwall.	'Penzance', Cornwall.	Randalls, W. Australia.	Kalgoorlie, W. Australia.
SiO_2	24·35	23·62	23·43	23·32
Al_2O_3	20·21	22·26	18·21	17·45
TiO_2	0·04	—	—	0·03
Fe_2O_3	2·13	nil†	4·49	4·09
FeO	36·27	38·97	36·30	38·90
MnO	0·48	0·98	trace	0·01
MgO	5·57	1·09	5·41	4·54
CaO	0·10	0·29	nil	0·24
Na_2O	n.d.	1·10	nil	nil
K_2O	n.d.	0·28	nil	trace
$H_2O > 105°$ C. ...	10·46 ⎫	11·16	12·15	10·89
$H_2O < 105°$ C. ...	0·35 ⎬		trace	0·80
Total	99·96	99·75	99·99	100·27
Sp. gr.	3·08	3·172	3·14	3·10
Refr. index ⎰ ω (D)	1·655	—	1·661	1·662
⎱ ϵ (D)	1·646	—	1·656	1·659

* Geol. Survey, Lab. no. 1020.
† 'Enthält kein Eisenoxyd' (Tschermak, 1891, p. 69).

These analyses are plotted in fig. 1: nos. recent 14, Orcel 132, and recent 18 and 16, respectively.

III. CHAMOSITE FROM FRODINGHAM, LINCOLNSHIRE.

The Frodingham ironstone is a shelly limestone alternating with bands richer in clay. It contains abundant limonite ooliths, but the clayey groundmass approximates in composition to a chalybite-chamosite mud-

stone, consisting of minute rhombohedra of chalybite in a weakly birefringent matrix of chamosite and clay.

Shells of *Gryphaea* are common in the ironstone; the specimen now described (pl. xviii, fig. 3) was presented by Mr. J. Behrendt many years ago, as representative of a curious green filling sometimes found in these shells. The shell was evidently intact when found, with the valves closed; it had been split open, the valves separating readily as shown, to reveal a smooth olive-green mass which is a cast of the interior of the shell. The green material resembles the groundmass of the ironstone outside the shell, but is almost free from ooliths and other coarser particles: evidently a slow infiltration has taken place while the dead shell was being enclosed in the ironstone, in such a way that the heavier particles were prevented almost completely from entering the cavity. The smooth green material in this case contains rather a large proportion of chalybite as minute rhombohedra.

Another shell of the same kind was collected by the writer at Froding-ham (pl. xviii, fig. 4). It is incompletely filled with the dark green paste, which occupies what was possibly the lower half of the shell. The remaining space has been filled with comby vein-calcite which is no doubt the cementing calcite of the limestone. The shell is imperfect in shape, as if it had been injured, possibly during life, but it forms a nearly complete enclosure. A microsection (pl. xviii, fig. 2) shows clearly the rounded irregular surface of the green paste. The green mineral forms distinct granules suggesting a flocculent colloid or chemical growth. There is a rather striking resemblance to structures much discussed in reference to greenalite and glauconite: the cauli-flower-like granules are embedded in calcite or closely aggregated. In bulk the mineral is almost isotropic, with scattered minute black specks, and a few pleochroic birefringent flakes (of chlorite); under the highest magnification it appears at the edges to be a felted mass of very minute flakes. Where quite free from staining, the colour is a clear jade-green. Chalybite crystals are present in places as groups of elongated rhombo-hedra, which are evidently of late origin, replacing the vein-calcite; they are somewhat stained by oxidation, and there is also a slight staining of the chlorite, but the latter has been chemically protected by the more readily oxidizable carbonate (Hallimond, 1925, p. 107).

Clastic particles, such as quartz or limonite grains, are absent; the flocculent aggregates would seem to represent a chemical precipitation of nearly pure chlorite. It was decided to sacrifice the greater part of the material in order to obtain an analysis, and the soft paste was removed

from the shell-cavity with a sharp steel point. Inevitably it was accompanied by small amounts of calcite and chalybite, but, as remarked above, these carbonates are of quite extraneous origin, and should be deducted from the analysis. The stained part of the material was not used.

The refractive index (by immersion) of the analysed material in sodium-light was approximately 1·665. By weighing in distilled water in a pyknometer the density was found to be 3·242. This includes carbonates, &c., and after correction for calcite, chalybite, and clay, as shown by the analysis below, the calculated density of the chlorite is 3·34; this may be a little high if the residual clay contains iron.

The chlorite was analysed by C. O. Harvey by extraction with $N/2$-HCl according to the method described by F. R. Ennos and R. Sutcliffe (in Hallimond, 1925). The revised electrometric method (Sutcliffe) was not used. On account of the small amount of material the methods were adapted to a semi-micro scale. Adequate precautions were taken, but beyond this no special description seems necessary. The semi-micro determination of carbon dioxide was not carried out until a satisfactory control result had been obtained with a splinter of pure calcite; this contained theoretically 0·00733 gm. CO_2, and the figure obtained was 0·00730 gm.

TABLE II. Analyses of chamosite and bavalite.

Analyst ...	C. O. Harvey[*]		H. Jung (1931)	V. V. Chernykh (1926)	J. Orcel (1927, p. 246)	H. Jung (1930)
Locality ...	Frodingham, Lincolnshire.		Schmiedefeld, Thuringia.	Hayanges, Lorraine.	Bas Vallon, Brittany.	Schmiedefeld, Thuringia.
SiO_2 ...	19·77	24·9	26·65	25·04	22·27	20·82
TiO_2 ...	—	—	trace	—	0·08	trace
Al_2O_3 ...	12·40	15·6	16·14	20·10	21·40	17·64
Fe_2O_3 ...	5·74	7·2	6·69	2·05	0·67	8·70
FeO ...	31·02	35·0	34·43	35·40	43·01	37·96
MnO ...	0·35	0·4	—	—	0·05	—
MgO ...	3·63	4·6	4·47	4·28	2·35	4·15
CaO ...	3·34	—	—	—	0·15	—
P_2O_5 ...	0·26	—	—	----	—	—
SO_3 ...	0·32	—	—	----	--	—
CO_2 ...	4·22	—	—	...	.-.	—
H_2O+ ...	—	(12·3)	11·42	} 12·87	10·10	10·31
H_2O- ...	—	—	0·08		0·11	0·07
Insol. ...	7·8	—	—	—	--	—
Total ...	(88·85)	100·0	99·88	99·74	100·54[†]	99·65
Sp. gr. ...	—	3·34	3·19			

[*] Geol. Survey, Lab. no. 1015. The second column gives the Frodingham analysis after deducting carbonates, &c., and recalculating to 100, assuming 12·3 % H_2O.
[†] Including alkalis 0·35.

From the above analysis the calculated mineral composition of the Frodingham material is as follows:

$Ca_3(PO_4)_2$	...	...	...	0·57	Remaining oxides.	Molecular ratios.
$CaSO_4$ ...	...	...	...	0·54	SiO_2 19·77	200
$CaCO_3$ ...	...	...	...	5·01	Al_2O_3 12·40 ⎫	96
$FeCO_3$ ...	...	...	...	5·26	Fe_2O_3 5·74 ⎭	
				11·38	(Fe,Mn)O 28·11 ⎫	292
					MgO 3·63 ⎭	
					69·65	

Total remaining oxides (69·65) correspond to 79·39 % of chamosite containing 12·3 % H_2O. The figure for 'insoluble' is approximate, owing to deflocculation difficulties during washing. The original material contained 1·3 % $H_2O < 105°$ C., 8·9 % $H_2O > 105°$ C. FeO may be slightly higher than the true value owing to presence of organic matter. The molecular proportions given above for the 'residual oxides' agree, within the limits of error in an analysis of this kind, sufficiently closely with the simple formula $2SiO_2.R_2O_3.3RO.aq.$

Analyses of chamosite from Schmiedefeld and Hayanges are given for comparison. Apparently the ferric iron substitutes part of the alumina. The last two analyses, of bavalite from Bas Vallon and 'thuringite' from Schmiedefeld, represent alteration products due to the incipient metamorphism of chamositic ironstones. They are characterized by lower SiO_2 and higher RO than the chamosites; both have orthochlorite composition (see section VII).

IV. EARLIER ANALYSES OF CHAMOSITE.

Analyses by acid extraction.—Chamosite, though present in very large amounts in bedded iron-ores, has never been found in the pure state. It is invariably fine-grained, though sparse crystalline flakes in the iron-stones have been provisionally regarded as chamosite. Alteration to chalybite and clay is extremely common, and the clay, which may be pseudomorphous after the chamosite, is so closely intergrown that there is little prospect of separating the two minerals by mechanical means, nor can they be distinguished with certainty under the microscope. Thus there seems to be no direct physical means of measuring the proportion of chamosite present, even when it forms the bulk of the rock. Fortunately a chemical method has served to distinguish the mineral. Unaltered chamosite is remarkably soluble in hot, very dilute ($N/2$) hydrochloric acid, while the clay constituent of the ironstones is almost insoluble. A standard method of acid extraction was developed by F. R. Ennos and R. Sutcliffe (in Hallimond, 1925). It was later successfully employed by T. Deans (1934 a) and has been used by Mr. C. O. Harvey in the present analysis and in other Survey analyses of chamo-

sitic rocks to be described below. Sutcliffe found that the peculiar solubility was confined to the unaltered ironstones; those from Wales, which have suffered some slight degree of recrystallization, dissolved more slowly and were difficult to filter (see later, on the alteration of chamosite). In the English unaltered ironstones the extract was fairly close to the simple chamosite composition, as will be seen from the following table, which gives the percentage of soluble chloritic oxides present and their molecular ratios.

TABLE III. Chamosite in British ironstones. Molecular proportions by acid extraction ($SiO_2 = 200$).

	% soluble oxides, or chamosite.	R_2O_3.	RO.
1. Frodingham ('sulphur bed')	21·91	99	282
2. „ ('top bed')	16·05	110	296
3. „ (Lias clay)	13·11	87	318
4. Cleveland ('dogger stone')	12·77	108	329
5. „ (Pecten seam)	46·21	107	303
6. „ (shale)	22·72	100	283
7. Marlstone (green ore)	39·94	100	301
8. * „ pebble (phosphatic)	48·61	152	299
9. *Westbury (? oxidized)	25·91	129	245
10. *Northants. (? oxidized)	17·45	152	239
11. Yorkshire (T. Deans, 1934 a, p. 58) ...	'70·55 % cham.'	115	290
12. *Ayrshire clay (B. E. Dixon, 1930, no. 874)	78·45	154	296
13. „ („ „ no. 875)	24·67	119	303
Omitting four analyses marked * ...	{ highest	119	329
	{ lowest	87	282

The first ten analyses are by F. Ennos and R. Sutcliffe (in Hallimond, 1925). Apart from the four marked * these values agree fairly well with the simple ratio 100 R_2O_3 : 300 RO.

Freshwater chamosite.—Chamosite is commonly a marine mineral; in the Coal Measures the chalybite mudstones form a special class of iron-ore from which chamosite is absent (Hallimond, 1925, p. 62). T. Deans (1934 a, p. 58), however, has described an exceptional bed from the Yorkshire Coal Measures, containing 70·55 % of chamosite; this rock apparently formed under conditions involving the reversible reaction between clay, chalybite, and chamosite. Other exceptional occurrences have been recorded from localities in Ayrshire: V. A. Eyles (1930, p. 67) describes green clays from Borland which resemble chamosite in bulk composition (Lab. no. 424) and which have been formed by the decomposition of Millstone Grit lavas. Similar clays are also discussed by G. V. Wilson (1930, p. 209), who regards them as freshwater lagoon-

deposits that have been covered by thick vegetation; they contain sphaerosiderite, kaolinite, bauxitic alumina, and the chloritic mineral, and show oolitic structures which he regards as originally formed of aluminium hydroxide. Indeed, the high proportion of alumina has given a commercial value to one bed, the Ayrshire bauxitic clay (Wilson, 1922). Kaolinite and the chlorite are often of secondary formation, which is attributed to the action of acids under the thick cover of vegetation (see also T. Deans, 1934 b); indeed, the whole mineral assemblage suggests a balance of products formed from the iron-bearing lavas by the continued action of circulating waters. These rocks have a good deal in common with those from Yorkshire, but the latter apparently owe their iron content to ordinary Coal Measures sedimentation, for there are no associated lavas. The green mineral is present in large amounts in some of the Ayrshire rocks; two analyses by acid extraction were made by B. E. Dixon (1930, p. 98) with the results shown in table III (12 and 13). The high proportion of soluble alumina in no. 874 is attributed to the soluble bauxitic alumina often present in this series of rocks; with this allowance, both analyses agree in composition with the simple ratios assigned to chamosite.

Another example of chloritic silicate from Ayrshire has been found in the Coal Measures (details communicated by Mr. V. A. Eyles). The rock occurs in a railway cutting a few yards north of the Ayr–Whitletts road. A micro-section, S 22520, shows minute rhombohedra and groups of chalybite sprinkled in a pale green chloritic groundmass which is composed of felted, weakly birefringent flakes, with positive elongation and pleochroism pale green to colourless.

Dehydration.—H. Jung (1931) has given a very careful account of the composition and dehydration of chamosite from Schmiedefeld. This was prepared by finely powdering the ore and separating the chalybite and magnetite by flotation in Clerici solution of density 3·55. After several days the small floating portion was recovered, washed, and further cleaned with warm dilute acetic acid. The analysis (table II) shows a rather higher percentage of silica than is required by the simple formula, but the treatment outlined above seems liable to give rise to such a result, either by the failure to remove silica disseminated in the rock, or by alteration of the fine powder during prolonged separation. A well-defined dehydration curve was obtained with the Hüttig tensi-eudiometer. The curve was similar to those for thuringite and kaolinite, nearly all the water being lost sharply at about 420° C. if the vacuum was maintained for a sufficient time; the loss began, however, at 390°.

Chernykh's results (1926) on chamosite from Hayanges near Metz form part of a general study of chlorites, &c. Thermal curves were obtained by fairly rapid heating, showing several rather blunt 'delays' between 280 and 1000° C.; there is, however, very little feature near the 420° point for chamosite, the 'leptochlorite' delay being at 620° for chamosite and thuringite. Two grams of material were heated in the short time of half an hour (details of method for brucite, Chernykh, tom. cit., p. 82). Jung (above) found that by successive removal of water vapour as the pressure rose to 3·0 mm., the dehydration at 420° was only completed after several intervals of $\frac{1}{2}$–2 hours. It seems likely, therefore, that the higher temperatures recorded by Chernykh relate to the evolution of water under, at least, atmospheric pressure and are less exact.

Differential thermal analyses are also recorded by Orcel (1927), with a summary of earlier work. Here again the rate of heating (9 degrees per minute) is sufficiently rapid to incur the risk of delay in view of the slow dehydration observed by Jung. Bavalite (no. 128) gave two peaks (endothermic) beginning near 470° and 530°. 'Aphrosiderite' (no. 123) and 'thuringite' (no. 25) also gave peaks at 500°, but the other chlorites decomposed at about 600° C. Other measurements were made by heating the chlorite in an exhausted enclosure and measuring the change of pressure with temperature. In this case the first evolution takes place under low pressure; by very slow heating, sharp inflexion points were obtained. The first inflexion temperatures were: aphrosiderite (no. 123) 420–440°; bavalite (no. 128) 440° very sharp; 'thuringite' (no. 13, Messina, Transvaal) 440–450°. These minerals showed a further loss beginning about 550° C., but the pressure had been allowed to rise at the end of the first dehydration to about 20 mm. The other chlorites decomposed at 500° or over, with a second evolution at 620–720°. Orcel's first rough measurements thus correspond with those of Chernykh, but the temperatures are lower, while the later measurements, 420–440°, are in close accord with 420° observed by Jung for chamosite.

By these dehydration experiments the distinctive behaviour of the 'leptochlorites' seems well established, but it is not clear whether their low decomposition temperature is due chiefly to the substitution of iron for magnesia or to structural difference. It will be shown in Mr. Bannister's report that chamosite has a different structure from bavalite (Orcel, no. 128), which is an orthochlorite, so that the iron content may be the important factor.

V. Graphical Representation of the Chlorites.

It is helpful to have some means of selecting those chlorite analyses that approximate to a given composition. For this purpose the nomenclature is so confused as to be useless, but it is possible to construct a diagram resembling that for the biotite group (Hallimond, 1926, p. 29) which will indicate chemically similar analyses regardless of theoretical considerations, and which may be used to test the extent to which the analyses agree with theory. The use of graphs is suggested by Orcel (1927, p. 412), though his parameters are unsuitable for plotting, and the analyses here plotted (fig. 1) are taken chiefly from his monograph, which gives a very complete survey of analyses up to 1927.

During recent years, since the announcement of the chlorite cell formulae obtained by X-ray methods, it has been usual to give the atomic ratios for (O,OH) = 18 in publishing new analyses. For a representation dealing only with analyses referable to the same cell-formula there is no doubt that a special plotting, using the variables of the cell-formula, would be of great interest. But for the general comparison of a series of analysed minerals which may not be isostructural, e.g. of the orthochlorites with stilpnomelane, chamosite, &c., and for the general relations of the chlorites as a part of the oxide system (phase rule) such a plotting cannot be used. For the purpose of the present investigation, therefore, the plotting of fig. 1, in terms of the component (grouped) oxides, RO, R_2O_3, SiO_2, was used.

By selecting the points nearest to that representing a new analysis it is possible to obtain a complete account of earlier similar analyses, regardless of nomenclature. This is easier than the selection of analyses with similar ratios in the Orcel tables, since his narrow sections (fig. 1) result in a highly artificial sub-division, which means that similar analyses occur in different sections and are liable to be overlooked.

Choice of parameters.—Practically all chemical theories accept as a common basis the mutual replacement of $(Fe,Al,Cr)_2O_3$ and of $(Fe,Mg,Mn)O$ (cf. Orcel, p. 324); the grouped oxides being written respectively R_2O_3 and RO. Calcium and the alkalis are usually absent from the chlorites, so that any member of the chlorite group (in the broad sense) can be represented in terms of the constituents SiO_2, R_2O_3, RO, and H_2O. So far as the 'solid' constituents are concerned, therefore, the chlorites can be represented by points on a plane diagram with co-ordinates proportional to the two variables R_2O_3/SiO_2 and RO/SiO_2. It is convenient, in discussing chamosite, to plot the values

of R_2O_3 and RO when $SiO_2 = 200$, but the diagram could be adapted to any other value for SiO_2 by re-scaling the co-ordinate axes.

If the chlorites formed a single isomorphous series, this diagram might serve to determine the position of any new analysis in relation to the rest of the group, but it is certain that besides the main chlorite group there are several non-isomorphous chloritic minerals, of which chamosite is an example, possibly also amesite and cronstedtite (see report on X-ray data); these also, when plotted, appear in the diagram and may sometimes coincide in composition with chlorites of the main series; additional tests, especially by X-ray and solubility, are therefore essential for complete identification. Nevertheless, the graph gives an interesting comparative view of the chlorite group.

Selection of analyses for plotting.—Orcel's tables contain 262 numbered analyses (omitting those with chromium). Many, however, are early or incomplete, so that a careful selection must be made. In the first place, all results dated before 1890 were omitted: this inevitably excludes a few good analyses, but a large number are eliminated that are certainly inaccurate. Next a certain number were omitted which showed important amounts of CaO or alkalis. The latter may in some cases represent true minerals, but they are rare and would be best studied separately. Even after this elimination, 79 analyses remained to be plotted.

Co-ordinates.—The ratios given by Orcel, $s = SiO_2/R_2O_3$, $a = Fe_2O_3/Al_2O_3$, and $f = FeO/MgO$, are not suitable for the present method of plotting. Values for the co-ordinates here used, namely 200 R_2O_3/SiO_2 and 200 RO/SiO_2, were therefore calculated from the molecular ratios listed by Orcel in the column following each analysis. As an example: amesite, no. 2 (Orcel, p. 331), has the equivalents SiO_2 347, R_2O_3 344, RO 692; when $SiO_2 = 200$ these become R_2O_3 198, RO 399, the co-ordinates of point 'Orcel 2' in fig. 1.

Recently published chlorite analyses can readily be plotted on this diagram, and the nearest existing analyses ascertained. No attempt has been made to include all the later chlorites which fall within the crowded area, but many recent daphnites have been added and are numbered as in table IV. Some less accurate chamosites extracted from sedimentary rocks by acid are given only in fig. 2.

VI. CHEMICAL RELATIONSHIP OF CHAMOSITE AND DAPHNITE TO THE CHLORITE GROUP.

Fig. 1 represents the main group of known chlorite analyses. Stilpnomelane and some delessites lie to the left of the area shown. Tschermak,

TABLE IV. Recent data for chamosite &c. ($SiO_2 = 200$).
The numbers refer to points on figs. 1 or 2.

Chamosite:				R_2O_3.	RO.	100 FeO/FeO+MgO.
1–7. The first seven in table III (acid extraction)				—	—	—
8. Harvey (p. 445). Frodingham	...	...		96	292	—
9. Jung, 1931. Schmiedefeld		...	...	92	271	81
10. Chernykh, 1926. Hayanges		...	...	100	287	82
11. Radley, 1920. Raasay	...	...	...	87	256	82
12. Deans, 1934. Yorkshire ...		...	...	115	290	—
13. Dixon, 1930 (875). Ayrshire		...	...	119	303	—
Daphnite, &c.:						
14. Harvey (p. 443). Tolgus mine		...	...	104	321	79
15. Agar and Emensdorfer, 1937		...	...	112	340	48
16. Simpson, 1937. Kalgoorlie		...	...	101	338	83
17. ,, ,, Mt. Satirist		...	...	146	311	86
18. Simpson, 1936. Randalls		...	...	107	331	79
19. ,, ,, Holleton ...		...	...	97	339	17
20. ,, ,, Ninghanboun		...	...	75	275	8
21. Pulfrey, 1933, IV. Wales ...		...	...	123	354	90
22. ,, ,, VII. ,,	...	...	...	121	338	91
23. Holzner, 1937. Weilburg ...		...	...	118	287	59
24. ,, ,, Georg-Joseph mine		...	150	276	68
25. ,, ,, Fortuna mine		...	...	131	316	84
26. Jung, 1930. Schmiedefeld		...	...	132	367	84
27. Chernykh, 1926. Schmiedefeld	...	...		115	319	100
28. ,, ,, ,,		...	...	126	311	84
29. Shannon, 1926. Shoshone Co.		...	...	111	424*	718
30. Sahlbom, 1939. Mourne Mts.		...	...	103	255	95

* All iron as FeO. This analysis would lie to the right of fig. 1, beyond Orcel 7 and 35. A few new analyses cited by Winchell lie in the crowded area and have not been plotted.

following Kenngott (1866),[1] showed that his orthochlorite division could be represented by mixtures of serpentine Sp and amesite At; the solid constituents of these mixtures are indicated in fig. 1 by a straight line, which may be termed the orthochlorite line. The numerous analyses now available confirm the original observation that the orthochlorite line is not uniformly occupied by analyses: amesite is almost isolated, the main chlorite group extending from corundophilite to pennine;

[1] Kenngott (1866, pp. 247–250) showed that, after calculation in some cases of all the iron as ferrous oxide, the chlorites could be represented as isomorphous mixtures in which $MgO.SiO_2$ was replaced by Al_2O_3 'just as in haematite $FeO.TiO_2$ is assumed to proxy [for Fe_2O_3] ... According to this hypothesis we may put $AlO.AlO_2$ in place of MgO and SiO_2.' After tabulating 13 chlorites to show that $SiO_2 + AlO_2$: $RO + AlO$: $H_{[2]}O = 2 : 3 : 2$, Kenngott deduces the formula $Mg(OH)_3 + 2MgO.SiO_2$ for the end-member, serpentine. For 35 chlorite analyses he found that in 26 (RO+AlO) lay between the limits 3·17 and 2·86. (Holzner, 1938, p. 411, gives 16 iron-chlorites with limits for Y 6·072 and 5·919.) Kenngott thus completely anticipated present-day ideas of proxy substitution.

then there is possibly another space between pennine and aluminous antigorites. The grouping is not confined to the orthochlorite line. Only scattered analyses are found to the right of the line in fig. 1, but there is a fairly crowded area on the left of the line, clearly indicating the existence of chloritic minerals with less RO than the orthochlorites. These were placed by Tschermak in his leptochlorite division, molecules (not now accepted) such as At′, $SiAl_2MgO_8H_4$, and At″, $SiAl_2O_7H_4$, being brought in to explain the composition. Winchell included the leptochlorites in the orthochlorite series, for by regarding the Fe_2O_3 as the result of secondary oxidation of FeO he was able to increase the value assigned to the RO group. The effect of transforming R_2O_3 to 2RO is to move the representative points in fig. 1 diagonally nearer to the orthochlorite line, but the Fe_2O_3 is sometimes too low or too high for exact coincidence. It is likely, however, that at least part of the Fe_2O_3 is really a normal constituent of the R_2O_3 group, replacing alumina. Holzner (1938) has given a very detailed discussion of the iron-bearing true chlorites. Following Winchell (and Kenngott, 1866) he shows that in many cases the analyses are reduced to orthochlorite composition when all the Fe_2O_3 is represented as FeO. This he assigns to the replacement (Kunitz, 1924) $Fe_2''(OH)_4 = Fe_2'''O_2(OH)_2+2H$. A diminution in water content is involved, and this is not verified in the tabulated analyses. In certain other chlorites the ferric iron cannot be so explained, but must be assigned to the normal replacement of Al by Fe‴.

It is easy to select from fig. 1 those chlorites that show outstanding departure from the orthochlorite line. There are several on the right (Orcel 166, 167, 69, 35, 7) which have not so far been discussed and which would seem to merit detailed examination. Many of those on the left can be explained by the above substitution, but it will be found that several, e.g. Orcel 188, 248, 219, 9, 15, and recent 30, 20, have insufficient ferric iron. It is unlikely, however, that the substitution is solely due to oxidation of the iron. A primary substitution might well take place with $Mg_2''(OH)_4 = Al_2'''O_2(OH)_2$.

Nomenclature.—In figs. 1 and 2 the names leptochlorite, chamosite, daphnite, thuringite, and bavalite have been marked at those (approximate) compositions which were generally associated with the minerals when they were first described (cf. Dana's System, 6th edition). Perhaps the simplest usage would be to retain Tschermak's *leptochlorite* for all the analyses to the left of the orthochlorite line. *Chamosite* is the structurally different chlorite of the sedimentary rocks. *Daphnite* usually implies the more ferrous leptochlorites, while *thuringite* has
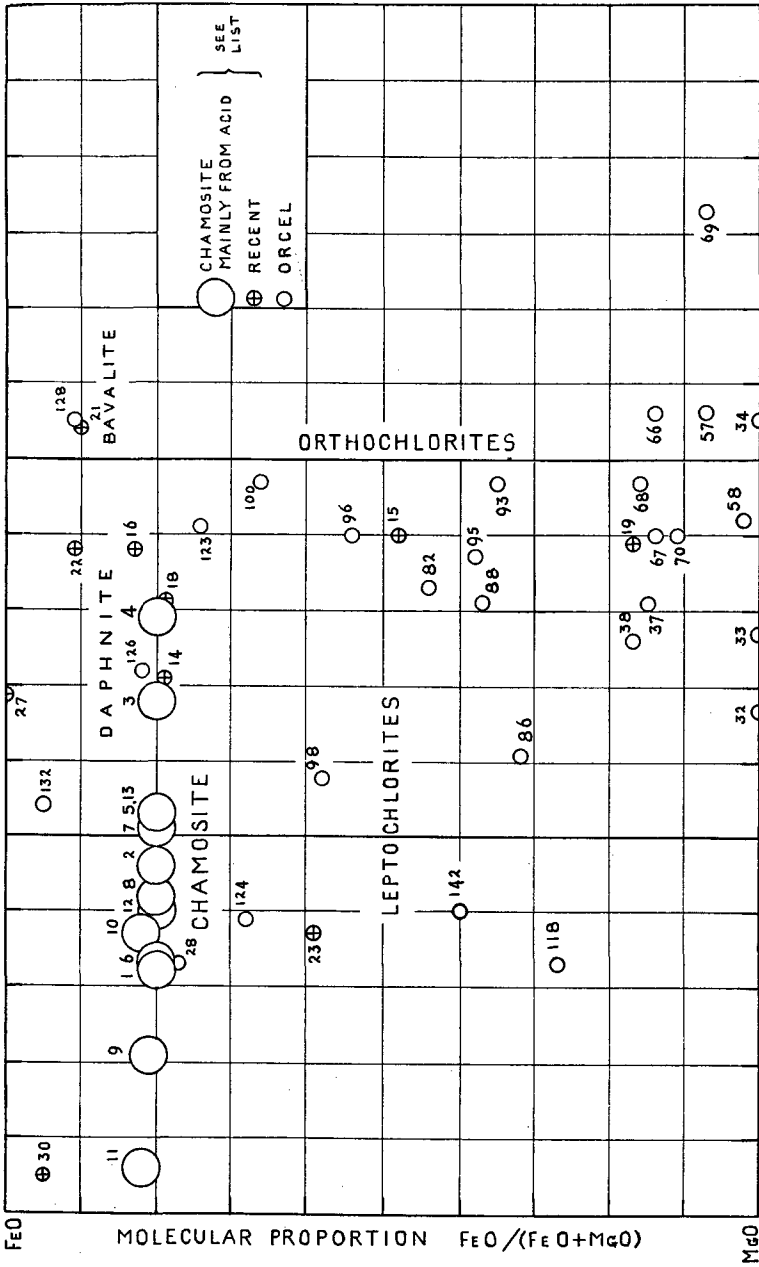
Fig. 1. Selected analyses of chlorites plotted with co-ordinates RO and R_2O_3 when $SiO_2 = 200$. The numbers refer to Orcel (1927) and table IV (p. 452).

FIG. 2. Selected analyses of chamosite and other chlorites having $Al_2O_3 : SiO_2$ approximately $1 : 2$, plotted with the ratios $FeO : (FeO+MgO)$ and $200\ RO : SiO_2$ as co-ordinates.

been used for leptochlorites with a noteworthy amount of ferric iron. *Bavalite* is a ferrous orthochlorite at the end of the daphnite series.

Tschermak's arbitrary sub-divisions of the magnesian orthochlorite series are indicated by the names down the right-hand side of fig. 1. On the left are the sub-divisions proposed by Orcel; these apply equally to the leptochlorites, so that they divide the whole diagram into narrow horizontal strips. Additional names are used by Orcel in his tables.

Cross-section through the chlorite group.—In order to show more clearly the chemical relation of chamosite to the daphnites, &c., a cross-section has been drawn through the chlorite group along the horizontal strip $R_2O_3 = 90$–120 (this is rather narrower than the horizontal section named prochlorite by Orcel). This section includes numerous analyses with RO contents varying through chamosite to the orthochlorite line. They have been represented upon a diagram (fig. 2) having the RO content as abscissae and the molecular ratio $FeO/(FeO+MgO)$ as ordinates. In acid extraction analyses of chamosite with carbonate present the ratio FeO/MgO is not directly determined, but it is certainly high and the value $5:1$ has been assumed; the chamosites, which have been plotted as large circles, all lie near the top of the diagram.

The following relations will be evident from fig. 2. (1) As regards RO contents, the chamosites cluster near the simple ratio $RO = 300$; some of the extraction analyses are not very accurate but they all lie well apart from the orthochlorite line, which is intersected by the diagram at $RO = 350$. (2) Chlorites that have been called daphnite, together with many others that have received different names, have an RO content intermediate between chamosite and the orthochlorite line, and they occur with increasing frequency toward the latter. (3) It is generally understood that the leptochlorites are dominantly iron-bearing, but this is by no means invariably the case, for the diagram shows both ferrous chlorites (bavalite) near the orthochlorite line and magnesian chlorites near the chamosite composition. Until these minerals have been examined by X-ray methods it is not possible to say whether they are all members of the main chlorite series, but the mode of occurrence makes this very likely. (4) The orthochlorite composition forms a very well-defined limit on one side of the group: relatively few analyses contain more than 350 RO, but the existence of a few chlorites with excess RO (e.g. Orcel, 69, 35, fig. 1) seems to be established.

From this brief review of the chlorites it might on the whole be concluded that the chamosite of the iron-ores is somewhat different from the daphnites (vein-chlorites), though their composition is in one or two

cases nearly identical; only the daphnites show a gradation toward the orthochlorites. A very interesting determination of this question has been reached by Mr. Bannister as the result of the X-ray investigation.

VII. ALTERATION OF CHAMOSITE.

The bedded iron-ores of North Wales contain abundant chlorite: although the mode of occurrence corresponds with that of chamosite, the chlorite has been recrystallized, the smooth 'onion-structure' of the ooliths being replaced by roughly tangential minute flakes (Hallimond, 1925, p. 73). Ennos and Sutcliffe found that the chlorite in these ores dissolved less readily and the extracted material differed from the simple chamosite formula. These results were confirmed by Pulfrey (1933).

A similar recrystallization affects the bavalite (no. 128) analysed by Orcel (1927, p. 246) (see p. 445). This was a new specimen obtained from the foot-wall of the ironstone bed (Devonian) at Bas Vallon; it was composed of pure chlorite, as felted minute scales. Another specimen contained garnet and stilpnomelane. Bas Vallon lies between two granite masses, and the iron-ore, which is oolitic, has apparently suffered an alteration similar to that affecting the Welsh ores.

Two of Pulfrey's specimens were pure chlorite, nearly as free from residue as the bavalite: their molecular ratios are shown below:

	Bavalite Orcel, 128.	Llandegai Pulfrey, IV.	Pen-yr-allt Pulfrey, VII.
SiO_2 ...	200	200	200
Al_2O_3 ...	114	117	98
Fe_2O_3 ...	—	6	23
$(Fe,Mg,Mn)O$	355	354	351
H_2O ...	304	339	338
Sp. gr. ...	3·20	3·03	—

These are plotted in fig. 1, nos. Orcel 128, recent 21, 22.

The Llandegai mineral was a felted mass of minute hexagonal scales, formed in a slip-plane in the ironstone bed; that from Pen-yr-allt was a green rock, chiefly composed of felted flakes of chlorite with scattered grains of magnetite associated with stilpnomelane. The three analyses contain more RO than chamosite and are close to orthochlorite in composition: it will be shown in the section dealing with X-ray investigation that the Llandegai chlorite and Orcel's bavalite have normal chlorite structure, and are not chamosite. On reference to fig. 1 it will be seen that bavalite (Orcel, 128) is closely similar in ratios to the magnesian

sheridanites (Orcel, 34 and 31). Evidently the first effect of alteration upon the chamositic ore has been to destroy the special chamosite structure and to produce bavalite, a rather more basic true chlorite which is at the orthochlorite end of the daphnite range. Another example of the same kind would seem to be the alteration of the Schmiedefeld chamosite (Jung, 1931) to 'thuringite' (Jung, 1930). This thuringite differs from the other thuringites, for it is an ortho-chlorite in composition, not far from bavalite (cf. analysis cited in table II and point 'recent 26' near the orthochlorite line in fig. 1).

The alteration to bavalite involves an increase in RO: it seems possible that this may have been provided by the elimination of CO_2 from chalybite, for several of the altered Welsh ores are notably free from carbonate, though otherwise resembling ordinary ironstones.

Note.

Chlorite analyses, when calculated to atomic proportions, show re-markably frequent and close agreement with the accepted X-ray formula for chlorite. This is very well exemplified in the series of iron-chlorite analyses tabulated by Holzner (1938, p. 411). The agreement somewhat exceeds the expectation that might at first be formed in view of the nature of the material and the errors of analysis. It becomes of interest, therefore, to inquire what deviation from complete agreement with the ideal X-ray formula will result (a) from the presence of, say 5 %, of quartz, clay, or mica, and (b) from common errors in analysis.

(a) Water is verified separately by Holzner, the 'solid' part of the analysis being recalculated to O = 14. Since Al is arbitrarily included with Si to make up $Al^{[4]} = 4$, the only total that is independently verified here is $Si + Al^{[4]} + Al^{[6]} = 10$ atoms.

Calculations as in Holzner's Table VIII (1938).

		$Al^{[4]}$.	Si..	H_2O.	ΣY.	O(solid).
Ideal chlorite	... ...	1·50	2·50	4·00	6·00	14·00
,,	+5 % SiO_2	1·42	2·58	3·80	5·85	14·00
,,	+5 % $Al_2O_3.2SiO_2.2H_2O$ ...	1·42	2·58	4·00	5·90	14·00
,,	+5 % $K_2O.3Al_2O_3.6SiO_2.2H_2O$	1·25	2·75	3·86	5·91	14·00

Even in these extreme cases the agreement with $\Sigma Y = 6·00$ is sur-prisingly close. It seems clear that quite a substantial amount of many foreign minerals might be present without seriously affecting the verification.

(b) As regards errors in analysis, the failure to separate silica from alumina has little influence on the atomic ratios, for by weight

$2SiO_2 : Al_2O_3 = 120 : 102$ so that the number of silicon atoms lost is about equal to the additional aluminium returned. Again, the return of some ferrous iron as ferric would appear as an oxidation according to Kunitz's or Winchell's theory. It is, of course, of the greatest interest that good chlorite analyses closely agree with the X-ray formula, but the above considerations have been mentioned in order to guard against the assumption that such an agreement necessarily indicates that the analysis is satisfactory and suitable for calculation.

For the orthochlorites the cell-formula $(Si,Al)_4(Mg,Al)_6O_{14}(OH)_8$, which agrees with that deduced by Kenngott (1866) and confirmed by Tschermak (1891), has been verified by direct X-ray determination in a number of cases. It would seem, however, that serious difficulties still exist for those chlorites (leptochlorites) which do not lie on the orthochlorite line (fig. 1). Holzner's list (table VIII, 1938) certainly points to the presence of a constant amount of $4H_2O$ in the unit cell, even when, as in Orcel no. 13, there is a very large amount of 'oxidized' ferric iron. Again, both the crystallization of the chlorite and its internal oxidation must take place below the dehydration temperature; Jung showed that all the water is evolved at about 420° C. Here, if anywhere, the internal oxidation should take place, and Jung accordingly tested the grey residue, after loss of 12·47 % water, by ignition in air. A gain of 3·54 % took place, indicating that the iron had been still in the ferrous state. Apparently, therefore, there is no internal oxidation during the complete dehydration of a chlorite in the laboratory.

Until a satisfactory explanation of the water content is obtained it would seem that caution is necessary in applying the accepted cell-formula to the leptochlorites.

An X-ray Comparison of Chamosite, Daphnite, and Other Chlorites.

(By F. A. Bannister.)

An examination made by Dr. Hallimond of many thin sections of chamosite showed that the isolation of single crystals for X-ray study would be impossible. Like many of the clay minerals, chamosite is extremely fine-grained and hence amenable only to the X-ray powder method. The thin sections showed, however, that the chamosite is of uniform texture, and since only a small speck is necessary for X-ray work it seemed probable that powder photographs of chamosite free from other minerals could readily be obtained. Six specimens of chamosite

(pl. XIX, figs. 1–6) were selected for this work including that from Froding-ham, Lincolnshire (fig. 1), and other material previously studied by Halli-mond and other workers. A specimen of chamosite from the type locality has also been photographed (fig. 3). Figs. 7–14 include daphnite fig. 13 (chemical analysis table I), H. Jung's 'thuringite' (= bavalite) fig. 9, cronstedtite fig. 7, and some other iron-rich chlorites for comparison.

The powder photographs reproduced in pl. XIX and the measured spacings of the powder lines given in table V show that all six photo-graphs of chamosite (figs. 1–6) are very similar to each other, but are distinct from those of thuringite, daphnite, &c. Fig. 5 shows a flecked line of medium intensity, 3·29 Å., due to quartz; and a weak line 2·75 Å. in figs. 4 and 6 may be due to admixed chalybite. The remaining photographs show no lines due to admixture with quartz, chalybite, iron oxide, clay, or mica minerals. A specimen of the Lias clay four inches above the Frodingham ironstone from the Yarborough pit, Frodingham, Lincolnshire (not reproduced in the plate), shows lines due to quartz, chamosite, and a member of the montmorillonite-nontronite family. Probably 5 % or more of quartz and chalybite and 10 % or more of a clay or mica mineral could readily be detected on the chamosite photographs. A specimen of oolitic material collected by Dr. L. J. Spencer from the Northampton ironstone at Burford Lodge pit, Kettering district, Northamptonshire, showed, in addition to coarsely flecked lines of chalybite, continuous lines of chamosite resembling most closely figs. 1 and 4. There is no difficulty, therefore, in recognizing the pattern of chamosite in a powder photograph of a mixture of two or three minerals.

When allowance has been made for the lines due to admixed minerals there are still apparent differences between the chamosite photographs; they are all very similar, but not identical. There may be three possible causes for this:

(1) Different degrees of orientation in different specimens.

(2) Variation in crystal size from one specimen to another.

(3) Variation in chemical composition, cell size, and crystal structure.

The last possibility is not excluded, since complete chemical analyses are not available. Of the other two possibilities the first is most likely to affect the intensities of the basal diffractions relatively to those of other diffracting planes. The variations in intensity, however, are most marked in lines which have not been indexed, but which are certainly not given by diffraction from (001). Variation in crystal size and per-fection of crystallization may readily account for the observed differ-

ences, but, in the absence of complete chemical analyses and of single-crystal measurements, the differences between the chamosite photographs remain unexplained. Nevertheless, the chamosite photographs form a distinctive group showing marked differences from the patterns of daphnite, thuringite, bavalite, corundophilite, and aphrosiderite, all of which give patterns of normal chlorite type. As a matter of interest, other well-known chlorites such as amesite and cronstedtite, figs. 14 and 7, give patterns distinct from each other and also from the normal chlorites. Evidently the chlorite family includes a number of minerals which yield distinctive patterns. Curiously enough the chamosite from the type locality differs from the other chamosite photographs and shows a certain affinity to patterns of the cronstedtite here studied.

It should be mentioned that the data in table V agree well with those listed by McMurchy for iron-bearing chlorites. He found that amesite gives a pattern different from that of the normal chlorite, and my measurements for amesite are also in close agreement with his. We have extended the work of H. Jung, who also found differences between the X-ray patterns of chamosite and thuringite, but he did not show that the latter mineral gives the normal chlorite pattern. Also, we now have X-ray evidence showing that bavalite and thuringite have the same crystal structure. The chlorite of the Welsh iron-ore, fig. 12, is of special interest, for though occurring in a typical chamositic ironstone it has normal chlorite structure. It is chemically similar to bavalite. We are indebted to Dr. G. Nagelschmidt for the loan of an X-ray photograph of Orcel's bavalite which is also identical with the normal chlorite pattern.

No attempt has been made to deduce the cell dimensions or cell contents of chamosite, since it is questionable whether powder photographs alone can be indexed reliably when they show distinct differences from the normal chlorite type. For daphnite, which, as we have shown, belongs to the normal chlorite type, we have, however, carried out single-crystal X-ray measurements, and these are given, together with cell contents calculated directly from the chemical analysis and specific gravity, in table VI. Single-crystal measurements for cronstedtite from Wheal Jane agree well with those given by Gossner (1935) for that mineral from Kisbánya. Recalculation of available chemical analyses (which show much variation) indicates that, if the crystal structure of cronstedtite is closely similar to that suggested by Pauling and McMurchy for the normal chlorites, then considerable replacement of silica by ferric iron atoms in the hexagonal silicon-oxygen sheets must

TABLE V. Spacings in Ångström units of lines of X-ray powder photographs (pl. XIX, figs. 1–14) of chamosite, daphnite, and other chlorites. Estimated intensities: w weak, m medium, s strong, vw very weak, &c.

Fig. 1.	Fig. 2.	Fig. 3.	Fig. 4.	Fig. 5.	Fig. 6.	Fig. 7.	Fig. 8.	Fig. 9.	Fig. 10.	Fig. 11.	Fig. 12.	Fig. 13.	Fig. 14.
6·98 vvs	6·72 vs	6·98 s	6·85 vs	6·72 s	6·76 vs	6·72 vs	7·03 vs	6·76 s	6·80 s	6·72 s	6·94 vs	6·76 s	6·76 vs
4·53 m	4·53 vvw	4·53 w	4·53 vw	4·49 w	4·53 w	4·62 vw	4·68 s	4·62 m	4·62 w	4·53 ms	4·64 m	4·62 w	4·53 m
—	—	—	—	—	—	—	—	—	—	—	—	—	3·76 w
3·51 s	3·42 s	3·51 s	3·48 m	3·47 s	3·42 s	3·49 s	3·51 vs	3·47 s	3·48 s	3·42 s	3·50 s	3·47 m	3·41 s
—	—	—	—	[3·29 m]	—	—	—	—	—	—	—	[3·28 vw]	—
—	—	—	2·74 mw	—	2·75 w	2·70 ms	2·80 mw	2·78 vvw	2·78 w	2·75 vvw	2·80 w	2·79 vw	—
2·66 w	2·62 w	2·65 mw	2·63 w	—	2·63 w	—	—	—	2·65 vvw	—	—	—	—
—	—	—	—	—	—	—	2·59 m	2·59 m	2·59 m	—	2·57 ms	2·55 mw	2·58 m
—	—	—	—	—	—	—	2·54 m	2·54 mw	2·54 m	2·54 m	—	—	—
2·48 m	2·46 s	—	2·49 s	2·46 vs	2·47 ms	—	—	—	—	—	2·46 m	—	2·46 ms
—	—	—	—	—	—	—	2·44 mw	2·44 mw	2·45 mw	—	—	—	—
—	—	—	—	—	—	2·41 ms	2·42 mw	2·42 mw	2·42 mw	—	2·41 m	—	—
—	—	2·39 m	—	—	—	—	—	—	—	—	—	—	—
—	2·35 ms	—	—	—	—	2·33 vw	—	—	—	2·36 w	—	2·38 mw	—
—	—	—	—	—	—	2·27 vw	—	—	—	—	2·27 m	—	2·29 w
—	—	—	—	—	—	—	2·25 w	2·25 mw	2·25 mw	2·25 w	—	2·25 w	—
2·12 w	2·10 ms	—	2·12 ms	2·14 m	2·10 vw	—	—	—	—	—	—	—	2·09 w
—	—	2·00 vw	—	—	—	2·02 m	2·00 m	2·00 m	2·00 m	1·98 m	2·02 s	2·00 m	—
—	1·98 w	—	—	—	—	1·96 vw	—	—	—	—	—	—	1·98 w
—	1·86 vvw	—	—	—	—	—	1·88 vw	1·88 w	1·88 w	1·86 w	1·90 m	1·88 vvw	1·90 m
—	—	—	—	—	—	—	1·81 vw	1·81 vw	1·81 vvw	1·81 vw	1·83 w	—	—
1·74 w	1·75 m	—	1·76 m	1·74 m	1·73 w	—	—	1·71 vvw	1·76 vvw	—	—	—	1·73 vw
—	1·64 vw	—	—	—	—	1·67 mw	—	1·63 w	1·66 vvw	1·64 vw	1·67 vw	—	1·68 vw
1·55 ms	1·54 s	1·55 m	1·55 m	1·54 ms	1·54 ms	1·58 s	1·56 mw	1·55 s	1·55 ms	1·57 m	1·56 s	1·55 ms	1·58 vw
1·52 m	—	1·52 w	1·52 w	—	—	1·55 mw	1·54 m	—	—	1·54 m	1·53 mw	—	1·52 ms
—	1·51 m	—	—	1·50 w	1·50 w	—	1·50 w	1·51 mw	1·51 w	1·50 vw	—	1·51 w	1·50 w
—	1·46 m	—	1·47 w	1·46 vw	—	1·44 mw	—	—	—	—	—	—	1·45 w
1·42 mw	1·41 w	1·42 w	1·42 w	1·41 vw	1·42 vw	—	1·41 vvw	1·42 w	1·42 vvw	1·41 vw	1·43 vw	1·41 vvw	—
—	—	—	—	—	—	—	1·39 w	1·39 mw	1·39 w	1·38 ms	1·39 m	1·39 vw	1·39 mw
—	—	—	—	—	—	1·37 vw	—	1·34 w	1·33 w	—	1·34 w	—	1·35 vw
1·32 w	1·32 w	—	—	—	1·32 w	1·32 w	1·32 vw	1·31 w	1·30 vw	1·32 w	1·31 vw	—	1·30 vw

take place. Such a replacement needs checking by a proper crystal structure study of cronstedtite, and until that is available I hesitate to publish any cell formula for that mineral.

TABLE VI. Cell dimensions and contents of daphnite, Tolgus mine, Cornwall.
(See table I.)

a.	b.	c'.	Sp. gr.	n.
5·40	9·36	28·2 Å.	3·08	71·3

Si.	Al.	Fe'''.	Fe''.	Mn.	Mg.	Ca.	H.
10·82	10·58	0·71	13·48	0·18	3·70	0·05	31·22

c' denotes the c spacing and not the cell dimension c.
n denotes calculated oxygen content.

The remaining atoms are then deduced assuming 72 oxygen atoms per unit cell. The cell contents if grouped in accordance with the usual structure formula are:

Si.	Al.	Al.	Fe'''.	$Fe.''$	Fe''.	Mg.	Ca.	Mn.	H_2O.
10·82	5·18	5·40	0·71	5·89	7·59	3·70	0·05	0·18	15·61

16	12	11·52

Summary.

New analyses are given of daphnite from Tolgus mine, Cornwall, and chamosite from Frodingham, Lincolnshire. Earlier analyses are discussed and a graphical representation is given of selected chlorite analyses. X-ray examination shows that daphnite has normal chlorite structure like that of clinochlore, but chamosite has a special structure of chlorite type. X-ray data for other chlorites are discussed. Under incipient metamorphism chamosite alters to bavalite, which has normal chlorite structure.

References.

AGAR (W. M.) and EMENDORFER (E. H.), 1937. Manganiferous prochlorite from Hawleyville, Conn. Amer. Journ. Sci., ser. 5, vol. 34, pp. 77–80. [M.A. 7–258.]

CHERNYKH (V. V.) in KURNAKOV (N. S.) and CHERNYKH (V. V.), 1926. Physico-chemische Untersuchung der Serpentine und Chlorite. Mém. Soc. Russe Min., ser. 2, vol. 55, pp. 183–194.

DEANS (T.), 1934 a. The spherulitic ironstones of west Yorkshire. Geol. Mag. London, vol. 71, pp. 49–65.

—— 1934 b. Some oolitic ironstones from the Coal Measures of Yorkshire. Trans. Leeds Geol. Assoc., vol. 5, pp. 161–187.

DIXON (B. E.), 1930. Summary of Progress for 1929, Mem. Geol. Surv. Great Britain, pt. I, p. 98.

EYLES (V. A.), 1930. Economic geology of the Ayrshire coalfields. Area III. Mem. Geol. Surv. Scotland, pp. 67–68.

GOSSNER (B.), 1935. Über Cronstedtit von Kisbánya. Zentr. Min., Abt. A, pp. 195–201. [M.A. 6–333.]

HALLIMOND (A. F.), 1925. Iron ores: bedded ores of England and Wales. Spec. Rep. Min. Res., Mem. Geol. Surv. Great Britain, vol. 29. With appendix by

F. R. Ennos and R. Sutcliffe: On the estimation of the chlorite in sedimentary rocks.

HALLIMOND (A. F.), 1926. On the chemical classification of the mica group. II. The basic micas. Min. Mag., vol. 21, pp. 25–33.

HOLZNER (J.), 1938. Eisenchlorite aus dem Lahngebiet. . . . Neues Jahrb. Min., Abt. A, Beil.-Bd. 73, pp. 389–418. [M.A. 7–408.]

JUNG (H.) and KÖHLER (E.), 1930. Untersuchungen über den Thuringit von Schmiedefeld in Thüringen. Chem. Erde, vol. 5, pp. 182–200. [M.A. 4–334.]

JUNG (H.), 1931. Untersuchungen über den Chamosit von Schmiedefeld i. Thür. Chem. Erde, vol. 6, pp. 275–306. [M.A. 5–40.]

KENNGOTT (A.), 1866. Mitt. über Pyrophyllit . . . Vierteljahrsschrift der Naturforsch. Gesell. Zürich, vol. 11, pp. 240–259.

KUNITZ (W.), 1924. Die Beziehungen . . . der Glimmergruppe. Neues Jahrb. Min., Abt. A, Beil.-Bd. 50, pp. 365–413. [M.A. 2–424.]

McMURCHY (R. C.), 1934. The crystal structure of the chlorite minerals. Zeits. Krist., vol. 88, pp. 420–432. [M.A. 6–45.]

ORCEL (J.), 1927. Recherches sur la composition chimique des chlorites. Bull. Soc. Franç. Min., vol. 50, pp. 75–454.

PULFREY (W.), 1933. The iron-ore oolites and pisolites of North Wales. Quart. Journ. Geol. Soc. London, vol. 89, pp. 401–430.

RADLEY (E. G.), 1920. The Mesozoic rocks of Applecross. . . . Mem. Geol. Surv. Scotland, p. 35.

SAHLBOM (N.) in Nockolds (S. R.) and Richey (J. E.), 1939. Replacement veins in the Mourne Mts. granites, N. Ireland. Amer. Journ. Sci., vol. 237, pp. 27–47. [M.A. 7–305.]

SHANNON (E. V.), 1926. The minerals of Idaho. Bull. U.S. Nat. Mus., no. 131, p. 378. [M.A. 3–130.]

SIMPSON (E. S.), 1936. Contributions to the mineralogy of Western Australia. Series IX. Journ. Roy. Soc. W. Australia, vol. 22, pp. 1–18. [M.A. 6–363.]

—— 1937. Ditto. Series X. Ibid., vol. 23, pp. 17–35. [M.A. 7–114.]

TSCHERMAK (G.), 1891. Die Chloritgruppe, II. Theil. Sitzungsber. Akad. Wiss. Wien, Math.-nat. Kl., vol. 100, Abt. 1, pp. 29–107.

WILSON (G. V.), 1922. The Ayrshire bauxitic clay. Mem. Geol. Surv. Scotland. [M.A. 2–556.]

—— 1930. Geology of North Ayrshire. Mem. Geol. Surv. Scotland, pp. 209–214.

WINCHELL (A. N.), 1936. A third study of chlorite. Amer. Min., vol. 21, pp. 642–651. [M.A. 6–532.]

EXPLANATION OF PLATES XVIII AND XIX.

PLATE XVIII, FIG. 1. Daphnite: fan-like aggregates filling the space between quartz crystals. From a vein at 1450 feet, Tolgus mine, Cornwall. × 28.

FIG. 2. Chamosite: granules of minutely crystalline chlorite in coarsely crystalline calcite; near the top there has been secondary replacement of the calcite by a group of elongated rhombohedra of chalybite with iron oxide. From the interior of a *Cardinia* shell (fig. 4) from the ironstone bed, Frodingham, Lincolnshire. × 28.

FIG. 3. Shell of *Gryphaea*: upper and lower valves, with a mould of the interior formed of chamosite-chalybite mud. From the ironstone bed, Frodingham, Lincolnshire. Natural size.

FIG. 4. Shell of *Cardinia*: cut in two, showing (left) the exterior with adherent oolitic ironstone; (right) polished section of the interior, filled partly with coarsely crystalline calcite, partly with granular chamosite (cf. fig. 2), but no ooliths. From the ironstone bed, Frodingham, Lincolnshire. Natural size.

PLATE XIX. A series of X-ray powder photographs of chamosites, daphnite, and other chlorites reproduced so that 10 cm. is equivalent to 15 cm. on the original film. All the photographs were taken with unfiltered cobalt-radiation of wavelength 1·787 Å. in a cylindrical camera of 6·04 cm. diameter. Small fragments were selected from material studied and were not powdered unless specifically stated below:

FIG. 1. Green filling of shell of *Cardinia* from the Frodingham ironstone, Lincolnshire. No. 8, table IV; chemical analysis, table II.

FIG. 2. Chloritic clay, Ayrshire. No. 12, table III; Geol. Survey, Lab. no. 874.

FIG. 3. Chamosite-chalybite mudstone, Chamoson, Valais, Switzerland. B.M. 35331.

FIG. 4. Pecten seam, Cleveland, Yorkshire. No. 5, table III; Geol. Survey, M.I. 14045.

FIG. 5. Chamositic ironstone, Coal Measures, Yorkshire. No. 12, table IV.

FIG. 6. Oolith from Raasay ironstone. No. 11, table IV; Geol. Survey, Lab. no. 458 A.

FIG. 7. Powdered crystals of cronstedtite, Wheal Jane, Cornwall. Geol. Survey, Ludlam collection, no. 2578.

FIG. 8. Powdered corundophilite, Chester, Massachusetts, U.S.A. Geol. Survey, Ludlam collection, no. 7944.

FIG. 9. Bavalite from the Lower Silurian, Schmiedefeld, Thuringia, Germany. Geol. Survey, M.I. 25323, presented by H. Jung, 1934.

FIG. 10. Thuringite, Saalfeld, Harz, Germany. B.M. 32701.

FIG. 11. Powdered crystals of aphrosiderite, Salida, Colorado, U.S.A. B.M. 1924,623.

FIG. 12. Chlorite rock (bavalite), Llandegai, North Wales. No. 21, table IV; Geol. Survey, M.I. 23877.

FIG. 13. Powdered daphnite, Tolgus mine, Cornwall. Chemical analysis, table I; Geol. Survey, M.I. 16006.

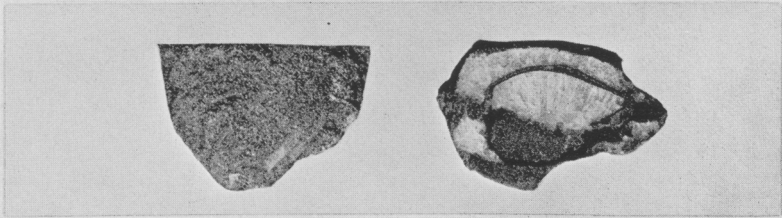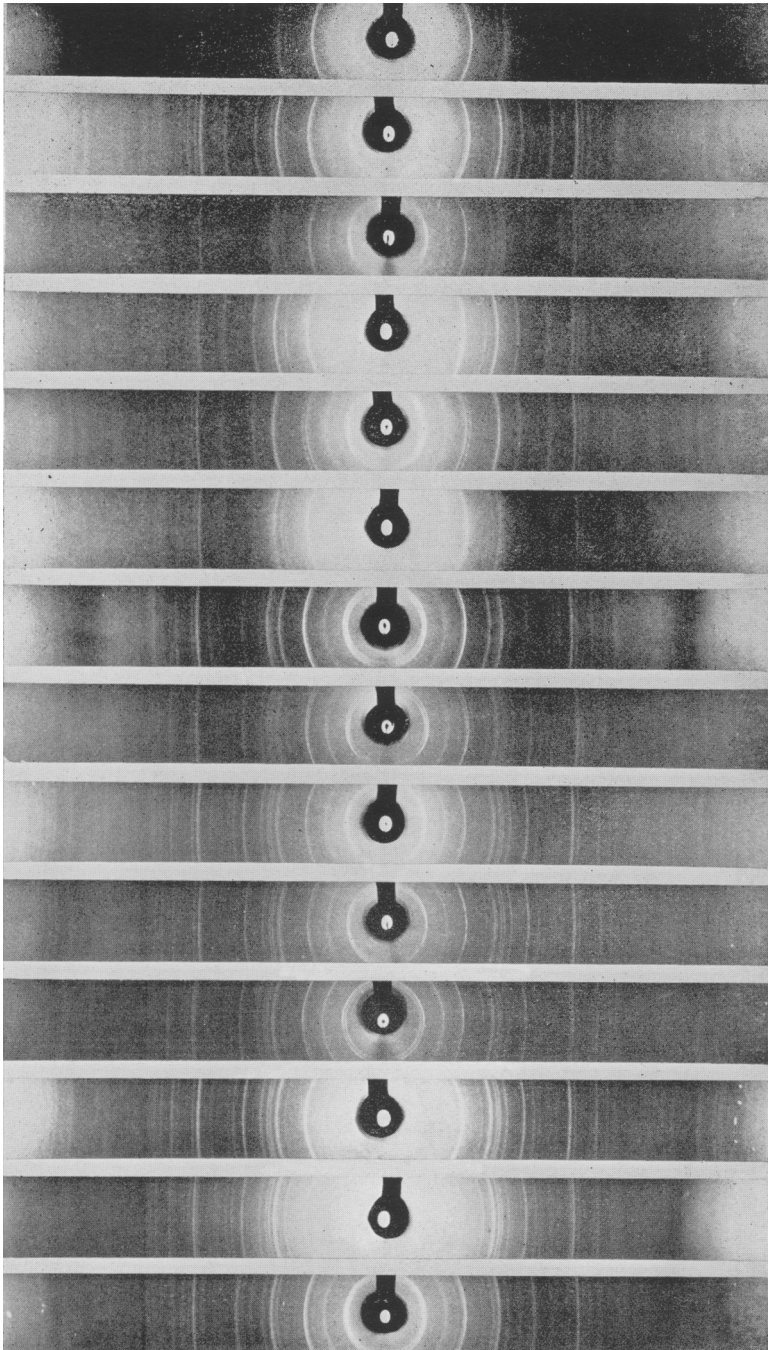FIG. 14. Powdered amesite from Chester, Massachusetts, U.S.A.

1 × 28   2 × 28

3 × 1

4 × 1

A. F. HALLIMOND : DAPHNITE AND CHAMOSITE.

Plate XIX.
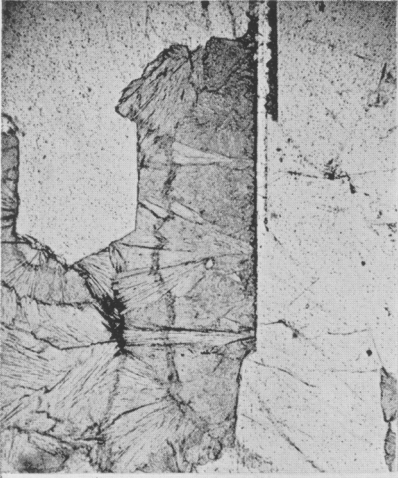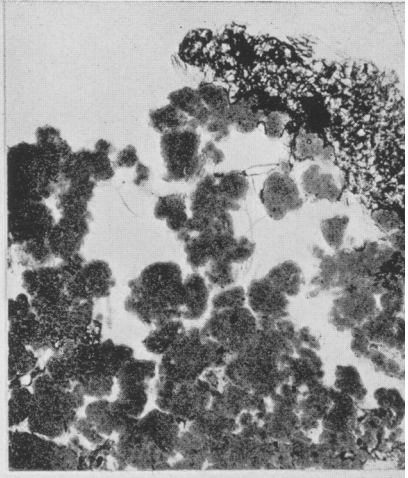
F. A. BANNISTER : X-RAY PHOTOGRAPHS OF CHAMOSITE, DAPHNITE, ETC.