Cummingtonite and gedrite from Sutherland.

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I. *Introduction.*

During the investigation of a migmatite complex near Strathy, north Sutherland, cummingtonite and gedrite were found to be common constituents of certain schists and granulites. Calcium-poor amphiboles have not hitherto been recorded from rocks of the Moine Series, and it is the purpose of this paper to give the results of the optical and chemical study of three examples of this group. The methods of separation and purification employed are described in some detail as it is considered that many of the previous analyses of these minerals are vitiated by faulty procedure. To avoid errors in separating two amphibole species, the investigated samples were taken from rocks containing a single amphibole phase. The paper concludes with a discussion of the correlation of optical properties and chemical composition of cummingtonites and gedrites.

II. *Methods of separation and purification.*

The fresh rock wrapped in layers of filter-paper was hammered down to fragments the size of a pea, which were transferred to an agate mortar and ground down until the powder passed through 60 and 120 mesh sieves. Centrifugation using bromoform floated off the quartz, the felspar, and some biotite. Iron-ore, garnet, and rutile were removed as a heavy crop by centrifugation with methylene iodide. The fraction obtained from twenty-four centrifugations still contained some biotite, which was removed mainly by using a carefully adjusted mixture of methylene iodide and benzene which just floated biotite. A 99·5 % pure sample resulted. Repeated panning on large sheets of filter-paper removed almost all the remaining biotite. There resulted an even-grained powder which was hand-picked on a hard white card using an × 8 pocket-lens. The dark cummingtonite sample contained some quartz-magnetite composite grains which defied gravity separation and were too numerous for hand-picking. The sample was ground down finer in a diamond mortar and the complex grains disintegrated. The quartz and magnetite were removed by bromoform and methylene iodide centrifugation. Samples of 4·5, 3·8, and 2·5 grams were sent for analysis.

The advantage of the rather lengthy method is the avoidance of contamination of the sample during pulverization and the prevention of leaching of alkalis by water during the purification. As no heat was used, the water content was unaffected by the preparation. The importance of these precautions is not yet generally recognized and many of the analytical data recorded in the literature are invalidated by faulty procedure. The effect of water on a mineral can be demonstrated by grinding a little biotite to a fine powder and adding water and a drop of colourless phenolphthalein solution. A pink coloration forms, indicating the solution of alkalis by water at room-temperature due to the action of the hydrogen ion. The leaching power of the hydrogen ion increases with the temperature and acidity. The use of inert liquids for separation purposes though accepted in principle has not always been strictly kept. All liquids with a water base, e.g. Clerici solution, should be avoided. Some workers in attempting to purify their mineral have digested the sample with acid, a drastic treatment which is no doubt responsible for many of the low alkali values recorded in the literature.

III. *Determination of optical data and specific gravities.*

The refractive indices were determined by the immersion method using an Abbe refractometer and a sodium lamp. The grains were splintered in oil under the microscope, using a fine needle. With careful manipulation it was possible to select and set up favourable grains with (010), (001), and (100) surfaces. On these the indices α, β, and γ were determined in duplicate, each on two surfaces. The mean results recorded in table I are believed to be accurate to $\pm 0{\cdot}001$.

The optic axial angles were measured on the universal stage following Reinhard[1] in the methods of adjustment to ensure correct centring and height. The observed angles were corrected graphically for the differences in refractive indices between the mineral and the glass segments of the universal stage. The results tabulated are the averages of six values in each case and represent an accuracy of $\pm 2^\circ$. Values calculated from the refractive indices by a graphical method[2] were in close agreement. The extinction-angle for cummingtonite was measured on the universal stage using the method of Burri.[3]

The specific gravities of grains of each analysed mineral were determined by flotation in mixtures of methylene iodide and carbon tetrachloride.[4]

IV. *Results and their interpretation on the basis of atomic constitution.*

The results of the chemical analyses, specific gravity, and the optical data obtained from the minerals sent for analysis are given in table I. It is, of course, impossible to calculate the number of oxygen atoms including hydroxyl groups directly from the chemical analyses and specific gravities without X-ray measurements of the unit-cell dimensions of the analysed specimens. However, assuming Wayland's[5] X-ray data for cummingtonite, the number of oxygen and hydroxyl groups is approximately 48 per unit cell. Table II gives the atomic constitution of the analysed specimens based on 24(O+OH), that is half the ideal oxygen hydroxyl content of the unit cell. The results are in good agreement with Warren's[6] formula for amphiboles with low (Ca,Na) content,

$$(\mathrm{Mg,Fe'',Ti,Al,Mn,Ca,Na})_7(\mathrm{Si,Al})_8\mathrm{O}_{22}(\mathrm{OH})_2.$$

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[1] M. Reinhard, Universal Drehtischmethoden. Basel, 1931. [M.A. 4–435.]

[2] J. H. Lane and H. T. U. Smith, Amer. Min., 1938, vol. 23, p. 457. [M.A. 7–249.]

[3] C. Burri, Schweiz. Min. Petr. Mitt., 1931, vol. 11, p. 285. [M.A. 5–71.]

[4] F. A. Bannister and M. H. Hey, Min. Mag., 1931, vol. 22, p. 573.

[5] R. G. Wayland, Amer. Min., 1936, vol. 21, p. 610. [M.A. 7–26.]

[6] B. E. Warren, Zeits. Krist., 1930, vol. 72, p. 516. [M.A. 4–278.]

Recorded cummingtonites and gedrites show $(\mathrm{Ca,Na})_n$ where n is much less than 2, and are low to moderately aluminous or aluminoferric. The Al-atoms are partly in 4-fold co-ordination (replacing Si-atoms) and partly in 6-fold co-ordination (replacing Mg, Fe, Mn, &c.). Analyses I, II, and III computed to the basis of (O,OH) = 24 show the (Ca,Na) total to be much below 2 in all cases. Analysis I is in good agreement with previously recorded cummingtonite. Analysis III, the most aluminous and correspondingly least magnesic variety, is more appropriately compared with gedrite. Analysis II occupies an intermediate position between I and III.

TABLE I. Analyses, optical data, and specific gravities of cummingtonite and gedrite from Strathy, Sutherland.

	I.	II.	III.
SiO_2	51·53	49·60	44·70
TiO_2	0·31	0·26	0·57
Al_2O_3	5·02	8·65	14·72
Fe_2O_3	0·82	0·48	1·62
FeO	16·91	18·54	18·96
MnO	0·22	1·08	0·21
MgO	20·84	16·78	14·89
CaO	1·34	0·97	0·69
Na_2O	0·65	0·79	1·34
K_2O	nil	nil	nil
P_2O_5	—	0·34	—
H_2O+ 105° C.	2·15	2·52	2·27
H_2O- 105° C.	0·64	0·29	0·29
	100·43	100·30	100·26
Sp. gr.	3·10	3·18	3·24
2V	75°	75°	85°
Sign	positive	positive	positive
$\gamma : c$	20°	19°	0°
α	1·643	1·645	1·652
β	1·650	1·652	1·656
γ	1·663	1·664	1·666
$\gamma - \alpha$	0·020	0·019	0·014
Pleochroism:			
α	almost colourless	pale yellow	yellow
β	very pale brown	pale brown	brownish
γ	very pale violet	pale violet	smoke-grey

I. Pale cummingtonite from oligoclase-biotite-rutile-schist. NW. end of Geodh Dubh, NNW. Strathy Point. Analyst, Geochemical Laboratories.

II. Dark cummingtonite from oligoclase-quartz-magnetite-granulite. 150 yards south of Toll Egain, NNE. Strathy Point. Deducting apatite, CaO 0·52 %. Analyst, Geochemical Laboratories.

III. Gedrite from oligoclase-quartz-biotite-garnet-schist. East side of Uamh nan Soithichean, NW. of Armadale. Analyst, Geochemical Laboratories.

TABLE II. Computation of the chemical analyses to the basis of (O,OH) = 24.

	I, Pale Cummingtonite.			II, Dark Cummingtonite.			III, Gedrite.		
Si	7·36	8·00		7·16	8·00		6·47	8·00	
Al	0·64			0·84			1·53		
Al	0·21	6·82	7·21	0·63	6·64	6·94	0·98	6·75	7·24
Fe‴	0·09			0·05			0·18		
Fe″	2·02			2·24			2·29		
Mn	0·03			0·13			0·03		
Mg	4·44			3·56			3·21		
Ti	0·03			0·03			0·06		
Ca	0·21	0·39		0·08	0·30		0·11	0·49	
Na	0·18			0·22			0·38		
O	21·95	24·00		21·57	24·00		21·83	24·00	
OH	2·05			2·43			2·17		

Although the basis of computation ensures that the positive (cation) charges will exactly balance the negative (anion) charges, it is noteworthy that the proportion of (OH)-groups for the computed constitutions (based on the analyst's findings for water above 105° C.) are very close to the $(OH)_2$ required by the theoretical relationship $O_{22}(OH)_2$. Unfortunately, the determination of the heating curves, for use in checking the validity of the assumption that water above 105° C. represents the (OH) content of the mineral, still remains to be done.

V. *Correlation of optical properties with chemical composition.*

The two cummingtonites have very similar optical properties. The optical properties of the gedrite are closely related to those of the cummingtonites, but there are certain important differences best seen by comparing the α values, and the birefringences. In the gedrite β is nearer to α, $\gamma - \alpha$ is smaller, and the optic axial angle is considerably larger. In the orthorhombic gedrite the c-axis corresponds to γ; in the monoclinic cummingtonites $\gamma : c = 20°$ maximum.

Search of the literature yielded few satisfactory sets of chemical and optical data which had been made on the same sample of material. Some workers performed detailed analyses on the minerals from one locality and quoted optical data obtained from specimens obtained elsewhere; others give detailed optical data accompanied by only partial analyses. From the mass of data examined four analyses of cummingtonites and four of gedrites have been chosen for comparison with the Strathy samples (tables III and IV).

Correlating optical properties with chemical composition, one observes that the mineral with the highest iron content has the highest refractive indices, and the minerals with high alumina content have the lowest birefringences. The effect of the R_2O_3 radicle in decreasing the birefringences has been demonstrated in the pyroxene series.[1] An increase in alumina at the expense of iron in members of the epidote group reduces both the refractive indices and the birefringences. In members of both the calcium-poor amphibole series and in the epidote series

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[1] A. N. Winchell, Elements of optical mineralogy. New York, 1933, pt. 2, p. 230.

TABLE III. Analyses and optical data of cummingtonites.

	A.	B.	C.	D.	E.
SiO_2	51·53	54·28	50·99	53·12	50·70
TiO_2	0·31	0·02	0·02	0·21	0·31
Al_2O_3	5·02	1·26	3·78	2·78	1·72
Fe_2O_3	0·82	0·80	0·85	0·25	3·11
FeO	16·91	21·79	21·70	22·46	26·63
MnO	0·22	0·26	0·18	0·27	0·19
MgO	20·84	18·64	18·61	15·46	14·36
CaO	1·34	0·15	—	2·26	0·87
Na_2O	0·65	0·14	0·24	—	0·60
K_2O	nil	trace	0·31	—	0·15
H_2O+	2·15	2·16	2·77	3·33	1·46
H_2O-	0·64	—	—	—	—
F	—	0·57	—	—	—
	100·43	100·07	99·45	100·14	100·10
Sp. gr.	3·10	3·241	—	—	3·307
2V	75°	68°	65°	—	—
Sign	positive	positive	positive	—	—
$\gamma:c$	20°	20°	20°	19°	—
α	1·643	1·639	1·640	1·643	α'1·661
β	1·650	1·647	1·647	—	—
γ	1·663	1·664	1·665	1·670	γ'1·681
$\gamma-\alpha$	0·020	0·025	0·025	0·027	0·020

A. Strathy, Sutherland. R. S. Collins, 1942. Analyst, Geochemical Laboratories.

B. Saude, Ryfylke, Norway. N. Sundius, Min. Petr. Mitt. (Tschermak), 1933, vol. 43, p. 425. [M.A. 3–153, 6–64.] Analyst, A. Bygdén.

C. Odalfältet, Persberg, Sweden. H. E. Johansson, Geol. För. Förh. Stockholm, 1914, vol. 36, p. 454. Analyst, N. Sahlbom.

D. *Kenidjack, Cornwall. C. E. Tilley and J. S. Flett*, Summ. Progr. Geol. Surv. Great Britain, 1930, for 1929, pt. 2, p. 31. [M.A. 4–402.]

E. Isopää, Finland. P. Eskola and T. Kervinen, Compt. Rend. Soc. Géol. Finlande, 1936, no. 9, p. 482. [M.A. 7–26.] Analyst, T. Kervinen.

increase in alumina content makes β approach more closely to a midway position between α and γ, $\beta-\alpha$ and $\gamma-\beta$ decreasing and approaching each other. Winchell (loc. cit., p. 239) considers that an increase in soda content leads to a more asbestiform mineral. As the Strathy results indicate quite the opposite tendency, the Na-rich member being the most robust, Winchell's view cannot be applied here. It may, however, be mentioned that the more asbestiform a mineral becomes, the more difficult it is to prepare a pure sample for analysis.

Winchell (loc. cit., pp. 242, 244), Sundius,[1] and Alling[2] plot the optical properties against percentages of 'minals', which Alling claims give a clearer picture than do the complex mineral compounds. In nature no pure 'minals' exist. They are hypothetical compounds and the suitability of plotting optical properties against them is doubtful. The 'minal' method shows a definite trend, increase of iron content causing increase in refractive indices, but beyond this its utility is doubtful.

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[1] N. Sundius, Über die Mischungslücken zwischen Anthophyllit-Gedrit-Cummingtonit-Grünerit und Tremolit-Aktinolith. Min. Petr. Mitt. (Tschermak) 1933, vol. 43, p. 427. [M.A. 6–64.]

[2] H. L. Alling, Interpretative petrology. New York, 1936, p. 111.

TABLE IV. Analyses and optical data of gedrites.

	F.	G.	H.	I.	J.
SiO_2	44·70	44·09	46·50	44·22	43·70
TiO_2	0·57	0·31	0·89	—	0·55
Al_2O_3	14·72	17·22	15·48	23·79	10·88
Fe_2O_3	1·62	1·87	0·89	0·20	3·52
FeO	18·96	15·02	16·01	9·21	26·53
MnO	0·21	0·14	nil	0·16	0·24
MgO	14·89	17·12	17·62	20·69	11·48
CaO	0·69	0·51	0·81	0·62	0·54
Na_2O	1·34	1·24	0·77	—	1·24
K_2O	nil	trace	0·12	—	0·15
H_2O+	2·27	2·03	1·19	1·42	1·21
H_2O-	0·29	nil	—	—	—
	100·26	99·55	100·28	100·31	100·04
Sp. gr.	3·24	3·259	—	3·178	3·371
2V	85°	—	78°	large	—
Sign	positive	positive	positive	negative	—
α	1·652	1·651	1·642	1·642	α'1·674
β	1·656	—	1·648	1·655	—
γ	1·666	1·672	1·658	1·661	1·697
$\gamma-\alpha$	0·014	0·021	0·016	0·019	0·023

F. Strathy, Sutherland. R. S. Collins, 1942. Analyst, Geochemical Laboratories.

G. Terbeostrov, Karelia. C. E. Tilley, Geol. Mag., 1939, vol. 76, p. 327. [M.A. 7–445.] Analyst, H. C. G. Vincent.

H. Terbeostrov, Karelia. N. A. Ignatiev, Trav. Inst. Pétrogr. Acad. Sci. U.S.S.R., 1934, no. 6, p. 65. [M.A. 6–419.]

I. Mason's Mountain, North Carolina. E. P. Henderson, Amer. Min., 1931, vol. 16, p. 566. [M.A. 5–76.] Analyst, E. P. Henderson.

J. Isopää, Finland. P. Eskola and T. Kervinen, Compt. Rend. Soc. Géol. Finlande, 1936, no. 9, p. 482. [M.A. 7–26.] Analyst, T. Kervinen.

Sundius states that anthophyllite (including gedrite) and cummingtonite are not dimorphous. He demonstrates with the best analyses at his disposal that a 6–9 % molecular increase in Al_2O_3 and Fe_2O_3 transforms the monoclinic into the orthorhombic amphibole, which is in accord with the results from Strathy. Winchell (loc. cit., p. 240) believes the calcium-poor amphiboles to be isodimorphous; he ignores alumina, over-emphasizing the iron oxides and magnesia, and treats theoretical 'minals' as actual mineral modes. Kunitz,[1] Winchell, and Alling are wrong in their belief that cummingtonite, anthophyllite, and gedrite form one homogeneous series.

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[1] W. Kunitz, Neues Jahrb. Min., Abt. A, 1930, vol. 60, p. 190. [M.A. 4–200.]