

CO-EXISTING CUMMINGTONITE AND HORNBLLENDE
IN AN AMPHIBOLITE FROM DUCHESS,
QUEENSLAND, AUSTRALIA

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ABSTRACT

Chemical composition and optical properties are given for co-existing cummingtonite and hornblende from an amphibolite occurring near Duchess in northwestern Queensland. The amphiboles are intergrown in regular and irregular fashion, a consistent feature being the occurrence in one amphibole of very thin (001) lamellae of the other. As far as available analyses show, hornblendes are richer in Fe³⁺, Ti, Na, and K than their associated cummingtonites, which probably may be correlated with the much larger amounts of tetrahedral Al in the hornblendes.

INTRODUCTION

The cummingtonite-bearing amphibolite described herein occurs 8,000 feet north-northeast of Duchess railway station, the township of Duchess being about 65 miles southwest of Cloncurry in northwestern Queensland, Australia. The specimen examined was one of a suite of Precambrian metamorphic rocks from the Duchess area submitted by Consolidated Zinc Pty. Ltd. to the Mineragraphic Investigations Section of the Commonwealth Scientific and Industrial Research Organization, Melbourne.

According to Edwards and Baker (1954, p. 17) the locality from which this specimen was taken consists of irregularly distributed outcrops of amphibolite and several small outcrops of slightly altered gabbro and norite. Most of the amphibolites examined by the writer are common hornblendic varieties, the one described in this paper being the only cummingtonite-bearing variety from this area so far investigated.

Preliminary examination indicated that the two amphiboles could be concentrated for analysis, and so a detailed study was undertaken in order to add further information on the association of cummingtonite and hornblende in metamorphosed basic igneous rocks. So far, only three quantitative studies of this association have been made (Eskola 1950, Seitsaari 1952, Watters 1959).

DESCRIPTION OF THE AMPHIBOLITE

The amphibolite (Fig. 1) consists of fresh, sub-prismatic to xenoblastic hornblende and cummingtonite, and altered xenoblastic andesine, with

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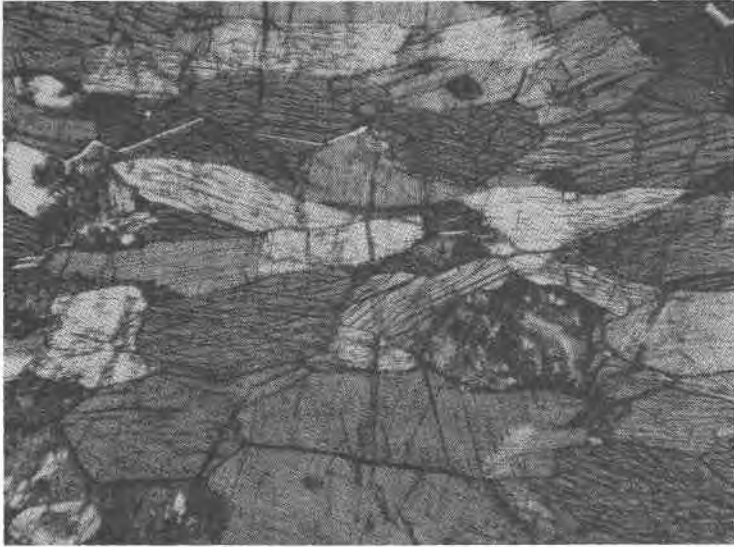


FIG. 1. Cummingtonite-bearing amphibolite from Duchess, Queensland, showing hornblende (shades of gray), cummingtonite (colorless), and heavily altered plagioclase. The cummingtonite occurs mainly as independent grains, but also as composite grains with hornblende. Lamellae parallel to (001) of cummingtonite in an independent hornblende grain (bottom) and a hornblende-cummingtonite composite grain (left-center) appear as "striations" at this magnification. Plane-polarized light ($\times 35$).

accessory apatite, quartz, rutile, altered ilmenite, and zircon. The rock shows a weak schistosity, owing to partial parallelism of the amphibole grains. The amphiboles and plagioclase are evenly distributed through the rock. The average size of the amphibole grains is 1.2×0.3 mm, and the plagioclase grains average 0.6 mm across. A little plagioclase occurs as small, generally rounded inclusions in the hornblende.

Because the plagioclase is extensively altered, the rock was not analyzed chemically. The mode (average of three) is:

	<i>Vol. per cent</i>
Hornblende	64.2
Cummingtonite	7.2
Altered plagioclase	28.6

Plagioclase. Some plagioclase grains are almost completely replaced by a very fine-grained sericite-clay mixture (Fig. 2). In fact, most grains show extensive alteration of this kind, though in streaks and patches, so that oriented fragments of fresh plagioclase can be removed from thin sections for measurement of their refractive indices. The plagioclase has $\beta_{(Na)} = 1.552 \pm 0.002$, equivalent to a composition of An_{39} mol. per cent

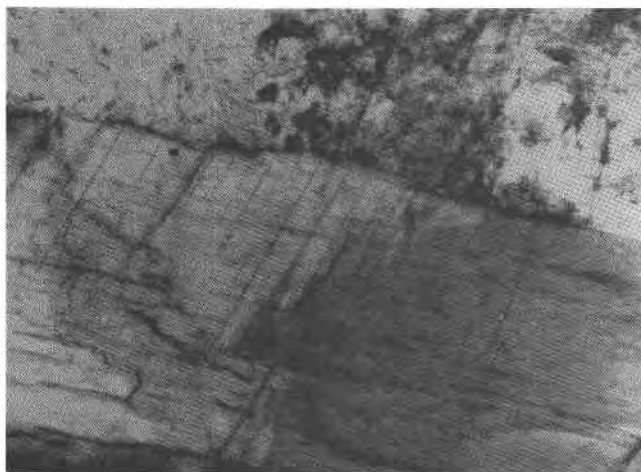


FIG. 2. Section parallel to (010) of a composite grain of cummingtonite and hornblende, showing lamellae parallel to (001) of cummingtonite in hornblende and *vice versa*. This grain shows an irregular, interfingered parallel to (001), boundary between the two amphiboles, in contrast to the planar boundary shown in the center of Fig. 1. Heavily altered plagioclase is visible at the top. Plane-polarized light ($\times 105$).

(Smith 1960). Unreplaced plagioclase grains show albite and pericline twinning.

Accessory minerals. A few colorless, irregular grains of apatite, up to 1.65 mm across, are present, some with rounded inclusions of hornblende. Rare, small, generally rounded grains of quartz, 0.03 to 0.08 mm across, are enclosed in the hornblende. Rutile occurs commonly in prismatic crystals with terminal faces, less commonly in rounded grains. The average grain-size of the rutile is 0.06 mm, but the largest crystals are 0.12 mm long. It is yellowish brown to orange-brown in thin section and shows strong red-brown internal reflections in polished section. Rare, irregular to ragged grains of ilmenite, many of which are partly altered to leucoxene, are present. They are elongated, and average 0.2×0.03 mm. A few granules of zircon averaging 0.03 mm across are scattered through the rock, producing pleochroic haloes where enclosed in hornblende.

TEXTURES OF THE AMPHIBOLES

Composite grains of hornblende and cummingtonite, in which the two amphiboles are coaxial, are common. The boundary between the amphiboles may be planar and parallel to (001), planar and parallel partly to (001) and partly to cleavage planes, largely planar with small irregularities, or irregular. Irregular intergrowths are common, patches of one

amphibole occurring enclosed by or adjacent to the other. Rarely, the enclosed amphibole forms a streak, lying in a cleavage plane. The junctions in these irregular intergrowths are generally sharp, and there does not appear to be any transitional amphibole between the cummingtonite and hornblende.

Under low magnification, many hornblende grains appear devoid of cummingtonite, and some cummingtonite grains appear devoid of hornblende (Fig. 1). However, almost all longitudinal sections of both amphiboles (independent and composite grains) show apparent striations parallel to (001) under low and medium magnifications (Fig. 1). High magnification reveals these to be very thin lamellae of cummingtonite (in hornblende) and hornblende (in cummingtonite), although the thinnest "striations" are difficult to characterize and may be simple partings.

The amphibole lamellae are identified by color, refractive index relative to the host amphibole, and birefringence (Table 1). The identifications can be verified by observing lamellae leading into larger patches of amphibole with the same color and birefringence (Fig. 2). Many lamellae are straight and of uniform thickness. However, small irregularities are

TABLE 1. OPTICAL PROPERTIES AND MAGNETIC SUSCEPTIBILITY OF CUMMINGTONITE AND HORNBLENDE FROM DUCHESS, QUEENSLAND

	Cummingtonite	Hornblende
α	1.630	1.642
β (Na; ± 0.003)	1.640	1.654
γ	1.655	1.663
$\gamma - \alpha$ (refractive indices)	0.025	0.021
$\gamma - \alpha$ (Berek compensator)	0.025	0.022
2V (meas. $\pm 2^\circ$)	$77\frac{1}{2}^\circ$	$83\frac{1}{2}^\circ$
2V (calc.)	79°	81°
Optic sign	Positive	Negative
Dispersion	Inclined, $r < v$	Inclined, $r > v$
$Z \wedge c$	20°	20°
Color	Gray-green	Greenish black
	X = colorless Y = very pale green Z = very pale green (X < Y = Z)	X = light greenish fawn Y = olive green Z = blue-green (X < Z < Y)
Specific magnetic susceptibility	35.6×10^{-6} e.m.u./gm	24.3×10^{-6} e.m.u./gm

commonly visible under high magnification. The lamellae are coaxial with the host amphibole, and vary in width from less than 0.001 mm to 0.003 mm, most being 0.0015 mm wide. In many composite grains the lamellae are thickest at or near the main cummingtonite-hornblende junctions.

OPTICAL AND MAGNETIC PROPERTIES OF THE AMPHIBOLES

The optical properties and magnetic susceptibilities of the cummingtonite and hornblende are listed in Table 1. The refractive indices were measured by the immersion method in sodium light on clean edges of correctly oriented grains removed from thin sections. Despite a higher iron content, the refractive indices of the cummingtonite are appreciably lower than those of the hornblende, owing, perhaps, to the much lower aluminium content of the cummingtonite. However, the birefringence of the cummingtonite is greater than that of the hornblende. Such features are also shown by the co-existing cummingtonite and hornblende described by Seitsaari (1952, p. 9) and Watters (1959, pp. 249, 250). The optical properties of the cummingtonite indicate a composition close to the actual composition, reading from the extrapolated curves for hydroxy-cummingtonite on the determinative chart of Bowen and Schairer (1935, p. 547).

The dispersion of the optic axes was estimated by observing a number of optic axis and Bxa sections. It is inclined, and is distinct for one axis, but weak for the other. However, the positions of the red and violet fringes relative to the isogyres are the same for both optic axes in both of the amphiboles.

Close examination of thin sections shows that the cummingtonite is very faintly colored in some orientations. This color (Table 1) is more clearly seen in fragments immersed in oil, the refractive index of which is within the cummingtonite range. The much stronger absorption of the hornblende, which is distinctly poorer in total iron than the cummingtonite, is probably due mainly to the higher $\text{Fe}^{3+}:\text{Fe}^{2+}$ ratio in the hornblende.

The specific magnetic susceptibilities of the amphiboles were measured with a calibrated Frantz isodynamic separator (McAndrew 1957). Since the only paramagnetic ions occurring in significant amounts in these minerals are Fe^{2+} and Fe^{3+} , the higher susceptibility of the cummingtonite is a function of its higher total iron content.

Layton and Phillips (1960, p. 660) have stated that "the only certain distinction between the cummingtonite and anthophyllite groups requires the use of x -rays." Although this may be true of asbestiform varieties (Rabbitt 1948), in relatively coarse-grained prismatic varieties the

monoclinic symmetry of cummingtonite is readily seen, so that optical properties can be reliable. The low Al content of the Duchess cummingtonite and the homoaxial intergrowths of cummingtonite and hornblende (both with $Z \wedge c = 20^\circ$) confirm the identification made from optical properties.

CHEMICAL ANALYSIS OF THE AMPHIBOLES

Separation. The difference between the magnetic susceptibilities of the amphiboles (Table 1) was sufficiently large to permit good separations to be made with the Frantz isodynamic separator. The plagioclase, its alteration products, and the accessory minerals were removed easily from the amphiboles, but repeated magnetic treatment was needed to obtain good concentrates of each amphibole. These concentrates were further purified by hand-picking under a binocular microscope. Grain-counts indicated that the analyzed hornblende concentrate was 99.5 per cent pure and that the cummingtonite concentrate was 99.3 per cent pure. Impurities consisted of small patches and (001) lamellae of cummingtonite and hornblende, respectively.

Analysis. The analyses were carried out by Mr. P. J. Sinnott in the chemical laboratory of the Mineragraphic Investigations Section of the C.S.I.R.O., Melbourne. Results are shown in Table 2, along with the structural formulae, calculated on the basis of 24 (O, OH, Cl, F) atoms per unit cell.

Al appears to substitute for Si in both amphiboles, though only to a small extent in the cummingtonite. The octahedral (Y) groups in both amphiboles are higher than the ideal figures of 5 for hornblende and 7 for cummingtonite, and this is probably due partly to the contamination of each amphibole by patches and lamellae of the other.

However, the hydroxyl group is somewhat low in the hornblende and very low in the cummingtonite, and this would also tend to raise the Y group totals. Unfortunately, the small size of the cummingtonite concentrate did not permit determination of F and Cl, which accounts for some of the discrepancy in the hydroxyl group, but most of the discrepancy is probably due to the failure of the Penfield method to release all the combined water (Rabbitt 1948, p. 281; Mason 1953, p. 863). A similarly low value for H_2O^+ was originally obtained for the hornblende, but this was greatly improved by determining the (corrected) loss of weight on ignition. FeO was determined on the ignited sample and a correction made for the $FeO \rightarrow Fe_2O_3$ reaction. A correction was also made for the F and Cl present. The method was not attempted for the cummingtonite, owing to the lack of sufficient cleaned material.

Comparison with other analyses. The chemical compositions of the

TABLE 2. CHEMICAL ANALYSIS AND STRUCTURAL FORMULAE OF CO-EXISTING CUMMINGTONITE AND HORNBLLENDE FROM DUCHESS, QUEENSLAND

	Cummingtonite	Hornblende
	(Weight percentages)	
SiO ₂	54.09	45.42
Al ₂ O ₃	2.82	13.01
Fe ₂ O ₃	1.89	2.35
FeO	16.84	10.24
MgO	20.31	13.75
CaO	2.17	10.92
Na ₂ O	0.16	1.20
K ₂ O	0.05	0.24
H ₂ O ⁺	1.08	1.61
H ₂ O ⁻	0.02	0.02
CO ₂	0.00	0.00
TiO ₂	0.12	0.74
P ₂ O ₅	<0.01	<0.01
MnO	0.84	0.36
Li ₂ O	0.00	0.00
Cl	—	0.10
F	—	0.61
Total	100.39	100.57
Less O≡Cl, F	—	0.28
Corrected Total	—	100.29

*Cations and (OH, Cl, F) ions on basis
24 (O, OH, Cl, F)*

Si	7.79	} 8.00 (Z)	6.55	} 8.00 (Z)
Al	0.48 { 0.21		2.21 { 1.45	
	0.27		0.76	
Ti	0.01		0.08	
Fe ³⁺	0.20		0.26	} 5.33 (Y)
Fe ²⁺	2.03		1.24	
Mg	4.36	} 7.37 (Y)	2.95	
Mn	0.10			0.04
Ca	0.34		1.69	
Na	0.05		0.34	} 2.08 (X)
K	0.01		0.05	
OH	1.04		1.55	
Cl	—	} 1.04	0.28	} 1.85
F	—			

Analyst: P. J. Sinnott.

TABLE 3. CHEMICAL COMPOSITION OF FOUR CUMMINGTONITES FROM CUMMINGTONITE-BEARING AMPHIBOLITES

(Ionic percentages)¹

	1	2	3	4
Si	50.90	50.70	51.47	51.53
Al	2.60	3.11	0.90	2.12
Fe ³⁺	0.04	1.33	2.53	1.43
Fe ²⁺	13.36	13.20	18.49	25.15
Mg	30.51	28.37	22.49	17.89
Ca	1.82	2.18	2.00	1.45
Na	0.54	0.29	0.40	0.00
K	0.12	0.06	0.09	0.00
Ti	0.09	0.08	0.45	0.30
P	—	<0.01	—	—
Mn	0.02	0.66	1.18	0.12
<i>Total cations</i>	100.00	99.98	100.00	99.99
O	149.51	149.48	146.87	146.81
OH	4.94	6.74	13.06	13.62
<i>Total anions</i>	154.45	156.22	159.93	160.43
Ca	3.98	4.77	4.28	3.15
Mg	66.69	62.02	48.17	38.86
Fe+Mn	29.33	33.21	47.55	57.99
$\frac{\text{Mg}}{\text{Mg}+\text{Fe}+\text{Mn}}$ (=mg)	0.69	0.65	0.50	0.40
	(Weight percentages)			
H ₂ O ⁺	0.80	1.08	1.96	2.01
H ₂ O ⁻	0.03	0.02	—	0.00
<i>Total oxides</i>	100.00 ²	100.39	99.99 ²	99.78
	(99.87)		(100.76)	

¹ 1957 atomic weights used (Green 1959).² Analysis recalculated after subtraction of impurities; summation of original analysis in parentheses.

1. From hornblende-bytownite rock, Muuruvesi, Finland (Eskola 1950, p. 730).
2. From amphibolite, Duchess, Queensland.
3. From amphibolite, Stewart Is., New Zealand (Watters 1959, p. 251).
4. From gabbro-diorite, Teisko, Finland (Seitsaari 1952, p. 8).

TABLE 4. CHEMICAL COMPOSITION OF FOUR HORNBLENDES FROM CUMMINGTONITE-BEARING AMPHIBOLITES

	(Ionic percentages) ¹			
	1	2	3	4
Si	47.66	42.54	44.46	41.57
Al	8.65	14.36	10.09	15.14
Fe ³⁺	1.05	1.65	3.24	4.04
Fe ²⁺	6.49	8.02	11.87	16.01
Mg	23.29	19.19	15.74	9.97
Ca	10.84	10.96	11.34	10.24
Na	0.95	2.18	1.84	2.05
K	0.56	0.29	0.38	0.27
Ti	0.50	0.52	0.51	0.56
P	—	<0.01	—	—
Mn	0.01	0.29	0.54	0.15
<i>Total cations</i>	100.00	100.00	100.01	100.00
O	149.59	143.82	143.64	146.06
OH	5.36	10.06	13.76	9.02
Cl	—	0.16	—	—
F	—	1.81	—	—
<i>Total anions</i>	154.95	155.85	157.40	155.08
Ca	26.01	27.32	25.57	25.34
Mg	55.88	47.85	35.49	24.67
Fe+Mn	18.11	24.83	38.94	49.99
Mg Mg+Fe+Mn (=mg)	0.76	0.66	0.48	0.33
	(Weight percentages)			
H ₂ O ⁺	0.87	1.61	2.13	1.37
H ₂ O ⁻	0.04	0.02	—	0.00
<i>Total oxides</i>	99.97 ²	100.29	100.38	99.85
	(99.93)			

Eplanation and localities as in Table 3.

Duchess amphiboles are compared with the three previously published pairs of analyses of similar amphiboles in Tables 3 and 4. They are expressed as ionic percentages, as advocated by Eskola (1954). From a comparison of the analyses the following points emerge:

1. All the cummingtonites contain some Al and Ca, part of which is due to impurities of hornblende in the analyzed samples.

2. All the cummingtonites contain some Mn. Layton and Phillips (1960, p. 659) have suggested that small amounts of Ca and Mn in octahedral co-ordination stabilize the monoclinic lattice of cummingtonite.

3. The Ca and Ti contents of the four hornblendes are remarkably constant.

4. The hornblendes are all richer in Fe^{3+} , Ti, Na, and K than their associated cummingtonites, which probably may be correlated with the much larger amounts of tetrahedral Al in the hornblendes.

5. Though the cummingtonites are all richer in Mg and Fe^{2+} , the degree of substitution of Mg for Fe is significantly variable, as shown by the *mg* ratios. Thus, the Muuruvesi cummingtonite is richer in Fe relative to Mg than its associated hornblende, whereas the reverse is true for the Teisko amphiboles. The cummingtonite and hornblende have similar *mg* ratios at Ringaringa and Duchess.

CONCLUSION

The writer has attempted to add new information and correlate existing chemical data on associated cummingtonite and hornblende. The petrogenesis of cummingtonite-bearing amphibolites remains a topic for future discussion, when more information is available. Perhaps the most important feature of the Duchess rock is the existence of cummingtonite in apparent equilibrium with hornblende; the original fabric of the rock has been replaced by a directional crystalloblastic fabric and there is no evidence of arrested reaction between the two amphiboles. This contrasts with the other cummingtonite-bearing amphibolites for which quantitative data are available, these rocks showing relict igneous textures (Eskola 1950, Seitsaari 1952, Watters 1959). Although in rocks such as these, the cummingtonite may owe its existence partly to incomplete attainment of equilibrium, it appears that in the Duchess rock other factors predominated, in particular the composition of the original rock.

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