

TABLE 3. UNIT CELL DATA FOR LAZULITE

Parameter	Berry (1948)	Lindberg (1959)	This Study
$a(\text{\AA})$	7.14	7.16	7.15
$b(\text{\AA})$	7.27	7.26	7.28
$c(\text{\AA})$	7.16	7.24	7.25
$\beta$	119°18'	120°40'	120°35'

employing  $Q_{102}$  and  $Q_{102}$  from the powder data the calculated  $\beta$  would be 120°40' but as the angle is  $\pm 5'$  at best and the  $Q_{102}$  value involves some of the 020 reflection this value is not considered better than 120°35'.

The space group for lazulite as determined by Lindberg and Christ (1959) is  $P2_1/c$ . The indices determined from the powder data are permissible for a mineral in this group (*i.e.* for *oko*,  $k = 2n$  and for *hol*,  $l = 2n$ ).

## REFERENCES

- BERRY, L. G. (1948), Structural crystallography of lazulite, scorzalite and veszelyite. *Am. Mineral.*, **33**, 750.
- LINDBERG, MARIE L. AND C. L. CHRIST (1959), Crystal structures of the isostructural mineral lazulite, scorzalite and barbosalite. *Acta Cryst.*, **12**, 695-696.
- PECORA, W. T. AND J. J. FAHEY (1949), The Corrego Frio Pegmatite, Minas Gerais: Scorzalite and souzalite, two new phosphate minerals. *Am. Mineral.*, **34**, 83-93.
- (1950), The lazulite-scorzalite isomorphous series. *Am. Mineral.*, **35**, 1-18.
- WINCHELL, A. N., AND H. WINCHELL (1956), Elements of Optical Mineralogy, Pt. 2. Descriptions of Minerals, 4th ed., John Wiley & Sons, Inc., New York.

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HORNBLende-CUMMINGTONITE INTERGROWTHS<sup>1</sup>

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It is commonly considered that a gap exists in nature between the cummingtonite-grunerite (or anthophyllite) series of amphiboles and the tremolite-hornblende series. Basic metamorphic rocks, which from their composition might be expected to contain a single amphibole of composition between these two groups, always appear to contain two (or three) amphiboles (Eskola, 1914; Asklund, 1923; Seitsaari, 1952; Pirani, 1952;

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Tilley, 1957). The amphiboles in such rocks are commonly intergrown on both a coarse and a fine scale. Eskola (1914) referred to such intergrowths in the amphibolites at Orijärvi, Finland and suggested that the cummingtonite may have arisen from the hornblende of a normal amphibolite by replacement. He thus tacitly assumed a miscibility gap between the two. One of us (Asklund, 1923) formally proposed such a gap after a study of amphibole intergrowths in amphibolites that had probably been formed from pyroxene-bearing gabbros. He also suggested that the intergrowths may be a result of unmixing i.e. that the immiscibility gap is smaller at higher temperatures.

Material from Sköthagen, Sweden containing such intergrown amphiboles has been examined by optical, x-ray and hydrothermal methods. The rock is an amphibolite probably formed from an original gabbro: it consists of plagioclase 46%, hornblende 13%, cummingtonite 26%, biotite 9%, magnetite etc. 6%. The rock has conspicuous dark aggregates of hornblende and biotite set in a dark gray matrix. Hornblende and biotite are restricted to the aggregates and labradorite to the matrix: cummingtonite is found both in the aggregates, where it is almost always coarsely intergrown with hornblende, and in the matrix where it occurs as long prismatic crystals.

The coarse intergrowth of hornblende and cummingtonite in the dark aggregates occurs mainly parallel to (100), though intergrowth along (001) is also common; the cummingtonite is commonly twinned on (100), in some cases multiple. In some examples the intergrowth surfaces differ by a few degrees from (100). The ratio of the two phases varies, and intergrowths occur that are equally divided. In addition to the coarse intergrowth, finer bands parallel to (001) may extend out from one amphibole into the other.

In each of the coarsely intergrown amphiboles very fine lamellae parallel to (001) can be seen, those in the hornblende appearing colorless, and those in the cummingtonite green. These lamellae are usually near the limit of resolution of the Leitz U.M. 4 objective and are difficult to detect unless viewed in the right direction. The latter lamellae show the same scheme of pleochroism as the hornblende. Similar green lamellae are found in the cummingtonite crystals of the matrix. It is suggested that the coarse intergrowth of cummingtonite and hornblende in the dark aggregates is primary, whereas the fine lamellae parallel to (001) represent exsolution analogous to that in the pyroxenes. The dark aggregates possibly represent the metamorphic relicts of an augite-like pyroxene, and the cummingtonite crystals in the matrix the relicts of hypersthene or olivine. Colorless cummingtonite lamellae have also been found in hornblende crystals of an amphibolite from Wildschafbach, Schwarzland: large crystals of cummingtonite do not occur in this rock.

Small crystals optically free from intergrowth parallel to (100) were x-rayed on a precession camera. Both cummingtonite and hornblende crystals gave two sets of x-ray reflections, whose intensity suggested that the subordinate phase was present at the 1 to 5 per cent level. Comparison of the photographs showed that the subordinate phase occurring in the hornblende was cummingtonite, and vice versa.

With the kind assistance of Dr. J. Gittins, large crystals of the hornblende were sealed in gold tubes with an excess of iron powder and a little water. Upon treatment with 12,000 p.s.i. H<sub>2</sub>O at various temperatures, the results obtained were:

<i>Temperature</i>	<i>Time</i>	<i>Results</i>
700° C.	20 hours	no change
740° C.	3 days	no change
800° C.	10 days	homogenized
900° C.	10 days	converted to orthopyroxene

These experiments, of course, are only exploratory and do not represent equilibrium conditions. Furthermore, although the color of the amphibole appeared unchanged, it is possible that some variation of the oxidation state of the iron occurred. Nevertheless homogenization of the fine-scale intergrowth did occur, thus supporting the idea of an exsolution origin.

Although no runs were made to test whether complete miscibility occurs between hornblende and cummingtonite at high temperature, it seems likely that this does not occur, because of the large difference in size between the Ca and Mg ions, and because cummingtonite appears to take little Al in substitutional disorder whereas hornblende carries large amounts. Although anthophyllite can take considerable Al in solid solution to give gedrite it is not possible to have complete miscibility between hornblende and anthophyllite because of the difference in crystal symmetry and cell size. These and other crystal-chemical viewpoints will be considered elsewhere (Brown and Gibbs, in preparation; see also Whitaker, 1960).

Exsolution has been reported by Sahama (1956) for an arfvedsonite, though we have not been able to repeat his findings using materials supplied by him.

#### REFERENCES

- ASKLUND, B. (1923), Petrological studies in the neighborhood of Stavsjö at Kolmården, *Årsbok*, 17, no. 6.
- ESKOLA, P. (1914) On the petrology of the Orijärvi region in south western Finland. *Bull. Comm. Geol. Finlande*, 40, 167-224.
- (1950) Paragenesis of cummingtonite and hornblende from Muuruvesi, Finland, *Am. Mineral.*, 35, 728-734.
- PIRANI, R. (1952), I minerali del gruppo dell Ortler IV Antofillite e actinolite di Val di Bresimo. Solubilità di questa actinolite. *Atti (Rend.) Accad. Naz. Lincei, Cl. Sci. Fis. mat. nat.*, ser. 8, 13, 315-319.

- SAHAMA, TH. G. (1956), Optical anomalies in arfvedsonite from Greenland. *Am. Mineral.*, **41**, 509-512.
- SEITSAARI, J. (1952), Association of cummingtonite and hornblende. *Ann. Acad. Sci. Fenn. Ser. A, III*, **30**, 1-20.
- TILLEY, C. E. (1957), Paragenesis of anthophyllite and hornblende from the Bancroft area, Ontario. *Am. Mineral.*, **42**, 412-416.
- WHITTAKER, E. J. W. (1960), The crystal chemistry of the amphiboles. *Acta Cryst.*, **13**, 291-298.

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ALLUAUDITE AND CARYINITE

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That alluaudite and caryinite are isostructural was pointed out by Strunz (1960). Using the less oblique  $I2_1/a$  cell for alluaudite (Fisher, 1956), the powder data (Fisher, 1955) are indexed as shown in Table 1,

TABLE 1. POWDER PHOTOGRAPH DATA

No.	Alluaudite					Caryinite		
	$d_0$	$d_m$	$I_s$	$I_p$	$hkl$	$d$	$I$	$hkl$
1	8.19	8.39-18	3	2-3	110	8.60	1	110
2	6.27	6.37-26	9	8	020	6.59	1	020
3	5.67	---	0	0	011	6.05	1	011
3	5.47	5.52-45	7	4-6	200			
---	---	4.90-88	---	$\frac{1}{2}$	---	5.10	1	---
---	---	4.65-64	---	$\frac{1}{2}$	---			
---	4.30	4.3-4.2	---	$\frac{1}{2}$	121	4.54	1	121
4a,b	4.18-14	4.16-12	5, 3	1-3	211, 220	4.45	1	211
---	3.99	---	---	0	121	4.19	1	121
---	3.91	---	1	0	130	4.09	1	130
---	3.71	---	1-	0	211	3.88	1	211
5	3.49	3.51-48	{7+}	5-7	{310 031}	3.69	1	031
---	---	3.35-31	---	1-	---	3.64	1	310
6a	3.17	3.20	1	1-	002	3.39	1	002
---	---	---	---	---	---	3.33	1	---
6b	3.13	3.16-11	6	1	040	3.29	2	040
7	3.07	3.09-05	9-	5-8	112	---	---	112
8	3.05	3.055	7	$\frac{1}{2}$	231	3.21	1	231
9	2.964	2.97	5-	$\frac{1}{2}$	321	3.14	2	202
10	2.917	2.93	5+	1-	202	3.12	1	321
11a	2.868	2.91-88	7+	1-2	112	3.03	3	112, 022
11b	2.849-36	2.86-85	5, 9	1-3	231, 022	2.964	1	231
11c	2.760	2.82-77	9	1-3	141	2.903	2	141
12a	2.745-34	2.74	6, 9-	7-	330, 400	2.868	10	330, 240
12b	2.715	2.74-72	9	10	240	2.849	1	400
13	2.696-80	2.71	1-, 5	$\frac{1}{2}$	321, 141	2.810	1	321
14	2.647	2.67-64	7+	1-2	222	2.790	2	---
15	2.600	2.61	5	1-	202	2.730	2	202

(continued on next page)

Explanation of columns

- No. = The number of the line as given in Fisher (1955)
- $d_0$  = Calculated spacing assuming  $I2_1/a$  with  $a=11.03$ ,  $b=12.53$ ,  $c=6.40$ ,  $\beta=97^\circ34'$  as given in Fisher (1956)
- $d_m$  = Measured spacings from Fisher (1955)
- $I_s$  = Uncorrected visual intensities estimated from single crystal photographs of the Buranga alluaudite. Those not observed are indicated by a dash.
- $I_p$  = Uncorrected visual intensities from Fisher (1955).
- Note: the caryinite figures are taken (with minor modifications) from Boström. The 3.14 spacing is a calculated value (with intensity from a Weissenberg photograph), since it was shadowed by a line from the standard.