

This locality is approximately forty-five miles from the one discussed in this paper but the two occurrences have many similarities. Their origins are probably the same, except that in one case the shale pseudomorphic casts were replaced by dolomite and in the other case they were not.

Two other similar forms are in the Oklahoma Geological Survey collections. One is a gray shale from Sec. 24, T. 21 N., R. 15 W., and the other is a pinkish shale from Sec. 34, T. 22 N., R. 1 W. The forms apparently are rather widespread in the Permian of Oklahoma.

CUMMINGTONITE FROM THE BLACK HILLS, SOUTH DAKOTA

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INTRODUCTION

The mineral cummingtonite occurs abundantly in the Homestake mine, Lead, South Dakota, and likewise to the north of this locality. It also occurs near Rochford, twenty miles southwest of Lead. The cummingtonite is developed in iron-magnesium carbonate horizons in pre-Cambrian schists. It has been described¹ as due to regional metamorphism and to direct reaction between the original iron-magnesium carbonate (sideroplesite) grains and associated grains of sedimentary quartz. However, recent mapping by the geological department of the Homestake Mining Company has shown cummingtonite to be developed only locally and to be associated with original unaltered quartz grains. It is closely related to ore minerals and shows none of the fracturing that might be expected if it had been subjected to regional stresses. In view of this, an alternative hypothesis is that the cummingtonite was formed by the action of hot silica-bearing solutions on sideroplesite. Some of the cummingtonite replaces minerals of known hydrothermal origin.

The greatest metamorphic intensity in the vicinity of Lead occurs about three miles to the northeast of the Homestake mine. Here the cummingtonite seems to be more strongly developed than in the mine. Specimens were collected in regular sequence southward to the mine from this more highly metamorphosed area by Mr. James A. Noble, chief geologist for the Homestake Mining Company. The writer has studied these in order to discover any progressive variations in chemical composition or physical properties which might throw light on the origin of the cummingtonite. This regular variation was not found, however; even the four specimens of cummingtonite taken from near Rochford,

¹ Gustafson, J. K., Metamorphism and hydrothermal alteration of the Homestake gold-bearing formation; *Econ. Geology*, vol. 28, p. 133, 1933.

where the intensity of regional metamorphism is less than at Lead, differ very little from the average of the Lead cummingtonites.

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PHYSICAL DATA

The cummingtonite occurs as radiating blades or fibers averaging a half a centimeter in length, but occasionally extending several centimeters. It is brownish or greenish-gray, and sometimes shows a slightly silky luster. Its hardness is 5 to 6, and the cleavage is parallel to (110). Cummingtonite in the form of asbestos-like material around quartz has been found; here its fibers may attain several inches in length and are a translucent yellowish gray.

The specific gravity² varies from 3.19 to 3.40, increasing with ferrous iron (Table 1). One specimen, shown by *x*-ray study to be impure, has a specific gravity of only 3.02.

In thin section the mineral is colorless, or faintly grayish brown. No pleochroism was observed by the writer. The extinction angle $Z \wedge c$ is from 17° to 24°. The lower angles belong to specimens higher in ferrous iron.³ $Y = b$. (Table 1).

The results of determinations of indices by the immersion method are:

| <i>Index</i> | <i>Minimum</i> | <i>Maximum</i> | <i>Average</i> |
|---------------------------|----------------|----------------|----------------|
| N_{α} | 1.653 | 1.672 | 1.662 |
| N_{β} | 1.670 | 1.694 | 1.680 |
| N_{γ} | 1.682 | 1.704 | 1.693 |
| $N_{\gamma} - N_{\alpha}$ | 0.025 | 0.040 | 0.031 |

The birefringence and refringence increase with ferrous iron. (Table 1).

The optic sign in most specimens is $-$, but in some, low in iron, it is $+$. In Table 1 those specimens which are on the border line are listed as \pm . The sign of elongation is always $+$. Dispersion is weak: $r > v$.

The optic angle was determined for each specimen with the aid of a universal stage, and was measured through the fast ray, *X*. It varies from 70° to 98°, being smaller with higher iron (Table 1).

² Determinations were made with a pycnometer, and, as a precaution, all air was removed from the crushed cummingtonite and the distilled water by boiling under reduced pressure.

³ Bowen, N. L., and Schairer, J. F., Grunerite from Rockport, Massachusetts, and a series of synthetic fluor-amphiboles: *Am. Mineral.*, vol. 20, pp. 543-551, 1935. These investigators have found that the curve of extinction angles of their synthetic fluor-grunerites and cummingtonites passes through a maximum at an intermediate composition corresponding to cummingtonite.

TABLE 1. PHYSICAL AND CHEMICAL DATA

| Sample | Indices | | | Biref. $\gamma - \alpha$ | Extinc. Angle $Z\Delta c'$ | Optic Angle (Thru X) | Optic Sign | Sp. Gr. (Obs.) | Per- cent FeO |
|-------------------------|----------|---------|----------|-----------------------------|----------------------------------|-------------------------------|---------------|-------------------|---------------------|
| | α | β | γ | | | | | | |
| hf#1 | 1.662 | 1.687 | 1.702 | 0.040 | 18° | 80° | — | — | 34.45 |
| hf#2 | 1.665 | 1.679 | 1.692 | 0.027 | 19 | 84 | ± | — | 26.61 |
| hf#3 | 1.662 | 1.680 | 1.693 | 0.031 | 19 | 98 | ± | 3.19 | 27.93 |
| hf#4 | 1.661 | 1.682 | 1.697 | 0.036 | 18 | 86 | — | 3.40 | 34.45 |
| hf#5 | 1.661 | 1.680 | 1.692 | 0.031 | 19 | 84 | — | — | — |
| hf#6 | 1.658 | 1.672 | 1.683 | 0.025 | 20 | 94 | ± | — | 24.20 |
| hf#7 | 1.660 | 1.679 | 1.689 | 0.029 | 24 | 70 | — | — | 29.92 |
| hf#8 | 1.664 | 1.687 | 1.697 | 0.033 | 17 | 85? | — | — | 33.05 |
| hf#9 | 1.653 | 1.670 | 1.682 | 0.029 | 18 | 82 | — | — | — |
| frf#1 | 1.657 | 1.672 | 1.683 | 0.026 | 20 | 88 | ± | — | 29.65 |
| frf#2 | 1.658 | 1.673 | 1.688 | 0.030 | 19 | 93 | ± | 3.26 | 31.10 |
| frf#3 | 1.669 | 1.684 | 1.697 | 0.028 | 20 | 92? | ± | — | 27.20 |
| R.hf#1 | 1.663 | 1.679 | 1.692 | 0.029 | 20 | 87 | ± | 3.02 | 21.54 |
| R.hf#2 | 1.665 | 1.686 | 1.698 | 0.033 | 18 | 80 | — | — | 33.72 |
| R.frf#1 | 1.672 | 1.694 | 1.704 | 0.032 | 18 | 80 | — | — | 30.40 |
| Cummington ^a | 1.661 | 1.677 | 1.689 | 0.028 | 17 | 84 | — | — | 32-33 |
| Limit of error | ±0.003 | ±0.004 | ±0.003 | — | ±1 | ±4 | — | ±0.01 | ±0.05 |
| Uttersvik ^b | 1.6555 | 1.6717 | 1.6859 | 0.0304 | 15.4 | 85°20' | — | — | 24.13 |

^a Smith, L., and Brush, G. J., *Am. Jour. Sci.*, vol. 16, p. 48, 1853.

^b Johansson, K., (See footnote⁵)

CHEMICAL DATA

The percentages of ferrous oxide are given in Table 1. They vary from 21.54 to 34.45. Some cummingtonites which appear in the hand specimen to be appreciably altered to limonite are found to be only superficially oxidized when analyzed for FeO, or studied by means of x -rays. The formula for cummingtonite given by Warren⁴ is:



THE UNIT CELL.

The powder method was used for x -ray study. Calculation of the unit cell was facilitated by comparison with data obtained by Johansson⁵ on cummingtonite from Uttersvik, Sweden, which is higher in manganese than are specimens from the Black Hills. The results for the first four specimens are:

⁴ Warren, B. E., The crystal structure and chemical composition of the monoclinic amphiboles: *Zeit. Krist.*, vol. 72, p. 513, 1929.

⁵ Johansson, K., Vergleichende Untersuchungen an Anthophyllit, Grammatit, und Cummingtonit: *Zeit. Krist.*, vol. 73, pp. 45-51, 1930.

| Specimen | a_0 | b_0 | c_0 |
|-----------|--------|---------|--------|
| hf#1 | 9.51 Å | 18.22 Å | 5.35 Å |
| hf#2 | 9.50 | 18.21 | 5.33 |
| hf#3 | 9.53 | 18.21 | 5.33 |
| hf#4 | 9.50 | 18.23 | 5.35 |
| Uttersvik | 9.55 | 18.18 | 5.33 |

The values of b_0 and c_0 seem to increase slightly with iron. The mean axial ratio is: 0.5224:1:0.2932.

The indices of the lines obtained from powder photographs show the cummingtonite to belong to the monoclinic space group C_{2h}^3 . There are two molecules per unit cell.

THEORETICAL DENSITY

By the relation $V = a_0 b_0 c_0 \sin \beta$, the volumes of the unit cells of specimens hf#3 and hf#4 are found to be 904.31 and 905.84 cubic Å, respectively.

Since complete chemical analyses were not made, it is impossible to compute the exact molecular weights for use in calculating the theoretical densities. However, the FeO percentages and the formula of the theoretical mineral, $(OH)_2(Fe, Mg)_7(Si_4O_{11})_2$, are known, and molecular weights may be calculated which neglect impurities such as manganese, calcium, sodium, and aluminum. The formula of cummingtonite may be thought of as consisting of $H_2O + 7(Fe, Mg)SiO_3 + SiO_2$. The excess silica and the water make up 6.7 and 2.0 per cent, respectively, of the mineral.

Specimen hf#3 contains 27.93 per cent FeO, which is equivalent to 51.25 per cent $FeSiO_3$. There remain 6.7 per cent SiO_2 , 2.0 per cent H_2O , and 40.05 per cent $MgSiO_3$. The molecular weight becomes 890. The theoretical density, 3.24, calculated from this agrees well with the observed density of 3.19.

Specimen hf#4, which contains 34.45 per cent FeO, is similar to a cummingtonite specimen analysed by W. J. Sharwood.⁶ In his mineral, which contains 34.02 per cent FeO, the ratio of Fe to Si ions is 4.31 to 8. Extrapolating a ratio of 4.5 to 8 for specimen hf#4, we arrive at a molecular weight of 924 and a theoretical density of 3.37. The observed density of specimen hf#4 is 3.40.

Sharwood observed that his analyzed specimen of cummingtonite had a specific gravity of 3.37. If the lattice constant found by the writer for specimen hf#4 is applied to his mineral, a theoretical density of 3.32 is obtained.

⁶ Sharwood, W. J., Analyses of some rocks and minerals from the Homestake Mine, Lead, South Dakota: *Econ. Geology*, vol. 6, p. 747, 1911.