

CHEMICAL PETROLOGY AND MINERALOGY OF HORNBLENDES IN NORTHWEST ADIRONDACK GRANITIC ROCKS*

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CONTENTS

| | |
|--|-----|
| Abstract | 891 |
| Introduction | 891 |
| Petrologic Notes..... | 892 |
| Hornblende from granitic rocks of Diana-Stark complex..... | 892 |
| Hornblende from younger granitic rocks..... | 893 |
| Optical and Chemical Data..... | 897 |
| Optical properties of some Adirondack hornblendes..... | 897 |
| Indices of refraction..... | 897 |
| Birefringence..... | 898 |
| Optic axial angle..... | 898 |
| Dispersion..... | 899 |
| Extinction angle..... | 899 |
| Pleochroism and absorption..... | 900 |
| General relations of the Adirondack hornblendes..... | 900 |
| References..... | 901 |

ABSTRACT

Chemical analyses and optical properties of seven hornblendes from granitic rocks of the northwest Adirondack Mountains, New York, are presented. The chemical analyses have been recalculated in terms of a theoretical amphibole formula. All the hornblendes belong to the femaghastingsite and ferrohastingsite varieties and carry chlorine as well as fluorine in significant amounts. The variations in composition of the hornblendes correlate with the degree of differentiation of the rock of which they are a part, or with the degree of modification of incorporated foreign material. The methods used in determining the optical properties are fully described and critically discussed. A satisfactory, detailed correlation of chemical and optical properties has not yet been achieved, even for the limited part of the hastingsite group investigated here.

INTRODUCTION

Granitic rocks with hornblende as a varietal mineral form very large masses and are a major element in the pre-Cambrian bedrock of the northwest Adirondack Mountains of New York (Buddington, 1939 and 1948). This paper is a contribution on the chemical composition and optical properties of the hornblendes, together with a brief discussion of their petrologic environment. Buddington initiated the study of the

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hornblendes and prepared the section on chemical petrology. Leonard contributed the optical data.

The chemical analyses were made at the Rock Analysis Laboratory of the University of Minnesota. The cost of the analyses was borne by a grant of funds from the Eugene Higgins Trust allocated to Princeton University.

The hornblendes were concentrated for analysis by use of the Frantz magnetic separator and heavy liquids. This work was done by H. L. James and R. J. Smith. The hornblende concentrates submitted for chemical analysis were better than 99.5 per cent pure. Most of them were about 99.9 per cent pure. The contaminants were chiefly minute grains of quartz and potash feldspar that had not broken free from the hornblende, even after crushing to $-100, +200$ mesh.

There is no reason to doubt that the hornblendes in the fraction studied optically were identical with those in the concentrate submitted for chemical analysis.

The writers have followed Billings' subdivision (1928) of the hastingsite group, according to the molecular proportions of FeO and MgO; *ferrohastingsite*, $\text{FeO/MgO} > 2$; *femaghastingsite*, $\text{FeO/MgO} < 2$ but $> \frac{1}{2}$; and *magnesiohastingsite*, $\text{FeO/MgO} < \frac{1}{2}$.

PETROLOGIC NOTES

The granitic rocks of the northwest Adirondacks are of two different ages. The older granitic rocks, part of the Diana-Stark complex, have been intensely deformed, recrystallized, and intruded by a younger series of granitic rocks. These younger granites in large part have a sheetlike, phacolithic, and domical relationship to all older rocks.

Chemical analyses of rocks from which the hornblendes 1, 3, 4, and 6 (Table 1) and pyroxene no. 8 (Table 1) were concentrated are to appear in a forthcoming publication of the U. S. Geological Survey entitled "Geology and mineral deposits of the St. Lawrence County magnetite district, New York," by Buddington and Leonard.

Hornblende from Granitic Rocks of Diana-Stark Complex

The older granitic rocks are facies of the Diana-Stark complex. This complex has been described and interpreted (Buddington, 1939, pp. 73-109; Buddington, 1948, pp. 24-29) as a very great sheet of igneous rock that has been intensely deformed and recrystallized. The sheet has a stratiform character resulting from differentiation primarily by fractional crystallization. Pyroxene syenite gneiss with lenses of shonkinite and feldspathic ultramafic (ferroaugite, ilmenite, and magnetite) gneiss occurs in the lower part. This grades upward through pyroxene quartz

syenite gneiss and hornblendic quartz-bearing syenite gneiss into hornblende granite gneiss, which forms the upper facies. The pyroxenic facies of this sheet are green in color, whereas the hornblendic facies are pink.

Hornblende 5 occurs as porphyroblasts in a pink granoblastic quartz-bearing syenite gneiss, which grades into a pyroxene quartz-bearing syenite gneiss stratigraphically below and a hornblende granite gneiss stratigraphically above. Hornblendes 6 and 7 are from wholly recrystallized granite gneiss characteristic of the upper facies of the Diana-Stark sheet. The variation of the mafic minerals from ferroaugite (nos. 8 and 9, Table 1) in the lower part of the sheet through femaghaastingsite (no. 5) to ferrohastingsite (nos. 6 and 7) in the upper part of the sheet is consistent with what might be expected as a product of fractional crystallization and gravity sorting of successive crystal fractions. The ratio of mol per cent (FeO plus MnO)/MgO increases systematically from that in the ferroaugite (nos. 8 and 9=0.86 and 0.85, respectively) through femaghaastingsite (no. 5=1.18) to ferrohastingsite (nos. 6 and 7=3.20 and 4.09, respectively). This increase in ratio of FeO to MgO is correlated with a higher percentage of quartz and a higher ratio of normative orthoclase to albite in the ferrohastingsite-bearing gneisses.

Hornblende from Younger Granitic Rocks

The predominant member of the younger granitic rocks is a hornblende-micropertthite granite commonly with 20 to 30 per cent quartz. Hornblende 2 is from this type of rock. The hornblende granite is in part strongly deformed and recrystallized to a gneiss. Hornblende 3 is from this gneissic facies. The micropertthite of the hornblende granite has been recrystallized in the gneissic facies to a granoblastic aggregate of oligoclase and potash feldspar. A little sphene has also developed in the gneiss as a reaction product. The hornblende of the normal hornblende-micropertthite granite is a green variety, whereas the recrystallized hornblende of the gneissic facies is commonly pleochroic from green to bluish green. Both types were found in one sample of partly recrystallized rocks. The indices of refraction of three specimens from the normal granite indicate the hornblende to be just in the border zone between femaghaastingsite and ferrohastingsite.

There is also a facies of the hornblende granite in which the quartz content is commonly greater than 27 per cent and the ratio K_2O/Na_2O is slightly higher than in the normal granite. The hornblende (no. 4) of this type of rock is a ferrohastingsite with a relatively high ratio of ferrous iron to magnesia. (The particular rock from which the analyzed hornblende was taken has a lower percentage of quartz than is normal for this facies of the granites.) All the chemical and mineralogical character-

TABLE 1. CHEMICAL ANALYSES OF SEVEN HORNBLENDES AND TWO PYROXENES FROM GRANITIC ROCKS OF THE NORTHWEST ADIRONDACKS

| | Hornblende from microcline granite gneiss | | Hornblendes from younger hornblende granite and hornblende granite gneiss | | Hornblendes from Diana-Stark complex | | | Pyroxenes from Diana complex | |
|--|---|----------|---|-----------|--------------------------------------|-----------|----------|------------------------------|-------|
| | 1 (B-555) | 2 (W-14) | 3 (956) | 4 (B-189) | 5 (D-8) | 6 (B-669) | 7 (5100) | 8 | 9 |
| SiO ₂ | 39.78 | 39.32 | 37.90 | 38.44 | 41.25 | 38.73 | 38.74 | 51.53 | 52.28 |
| Al ₂ O ₃ | 11.39 | 10.82 | 11.89 | 11.03 | 10.40 | 11.49 | 11.42 | 1.50 | 2.71 |
| Fe ₂ O ₃ | 5.93 | 5.52 | 7.75 | 5.80 | 3.85 | 5.22 | 4.34 | 2.72 | 2.58 |
| FeO | 14.21 | 20.43 | 20.71 | 24.67 | 16.28 | 22.89 | 23.28 | 13.13 | 12.61 |
| MgO | 9.62 | 6.16 | 4.16 | 1.97 | 8.02 | 4.10 | 3.25 | 8.92 | 8.70 |
| CaO | 9.68 | 9.17 | 9.54 | 9.56 | 10.26 | 9.45 | 10.16 | 20.17 | 16.69 |
| Na ₂ O | 1.57 | 1.99 | 1.57 | 1.81 | 1.58 | 1.68 | 1.98 | 0.67 | 0.78 |
| K ₂ O | 1.60 | 1.47 | 1.75 | 1.72 | 1.46 | 1.61 | 1.97 | 0.00 | 0.28 |
| H ₂ O+ | 2.59 | 1.75 | 1.82 | 1.09 | 1.69 | 1.67 | 1.83 | 0.36 | 0.38 |
| H ₂ O- | 0.25 | 0.33 | 0.10 | 0.19 | 0.10 | 0.04 | 0.09 | 0.06 | 0.56 |
| TiO ₂ | 1.47 | 1.76 | 0.83 | 2.37 | 2.90 | 1.70 | 2.83 | 0.19 | 1.32 |
| F | 1.29 | 1.50 | 0.72 | 0.96 | 1.17 | 0.61 | 0.95 | — | — |
| Cl | 0.58 | 0.37 | 0.26 | 0.60 | 0.60 | 0.53 | 0.77 | — | — |
| MnO | 0.68 | 0.50 | 0.85 | 0.48 | 0.76 | 0.58 | 0.44 | 0.82 | 0.72 |
| Total | 100.64 | 101.09 | 99.85 | 100.69 | 100.32 | 100.30 | 101.05 | 100.07 | 99.61 |
| Less O for F and Cl | 0.67 | 0.71 | 0.36 | 0.54 | 0.62 | 0.38 | 0.57 | — | — |
| Total (corrected) | 99.97 | 100.38 | 99.49 | 100.15 | 99.70 | 99.92 | 100.48 | — | — |
| Modal wt. per cent hornblende | 2.9 | 2.5 | 5.0 | 8.6 | 7.1 | 10.7 | 11.0 | 58.0* | 4.0* |
| Modal wt. per cent quartz | 21.6 | 25.0 | 27.5 | 24.0 | 9.2 | 18.7 | 14.4 | 0.6 | 11.0 |
| Normative ratio orthoclase/albite | 2.97 | 1.18 | 1.33 | 1.26 | 0.86 | 0.99 | 0.96 | — | — |
| Ratio $\frac{\text{FeO}+\text{MnO}}{\text{MgO}}$ (mol. props.) | 0.86 | 1.89 | 2.91 | 7.14 | 1.18 | 3.20 | 4.09 | 0.86 | 0.85 |
| Ratio MgO/FeO (mol. props.) | 1.22 | 0.54 | 0.36 | 0.14 | 0.89 | 0.32 | 0.25 | — | — |

* Pyroxene.

TABLE 2. OPTICAL PROPERTIES OF SEVEN HORNBLendes FROM GRANITIC ROCKS OF THE NORTHWEST ADIRONDACKS

| | 1 (B-555) | 2 (W-14) | 3 (956) | 4 (B-189) | 5 (D-8) | 6 (B-669) | 7 (5100) |
|---|---------------------------------|--------------------------------|-----------------------------|------------------------------------|------------------------------------|--------------------------------|------------------------------------|
| α | 1.666 | 1.674 | 1.682 | 1.6940 | 1.680 | 1.688 | 1.692 |
| β | 1.689 | 1.693 | 1.701 | 1.7170 | 1.692 | 1.709 | 1.712 |
| γ | 1.693 | 1.700 | 1.705 | 1.7235 | 1.696 | 1.714 | 1.716 |
| $\gamma - \alpha$ | 0.027 | 0.026 | 0.023 | 0.0295 | 0.016 | 0.026 | 0.024 |
| Optic sign | (-) | (-) | (-) | (-) | (-) | (-) | (-) |
| $2V_{meas.}$ | $51 \pm 1^\circ$ | $62 \pm 3^\circ$ | $49 \pm 3^\circ$ | $52 \pm 2^\circ$ | $58 \pm 4^\circ$ | $51 \pm 5^\circ$ | $52 \pm 3^\circ$ |
| $2V_{calc.}$ | 46° | $62\frac{1}{2}^\circ$ | $49\frac{1}{2}^\circ$ | 55° | $60\frac{1}{2}^\circ$ | 52° | 48° |
| Dispersion | $r > v$ strong | $r < v$ distinct | $r > v$ strong | $r < v$ strong | $r < v$ strong | $r < v$ strong | $r < v$ strong |
| 2nd axis | $r < v$ strong | same? | $r > v$ weak | $r < v$ distinct | $r > v$ very weak | $r > v$ distinct | $r < v$ weak |
| $Z \wedge c$ | $21 \pm 5^\circ$ | $14 \pm 3^\circ$ | $10\frac{1}{2}^\circ$ | $12-13^\circ$ | $15 \pm 5^\circ$ | $12 \pm 2^\circ$ | $9\frac{1}{2} \pm 3^\circ$ |
| X | Pale greenish yellow | Greenish yellow | Straw yellow | Pale olive | Greenish yellow | Pale greenish yellow | Yellowish green |
| Y | Olive | Olive | Green | Dark grayish olive | Olive | Dark olive | Very dark olive |
| Z | Greenish blue | Green | Bluish green | Dark green with bluish tint | Green | Dark green | Very dark green |
| Absorption Orientation | $Y > Z > X$ $Y = b$ 3.211 | $Y \geq Z > X$ $Y = b$ — | $Y = Z > X$ $Y = b$ — | $Y \geq Z > X$ $Y = b$ 3.445 | $Y \geq Z > X$ $Y = b$ 3.258 | $Y \geq Z > X$ $Y = b$ — | $Y \geq Z > X$ $Y = b$ 3.432 |
| G. | | | | | | | |
| Birefringences determined by means of Berek compensator | | | | | | | |
| $\gamma - \beta$ | 0.004 | — | — | 0.0063* | 0.004 | 0.005 | — |
| $\beta - \alpha$ | — | — | — | 0.0230* | 0.0125 | 0.020 | — |
| $\gamma - \alpha$ | ca. 0.025+ | — | — | 0.0295* | — | — | 0.024 |

* Determined by H. H. Hess.

TABLE 3. STRUCTURAL FORMULAE* OF SEVEN HORNBLENDES FROM GRANITIC ROCKS OF THE NORTHWEST ADIRONDACKS

| | 1 (B-555) | 2 (W-14) | 3 (956) | 4 (B-189) | 5 (D-8) | 6 (B-669) | 7 (5100) |
|-----|--------------------------|-------------|------------|--------------|------------|--------------|-------------|
| (W) | K 0.31 | 0.30 | 0.36 | 0.35 | 0.28 | 0.32 | 0.40 |
| | Na 0.46 | 0.60 | 0.50 | 0.56 | 0.48 | 0.51 | 0.61 |
| | Ca 1.56 | 2.33 | 2.43 | 1.65 | 2.56 | 1.60 | 2.43 |
| | | | | 2.48 | 2.44 | 2.43 | 2.75 |
| (X) | Mg 2.17 | 1.43 | 0.98 | 0.47 | 1.84 | 0.97 | 0.78 |
| | Fe ²⁺ 1.77 | 2.65 | 2.74 | 3.31 | 2.07 | 3.03 | 3.12 |
| | Mn 0.09 | 4.03 | 0.11 | 3.83 | 0.09 | 4.00 | 0.06 |
| (Y) | Al 0.01 | 0.09 | 0.23 | 0.29 | 0.17 | 0.28 | 0.33 |
| | Fe ³⁺ 0.67 | 0.64 | 0.92 | 0.70 | 0.44 | 0.63 | 0.52 |
| | Ti 0.17 | 0.85 | 0.10 | 1.25 | 0.33 | 0.94 | 1.12 |
| (Z) | Si 5.98 | 6.11 | 6.00 | 6.20 | 6.30 | 6.13 | 6.18 |
| | Al 2.02 | 1.89 | 2.00 | 1.80 | 1.70 | 1.87 | 1.82 |
| | OH 2.60 | 1.81 | 1.92 | 1.17 | 1.72 | 1.77 | 0.88 |
| | F 0.61 | 0.74 | 0.36 | 0.48 | 0.56 | 0.30 | 0.48 |
| | Cl 0.16 | 3.37 | 0.07 | 2.35 | 0.15 | 2.43 | 0.21 |
| | | | | 1.80 | 0.15 | 0.13 | 2.20 |
| | | | | 0.15 | 2.43 | 0.13 | 1.57 |

* The structural type is taken as $W_{2-3}(XV)_n(ZrO)_2(OH, F, Cl)_z$.

- (B-555) Femagastingsite, from hornblende microcline-rich granite gneiss, quarry at crossing of Dead Creek and New York Route 3, Tupper Lake quadrangle. Analyst, Eileen K. Oslund.
- (W-14) Femagastingsite, from hornblende granite, 1.2 miles NNE of Bush's Corners, Lowville quadrangle. Analyst, Lee C. Peck. (From rock whose analysis is given in Geol. Soc. Amer. Mem. 7, Table 37, no. 133, p. 138.)
- (956) Ferrohastingsite, from granoblastic hornblende granite gneiss, a mile S of Palmerville, Blanchard Hill, Russell quadrangle. Analyst, Lee C. Peck.
- (B-189) Ferrohastingsite, from hornblende granite, 0.5 mile N of Cranberry Lake State Park, Cranberry Lake quadrangle. Analyst, Lee C. Peck.
- (D-8) Femagastingsite, from red granoblastic quartz-bearing syenite gneiss (Diana complex), 3.1 miles SSE of Harrisville bridge, 3.6 miles from Harrisville by road, Lake Bonaparte quadrangle. Analyst, Eileen K. Oslund.
- (B-669) Ferrohastingsite, from red granoblastic phacoidal hornblende granite gneiss (Stark complex), 2 miles SE of Degrasse, Russell quadrangle. Analyst, Lee C. Peck.
- (5100) Ferrohastingsite, from green granoblastic phacoidal hornblende granite gneiss (Stark complex), top of Downey Mountain, Santa Clara quadrangle. Analyst, Lee C. Peck.
- Ferroaugite, from feldspathic ultramafic gneiss layer in pyroxene syenite gneiss, 1.25 miles W of Kalurah, Oswegatchie quadrangle. Analyst, Lee C. Peck. Atomic ratio, $Ca_{4.5}Mg_{9.25}Fe_{38.50}$. (Originally published in Hess, 1949, p. 652.)
- Ferroaugite, from pyroxene quartz syenite gneiss, 1.25 miles SW of Harrisville, Lake Bonaparte quadrangle. Analyst, Lee C. Peck. Atomic ratio, $Ca_{4.0}Mg_{9.0}Fe_{38.0}$.

istics of this granite, as well as the field evidence, are consistent with the hypothesis that the more quartzose facies represents a slightly younger differentiate of the same magma that yielded the normal granite.

Microcline-rich granite gneiss occurs as sheetlike masses intimately associated with metasedimentary rocks and amphibolite. The microcline granite gneiss is interpreted as in large part the product of modification, granitization, and migmatitization of metasediments and amphibolite by potash-rich solutions. The hornblendic facies of the microcline granite gneisses are always associated with included layers, schlieren, and disintegrated relics of amphibolite. The hornblende ranges from femaghaastingsite to ferrohastingsite. The variation in composition probably depends in part upon the degree of modification by granitizing solutions of the hornblende derived by incorporation from amphibolite.

OPTICAL AND CHEMICAL DATA

*Optical Properties of Some Adirondack Hornblendes**

Indices of Refraction

The indices of refraction were determined in sodium light by the immersion method, using freshly standardized liquids varying by intervals of 0.002 in the range from 1.660 to 1.700, and by slightly less than 0.005 in the range from 1.700 to 1.725. The temperature at which the measurements were made was closely controlled.

The indices α and γ were determined on cleavage flakes parallel to the {010} parting. The index β was determined on rare grains perpendicular to an optic axis, or on very rare grains perpendicular to Bx_a .

Five separate determinations of α , β , and γ were made for most hornblendes, though the number of determinations ranged from 4 to 11. For hornblende 4, α was determined with exceptional precision; total and partial birefringences were measured by H. H. Hess, using a technique developed for the study of pyroxenes (Hess, 1949); and the values for β and γ were calculated from α and the partial birefringences.

The reported values for indices of refraction are thought to be the best approximations possible at this time. Two factors seriously affect the accuracy of the determinations:

1. Pure hornblende concentrates from a single hand specimen are slightly variable in composition. Because of weak absorption parallel to X, α can usually be determined with greater accuracy than β or γ ; and on a given grain the value of α can be determined in sodium light with an

* To keep within the page limits imposed for this issue of the journal, it was necessary to delete a section on crystal form and cleavage of the hornblendes and to condense the sections on measurement of indices of refraction, $2V$, and extinction angle.

error of 0.001 or less. However, the range in α for several grains in the same mount may be as much as 0.003. A similar range was observed for the values of β and γ . (But see factor 2, just below.)

2. Absorption parallel to Y and Z is so strong that the determinative error in β and γ may be slightly greater than 0.001.

Birefringence

The values for total birefringence reported just below the indices of refraction in Table 2 were determined, as usual, by difference. Because of the range in α and γ , reflecting variable composition, it was feared that these values for total birefringence might be slightly in error. To check this possibility, separate birefringence determinations were made by means of a Berek compensator for all hornblendes except nos. 2 and 3. The results are given at the bottom of Table 2. For hornblendes, except no. 4, described in the preceding section, the measurements were made on ordinary thin sections. The thickness of a quartz grain adjacent to, or only one grain removed from, a suitable hornblende was determined by means of the Berek compensator. The total or partial birefringence of the hornblende was then determined. The measurements for hornblendes 5 and 6 were made on the microscope stage, using X-Z sections of quartz and suitably oriented sections of hornblende. The measurements for hornblendes 1 and 7 were made on a universal stage according to the technique described by Emmons (1943, pp. 172-182).

The agreement between birefringences determined by immersion and by measurement of retardation in ordinary thin sections is generally good. (See table 2.) At least the direct determination of birefringence serves as a check against serious errors in the relative values of the indices of refraction of a given hornblende. For example, γ minus α for hornblende 5 seemed very low relative to the total birefringence of the other hornblendes. However, direct measurements of the partial birefringences of this hornblende confirmed the results of the immersion work.

Optic Axial Angle

The optic axial angle was measured in thin section on the universal stage, using a number of grains normal or nearly normal to Bx_a . This angle is reported in Table 2 as $2V_{meas}$. Under the best of conditions, the precision of measurement on these hornblendes ranges from $\frac{1}{2}^\circ$ to 2° . The range of values reported for $2V_{meas}$ in Table 2 is due in part to slight variation in composition of the hornblende, from grain to grain, and in part to unavoidable errors in measurement. Strong absorption parallel to Y and Z makes proper orientation of sections subnormal to Bx_a ex-

ceedingly difficult on the universal stage, and the resulting determination of $2V$ is therefore suspect. In addition, total reflection from the surface of the grain may occasionally be confused with one extinction position.

Dispersion

The dispersion of the optic axes is inclined. It is always distinct or strong for one optic axis; it is less pronounced for the other, even when apparent dispersion is reported as strong for both axes (e.g., hornblende 1, Table 2). Dispersion was determined qualitatively by examining many optic axis figures for each hornblende. It was not possible to assign the relative intensity of dispersion to optic axes A or B, nor was it possible to measure $2V$ in red light and in blue light. A correct statement of the true optic axial dispersion for hornblende 1, and perhaps for hornblendes 5 and 6, would of course depend on such measurements.

Extinction Angle

The extinction angle $Z \wedge c$ was measured on the microscope stage, using hornblende sections parallel to the optic plane. The values reported in Table 2 are averages of repeated determinations made on a number of suitably oriented grains. Thin sections, rather than immersed fragments, were used. Because of strong absorption parallel to Z , it is difficult to get the correct extinction position of Z , as well as to see the trace of the cleavage whose zone axis is c . Moreover, the cleavage trace observed on sections parallel to the optic plane is moderately to highly irregular. Consequently, the extinction angle measured on a single grain may vary by as much as 9° . A range of 3° to 4° is common. Probably relatively little of this variation is due to compositional variation in the hornblende.

Owing to the difficulty of determining extinction positions and orienting cleavage planes on the universal stage, U-stage measurements of $Z \wedge c$ for hornblende 1 showed a greater range ($\pm 7^\circ$) than microscope-stage measurements made on the same grains cut parallel to the optic plane. U-stage measurements of $Z \wedge c$ in re-oriented random sections of hornblende 1 were even less reliable, showing a range of $\pm 10^\circ$. Measuring $Z \wedge c$ by observing the extinction position of X , and then rotating 90° on the outer vertical axis, may have increased the accuracy of some determinations by $\frac{1}{2}^\circ$ or 1° .

At present, there seems to be no reliable method for accurately determining $Z \wedge c$ on the hastingsites described in this paper. Leonard prefers to measure $Z \wedge c$ on X-Z sections on the microscope stage, if necessary checking the orientation of the same grains on the universal stage and checking to see that c is truly the zone axis for the observed cleavage traces.

Pleochroism and Absorption

The colors reported for X, Y, and Z are those observed in thin sections having an average thickness of 0.020 to 0.025 mm. (These thicknesses were determined by measurements of retardation in suitably oriented quartz grains.) In thin sections 0.030 mm. thick, X is pale but Y and Z for most hornblendes are very dark or almost black, the body color of hornblendes seen in hand specimen. Crushed hornblendes immersed in oil transmit almost no light parallel to Y and Z unless the fragments are smaller than about 200 mesh. For most hornblendes, Y and Z remain very dark, though appreciably colored, for fragments as small as -400, +600 mesh.

The determination of the color of Y is sometimes difficult if the hornblende has strong dispersion. A section a few degrees subnormal to an optic axis will include more emergent red light or more emergent blue, depending on the orientation of the grain. A relatively small tilt will thus produce a substantial change in the observed color of Y, which is actually Y'. The difficulty is obviated, of course, if the sections are truly normal to the optic axis or acute bisectrix.

The absorption indicatrix of the hornblendes coincides with the optical indicatrix. This relation is quite different from that obtaining among certain common clinopyroxenes, especially among members rich in Fe⁺⁺⁺ (Hess, 1949).

General Relations of the Adirondack Hornblendes

All the Adirondack hornblendes in granitic rocks for which data are available show a noteworthy amount of chlorine. There are but few analyses of hornblendes in the literature that give the per cent of chlorine. If this is to be taken to indicate that chlorine is minor in amount, then the Adirondack hornblendes are exceptionally rich in this element. It is possible, however, that chlorine occurs in significant amounts in some hornblendes in which it has not been determined. A ferrohastingsite from the rapakivi granites of Finland, described by Sahama (1947), has 0.51 per cent Cl and 1.06 per cent F. A pargasite from the Tíree marble of the Hebrides, described by Hallimond (1947), has 0.46 per cent Cl and 0.16 per cent F. Hallimond (1947, pp. 237-238) notes that the amphibole approaches hastingsite in composition. A ferrohastingsite described by Krutov (1936) and named by him dashkessanite, has 7.24 per cent Cl. A femaghastingsite from garnetiferous amphibolite of the central Adirondacks, New York, described by Buddington (1952, p. 42, no. 9), has 0.63 per cent Cl and only 0.08 per cent F. A comparison of hornblendes from Adirondack amphibolites (Buddington, 1952, pp. 42 and 53) also shows that the total alkalis are higher in hornblendes having significant

amounts of F or Cl than in those having only a slight amount of the halogens.

Both in the granitic rocks of the Diana-Stark complex and in the younger granitic rocks, the ferrohastingsite hornblendes carry a very slightly higher percentage of total alkalis than the femaghastingsites. Also, in each of the two rock series there is a systematic decrease in the per cent of total OH, F, and Cl as the ratio MgO/FeO decreases.

Hornblendes of similar chemical composition occur both in primary igneous rock and in the gneissic equivalents.

A pargasitic variety of hornblende is found in a thin layer of thoroughly recrystallized amphibolite enclosed in the granite from which hornblende 2 was concentrated. Pargasite from the amphibolite contains 0.91 per cent F and 0.03 per cent Cl (Buddington, 1952, p. 42, no. 1). This contrasts with 1.50 per cent F and 0.37 per cent Cl found in the femaghastingsite (no. 2) of the granite. The femaghastingsite (no. 2) of the granite has a much higher ratio of

$$\frac{\text{FeO} + \text{MnO}}{\text{MgO}} = 1.89$$

than the pargasite of the amphibolite, which has

$$\frac{\text{FeO} + \text{MnO}}{\text{MgO}} = 0.78,$$

as one would expect.

The main purpose of this investigation has been to define the chemical composition and optical properties of hornblendes from granitic rocks of the northwest Adirondacks, and to discuss their petrologic significance. A secondary goal was to correlate these data and the previously published data on similar amphiboles, in order to increase our understanding of the hastingsite group. So far, a reasonably precise correlation has not been achieved, owing mainly to the extreme complexity of the hastingsite group and to the lack of reliable and essentially complete chemical and optical data on its members. The lines of attack recently employed by Foslie (1945) and Sundius (1946) have been especially fruitful, but the need for additional data is great.

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