The object glass used was constructed for the purpose. It consists of a small rectangular metallic cell equipped with two tubes—one for intake and the other for the outlet of circulating water, as shown in Fig. 2. On the lower side of the center of the cell is a glass plate of the thickness of ordinary object glasses. Directly above this is a round cover glass fixed in the upper side of the cell. The circulating water flows between these glass plates. The mount is placed directly on the cover glass and is covered by a quarter-size cover glass. The purpose of the cover glass on the upper side of the cell is to place as little insulation as possible between the circulating water and the mount. The cell is mounted on a mechanical stage but this is not necessary.

A pump serves to circulate the water. The water passes a thermometer, through the cell on the microscope, through the refractometer and by another thermometer. When the thermometer readings check the temperature of the system is assumed to be uniform. The temperature is not raised above 50°C because high temperatures are injurious to the refractometer. A range of 40° is then available and this has been found quite satisfactory. A small reservoir in the system contains a copper coil through which hot or cold tap water circulates—this gives excellent control of temperature.

About one hundred liquids have been examined to obtain the best possible with respect to dispersion and temperature coefficients. More are to be examined before final selection of liquids will be made; we offer none, therefore, at this time. Further modifications of the apparatus are being attempted in order to include the higher refractive indices, thereby overcoming the limitations imposed by the Abbé refractometer.

NOTES ON HORNBLENDE

W. A. P. Graham, *University of Minnesota*

Variations in the Chemical Composition of Hornblende from Different Types of Igneous Rocks

Certain petrographers have assumed[1] that the hornblendes from any given type of igneous rock have approximately uniform composition and have utilized this assumption in estimating the chemical composition of rocks. With a view of investigating the

[1] Iddings, I. P.; Rock Minerals, pp. 350–354 (**1911**).

truth of this hypothesis a study of seventy-five or more analyses of hornblende[2] from different rocks, occurring the world over, was made. It was found that the composition of hornblende in any family of rocks varied widely. The assumption that they are uniform is not warranted. In some analyses the elements which are usually present in only small amounts in the hornblende are found to vary even more than some of the main constituents; for example, MnO is reported to be 16% in one analysis of hornblende while it is absent in others.

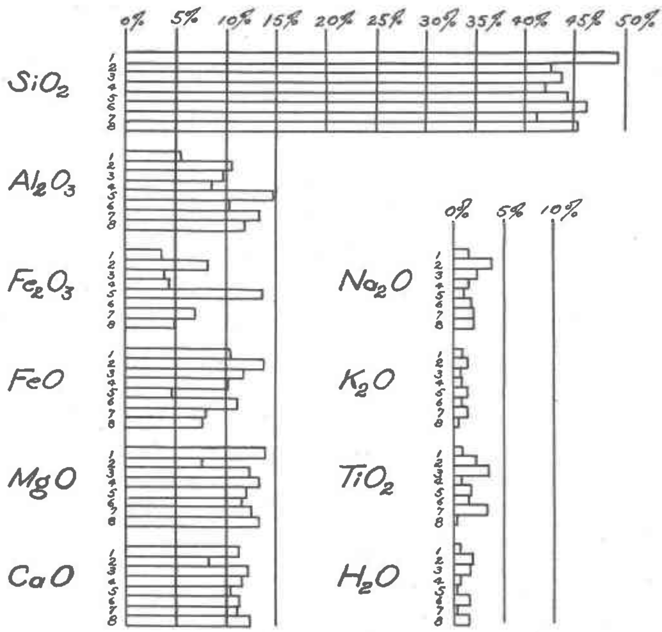

FIG. 1. Average of Each Constituent in the Hornblendes of the Several Rock Families.

1. Granite
2. Syenite
3. Monzonite
4. Granodiorite
5. Andesite
6. Diorite
7. Basalt
8. Gabbro

[2] Doelter; Handbuch der Mineralchemie, Band II, pp. 610–628 (**1914**). Osann, A.; Beiträge zur chemischen Petrographie, Teil 2, pp. 247–250 (**1905**). Clarke, F. W.; *U.S.G.S., Bull.* **168,** p. 131. Penfield, S. L.; *Am. Jour. Sci.,* (4) **XXIII,** p. 23 (1907). Stanley, F. C.; *Am. Jour. Sci.,* (4) **XXIII,** p. 23 (1907).

The analyses of hornblende that occur in the several rock families were grouped together and averaged. Following are the number of hornblende analyses used in determining the averages of each rock type; granite 6, syenite 10, monzonite 5, granodiorite 4, andesite 5, diorite 8, basalt 5, gabbro 10. (See Fig. 1.) It seems clear that the optical properties such as those discussed by Winchell[3] are more accurate indications of the composition of the hornblendes than the type of rock in which they are found.

Relation of Brown to Green Hornblende

A study of the optical properties of the amphiboles has been made by Winchell.[4] He states that it has not been found possible to include in his work the so-called basaltic hornblendes; that is, those characterized by small extinction angles, high relief, brown color, and strong birefringence; due to lack of chemical data on the factors producing these properties. He suggests that the differences between the brown and green hornblendes are due to titanium, occurring as TiO_2 and Ti_2O_3.

Schneider[5] states that there is nearly 5% titanium oxide in the balsatic hornblendes but this is not borne out in the present study.

Weinschenk[6] says that the basaltic varieties of hornblende owe their brown color to the presence of ferric oxide and that they contain up to 5% titanium. He also notes that all green amphiboles assume a brown color when heated in air and those rich in iron, after heating, have the optical properties of basaltic hornblende.

A. Belovsky[7] heated green hornblende for an hour over a bunsen flame and found that he was able to change the color from green to brown and lower the extinction angle. He attributes this change to the oxidation of the iron.

Allen and Clement[8] suggest that the loss of water by amphiboles on heating without notably affecting the optical properties indicates that the water is present as a solid solution although the mineral holds the water with great tenacity.

[3] Winchell, A. N. Studies in the Amphibole Group, *Am. Jour. Sci.*, **7**, 5th Series, pp. 287–310, April, **1924**.

[4] Winchell, A. N., *op. cit.*

[5] Schneider; *Z. Kryst.*, **XVIII**, 580 (1890).

[6] Weinschenk, Ernst; Petrographic Methods, pp. 291–292 (**1912**).

[7] Belovsky, A.; *Neues Jahrb. Min.*, **1**, p. 291 (1891).

[8] Allen, E. T. and Clement, J. K.; Rôle of Water in Tremolite. *Am. Jour. Sci.*, **26**, p. 118 (1908).

J. deLapparent[9] suggests that the optical differences developed in the change from green to brown hornblende are due to the loss of water which is present as a solid solution in the green variety.

Average of the Main Constituents in Green and Brown Hornblende from Analyses Studied

	Brown	Green		Brown	Green
SiO_2	39.42%	46.42%	CaO	10.25%	10.56%
Al_2O_3	15.43	7.57	MgO	11.90	11.46
Fe_2O_3	7.07	4.20	Alkalies	1.91	1.32
FeO	8.21	11.91	TiO_2	2.52	0.90
			H_2O	0.46	1.58

Many of the published analyses of hornblende do not report the water content, but it is quite evident that the brown basaltic varieties have less water than the green ones. The average combined water in six good analyses[10] of the brown variety is 0.46%, while that in 19 analyses of the green variety is 1.58%.

A study of the occurrences of hornblende show that the brown hornblendes are usually found in the fine grained surficial igneous rocks such as basalts, dacites, andesites, etc., as Clarke has noted,[11] while the green varieties usually occur in the granitoid igneous rocks. It is not improbable that some hornblende may be brown because of other constituents, such as alumina, ferric oxide, or titanium.

This occurrence of most brown hornblendes in surface rocks which could have been dehydrated, in connection with the contrast in water shown in the analyses, suggests that deLapparent may have been correct in attributing the change from green to brown hornblende to the loss of water.[12] The difference in the state of oxidation of iron seems relatively unimportant and the titanium content is rarely as large as suggested by Schneider.[13]

Experiments were undertaken in elaboration of the suggestions of Belovsky and deLapparent. Large crystals of green hornblende were crushed to pass through a 100-mesh screen. Some of the impurities were picked out during the preparation. A small portion of each hornblende was weighed into a platinum crucible

[9] deLapparent, J.; Leçons de Petrography, pp. 50–53 (1923).

[10] Two old analyses of poor quality were discarded. Their water content was high and if included would raise the average combined water to 0.89%.

[11] Clarke, F. W., Data of Geochemistry, *U.S.G.S. Bull.* **770,** p. 389 (1924).

[12] deLapparent, J., *op. cit.*

[13] Schneider, *op. cit.*

and weighed again after heating to about 800°C to determine the amount of water lost. A CO_2 blanket was kept over the hornblende during the heating to prevent oxidation by air.[14] The heated samples were examined in oils for any changes in optical properties. Figure 2 shows the results obtained from two samples with heats of different durations.

It is clear that a brown color is developed in green hornblende through the loss of water as was indicated by the analyses studied. There is a progressive decrease in the water content produced by heating and this seems to be complete after ten minutes heating. This change is accompanied by a lowering of the extinction angle, increasing birefringence, increasing index of refraction, and the brown color, which are all characteristics of basaltic hornblende. (See figure 2.) These experiments strongly suggest that the water is the controlling constituent.

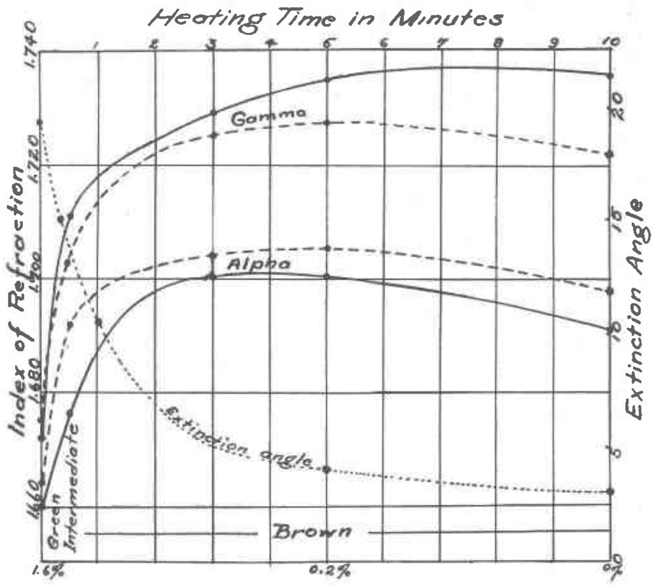

Fig. 2. Optical Changes Produced by Heating Common Green Hornblende. Approximate Water Content
——— Index of Refraction Sample No. 1
- - - - - Index of Refraction Sample No. 2
. . . . . . Approximate Extinction Angle

[14] It is possible there may have been oxidation by water driven from the hornblende during heating, but this is a reaction of the original parts of the mineral and not an oxidation from atmospheric oxidation.

An x-ray picture was taken of one sample of hornblende before and after ten minutes heating. The diffraction angles of the heated sample are slightly greater than in the unheated one. This indicates that in the heated hornblende the planes of atomic structure are a trifle closer together and the mineral is slightly denser.

Finally, seven different samples of hornblende were tested by ten minutes heating and, while the results are not entirely regular, the hornblendes which had relatively high indices in their original green condition gave generally high indices and birefringence in their dehydrated modifications. (See figure 3.)

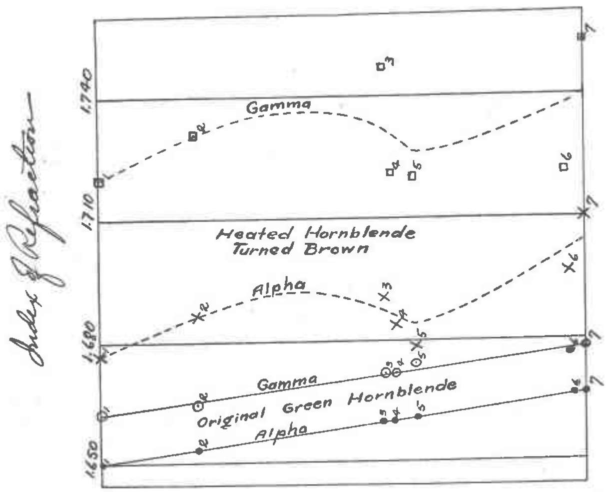

FIG. 3. Comparison of Indices of Common Hornblende before and After 10 Minutes Heating.

Spot = Alpha of Green Hornblende
Circle = Gamma of Green Hornblende
Cross = Alpha of Heated Hornblende, Brown
Square = Gamma of Heated Hornblende, Brown

The different indices of the original Green Hornblende are due to different chemical proportions of constituents.