

Article XXXIV.—GLAUCOPHANE FROM EASTERN PENNSYLVANIA.

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In the Reading-Durham Hills of Pennsylvania there are numerous occurrences of a fibrous, blue amphibole which appears to possess the characteristics of glaucophane, a mineral which, while not in itself uncommon, has not hitherto been reported from the eastern United States. In 1897 a blue amphibole from the granite of Quincy, Massachusetts, was described by T. G. White² as glaucophane, but this mineral was later referred to an essentially riebeckite molecule, having the composition Rb_2Gl_2 .³ This is the only mention which I have been able to find of glaucophane from the rocks of the Eastern States.

Elsewhere in the United States glaucophane-schists have been described from the following localities:— in California from Sulphur Bank, Lake County,⁴ Mt. Diablo (Pine Cañon),⁵ Sta. Catalina Island,⁶ Oak Hill, San Jose,⁷ Angel Island,⁸ Berkeley,⁹ North Berkeley,¹⁰ San Francisco Peninsula,¹¹ Healdsburg and Camp Meeker,¹² Melitta near Sta. Rosa, and Pine Flat, Sonoma County,¹³ Tiburon Peninsula, Marin County,¹⁴ San Pablo, Belmont School, Belmont, Redwood, San Mateo County,¹⁵ Calaveras Valley, Alameda County, San Luis Obispo;¹⁶ and in Oregon from Tupper Rock near Bandon, Coos Bay, Four Mile Creek, Coos County, and Roseburg.¹⁷ It has also been reported from Alaska from the Hubbard Glacier, Yakutat Bay.¹⁸ Most of

¹ Geologic Aid, United States Geological Survey. (By permission of the Director of the U. S. Geological Survey.)

² T. G. White. Bost. Soc. Nat. Hist., XXVIII, 128, 1897.

³ H. S. Washington. Am. Jour. of Sci., ser. 4, VI, 180, 1898.

⁴ G. F. Becker. Mon. U. S. Geol. Surv., XIII, 76, 1888.

⁵ Melville. Bull. Geol. Soc. Am., 2, 413, 1890.

⁶ W. S. T. Smith. Proc. Cal. Acad. Sci. (3), Geol., I, 1, 1897.

⁷ E. P. Carey & W. J. Miller. Jour. of Geol., XV, No. 2, 166, 1907.

⁸ F. L. Ransome. Bull. Dept. Geol. Un. of Cal., I, 211, 1894.

⁹ Thelen. *Ibid.*, IV, 221, 1905.

¹⁰ Palache. *Ibid.*, I, 181, 1894.

H. S. Washington. Am. Jour. Sci., Ser. 4, XI, 51, 1901.

¹¹ Crandall. Proc. Am. Phil. Soc., XLVI, No. 185, 3-58, 1907.

J. P. Smith. *Ibid.*, v. 45, 183-242, 1906

¹² E. H. Nutter & W. B. Barber. Jour. of Geol., X, 738, 1902.

¹³ Murgoci. Bull. Dept. Geol. Un. of Cal., IV, 389, 1906.

¹⁴ E. H. Nutter & W. B. Barber, *loc. cit.*

¹⁵ Murgoci. *loc. cit.*

¹⁶ E. H. Nutter & W. B. Barber, *loc. cit.*

¹⁷ Diller. 17th Ann. Rept. U. S. Geol. Surv., Pt. 1, 454, 1896.

¹⁸ Harriman Alaska Expedition, IV, 231, 1904.

the material which I have studied in order to make the following report was collected during the course of field work in the eastern portion of Berks County, Pennsylvania. For two specimens, collected from Limeport in

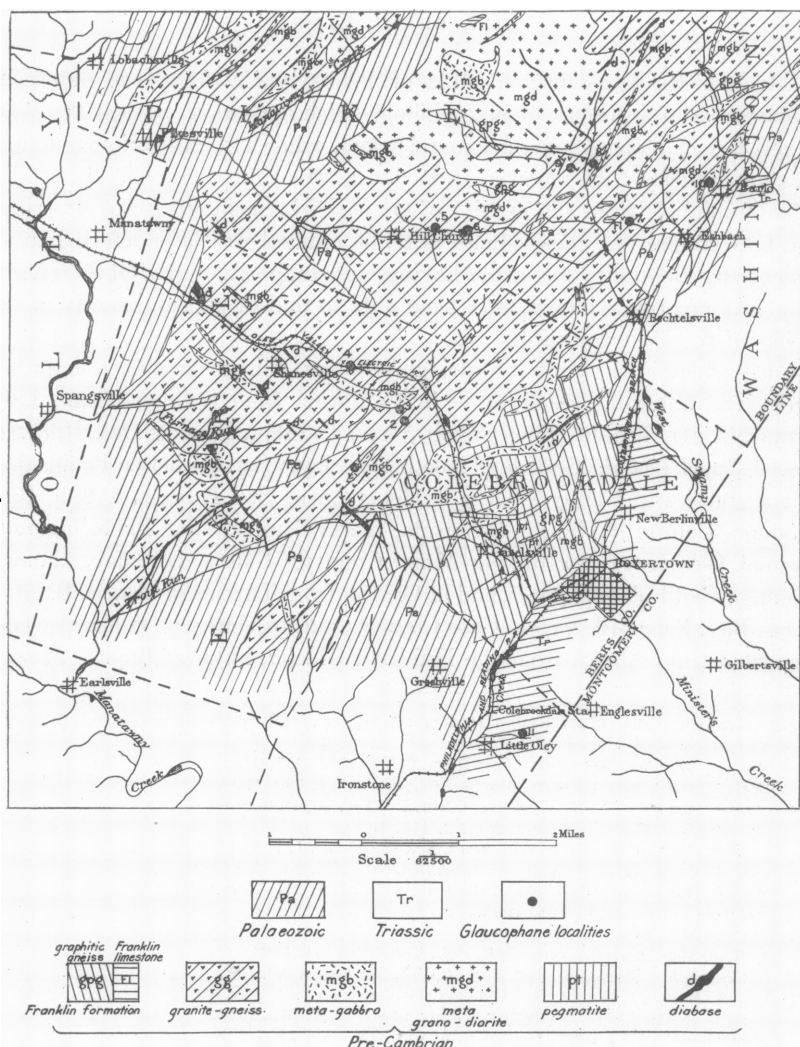


Fig. 1. PRE-CAMBRIAN AREAL GEOLOGY of BOYERTOWN REGION

Lehigh County, and from near Quakertown in Bucks County, I am indebted to the courtesy of Dr. Edgar T. Wherry of Lehigh University. I am also

indebted to Dr. Austin F. Rogers of Leland Stanford Jr. University, California, for several specimens of glaucophane- and crocidolite-schists which he has very kindly furnished me for comparative study. I owe to the kindness of Miss F. Bascom of the United States Geological Survey six out of the eighteen slides studied and I wish to make special acknowledgment to her and to Dr. E. O. Hovey of the American Museum of Natural History, New York, for their kindly advice and assistance in the preparation of this paper.

Occurrence: — The Reading-Durham Hills, a continuation of the Blue Ridge-South Mountain Range are a part of the Appalachian Mountain system which forms the western division of the Piedmont Plateau. They extend from Reading, Berks County, Pennsylvania in a northeast direction through Bucks and Lehigh Counties as far as Easton, Pennsylvania, where they merge into the Highlands of New Jersey. The rocks of this region comprise a series of pre-Cambrian ortho-gneisses, which vary in composition from a granite through an intermediate dioritic type to a gabbro. Associated with the rocks of igneous origin is a pre-Cambrian sedimentary gneiss which in many localities carries graphite. The older gneisses are cut by a series of parallel diabase dykes which are presumably pre-Cambrian in age; they are flanked by a succession of steeply folded, altered, Palæozoic sediments comprising a quartzite of Cambrian age, a Cambro-Ordovician limestone series, and an Ordovician schist. On the southeastern border of the hills the Palæozoic rocks disappear under a cover of gently dipping Triassic shales and sandstones. The blue amphibole discussed in this paper has so far been discovered in the following localities in Berks County, Pennsylvania: — (Fig. 1.)

- | | | |
|----------------|-----|---|
| Locality | 1. | $1\frac{1}{2}$ miles southeast of Shanesville. |
| " | 2. | $1\frac{3}{4}$ miles northwest of Gabelsville. |
| " | 3. | $1\frac{3}{4}$ miles northwest of Gabelsville. |
| " | 4. | $\frac{3}{4}$ mile east of Shanesville, in a cutting of the Oley Valley |
| Electric R. R. | | |
| Locality | 5. | $\frac{1}{4}$ mile northeast of Hill Church. |
| " | 6. | $\frac{3}{4}$ mile northeast of Hill Church. |
| " | 7. | 1 mile north of Bechtelsville. |
| " | 8. | $1\frac{3}{4}$ miles north of Bechtelsville, in Gilbert's iron ore pit. |
| " | 9. | $\frac{1}{4}$ mile west of Gilbert's ore pit. |
| " | 10. | Iron ore pit south of Barto. |
| " | 11. | $\frac{1}{4}$ mile northeast of Little Oley. |

The occurrence of the blue mineral does not seem to be restricted to any one lithologic formation or horizon since it has been found in igneous rocks having the composition of a granite, a quartz-porphyry, and of a gabbro,

in a Triassic sandstone, and in one case as a coating upon the surface of quartz crystals.

A curious feature of the development of the blue amphibole is the fact that it commonly occurs, not only disseminated throughout the rock as one of the chief constituents, but also as a thick coating upon the weathered surface, thereby giving the appearance of a product of weathering caused by the leaching out from the original rock of certain chemical constituents, which have been reacted upon by other substances brought in by percolating waters. The chemical compound formed in this way is then deposited from solution upon weathered surfaces of the rock. The coating, which varies in color from a deep blue or almost black to an ultramarine blue, sometimes attains a thickness of 5 mm. It can readily be removed by scraping with a knife and crushes to an earthy powder. The lustre is normally dull; a silky lustre which is occasionally seen is caused by the presence of minute prismatic flakes of hornblende. In a rich occurrence, discovered in a cutting of the Oley Valley Electric Railway about $3\frac{1}{2}$ miles northwest of Boyertown (Locality 4) the country rock which is a granite, has been thoroughly shattered and faulted, with the development of quartz veins along the lines of fracture. The blue mineral is formed over the surface of the quartz crystals to such a degree that in places fragments of practically pure amphibole two to three centimetres in length can be dug out. Such an occurrence recalls Heddle's description of the earthy blue abriachanite from Scotland.¹ A similar development occurs in two road cuttings about one quarter and three quarters of a mile respectively, northeast of Hill Church (Localities 5 and 6) where for a distance of a quarter of a mile, the mineral forms not only a coating upon the granite and intrusive gabbro, but is also the dominant constituent of a schistose rock which weathers readily, strewing the roadsides with thin fragments, conspicuous on account of their deep blue color. In addition to its occurrence as a coating upon the weathered surface, the amphibole occurs abundantly scattered throughout the mass of the rock, in small dark blue individuals of irregular outline. These grains, which do not exceed .2 mm. in diameter, have a dull lustre, a hardness of from 5 to 6, and show neither crystal outline nor cleavage faces. In some instances they are associated with flashing, prismatic crystals of an almost black hornblende, while in other cases the original hornblende seems to be entirely replaced by the blue amphibole.

Optical Properties: — The exact determination of the mineral species in thin section is rendered difficult by the intensity of the pleochroism which obscures the angle of extinction and which makes it hard to establish the

¹ Heddle. *Min. Mag.*, III, pp. 61, 193, 1879.

optical orientation. In some cases the thin section shows merely a confused aggregate of a blue pleochroic mineral in which it is impossible to make out crystal outline or cleavage and in which the depth of coloration makes the mineral appear almost isotropic between crossed nicols. In other slides the blue mineral forms a mass of frayed and twisted fibres surrounded by minute prismatic needles .02 mm. to .1 mm. in length, which are scattered at random throughout the section or else concentrated in a felty intergrowth along the edges of cracks in the amphibole or in the feldspar. (Fig. 2.)

Wherever the original hornblende is visible, the amphibolic characteristics and secondary nature of the blue mineral are clearly shown by its development as a terminal growth or as a fringe upon the prismatic edges and along the cleavage cracks of the green amphibole. Fig. 3 represents a crystal of actinolite, surrounded by a fringe and flame-like terminations of blue amphibole, which shows by its prismatic cleavage an orientation similar to that of the original amphibole. The difference between the original and secondary mineral is very noticeable along a direction parallel to the *c* axis, for in that direction

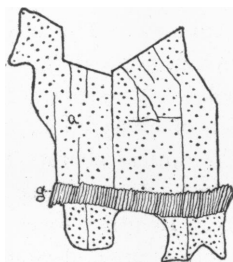
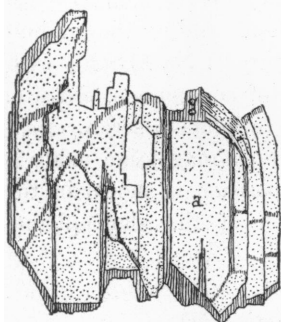
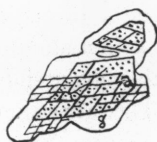


Fig. 2. Hornblende crystal, *a*, with glaucophane, *g*, filling cracks. $\times 50$.



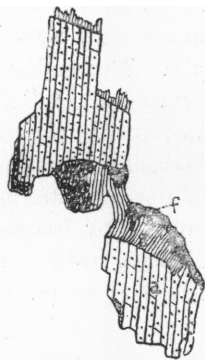
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Fig. 3. Actinolite, *a*, surrounded by a fringe of glaucophane, *g*. $\times 50$.



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Fig. 4. Basal section of hornblende, *a*, with halo of glaucophane, *g*. $\times 50$.



5

Fig. 5. Hornblende, *a*, with terminal growth of glaucophane, *g*. *f* = iron oxide. $\times 50$.

the pleochroism of the actinolite is green while that of the glaucophane is deep blue. In a direction at right angles to *c* both minerals show a pale yellow color. Fig. 4 represents a basal section of hornblende with the blue amphibole forming an addition to the prismatic faces. Fig. 5 shows the terminal growth of blue mineral associated with patches of dark brown

iron oxide stain which have been developed in connection with the hornblende alteration.

The average length of the original mineral is about .7 mm. along the direction of the prismatic elongation. Both the original and secondary minerals show the prismatic angle of 124° which is characteristic of an amphibole. The pleochroism of the original amphibole, which is distinct though not strong, is in some cases Z =light yellowish green or brownish yellow, Y =straw yellow, X =colorless to pale yellow. The minimum axis of elasticity Z , makes an angle with crystallographic c of 11° to 18° . The optical character is negative, and the axial dispersion which is weak shows $\rho < v$. These properties indicate the variety of amphibole as actinolite. In other cases the original mineral shows the pleochroism and extinction angle of common hornblende.

The secondary blue growth possesses a strong pleochroism showing the axial colors, Z =grayish blue or greenish blue to violet, Y =pale green, and X =colorless to pale yellow. The axis of elasticity which lies nearest the vertical axis is Z , making an angle with c which is extremely variable, ranging from 3° to 15° . The axial plane is parallel to 010. The index of refraction is about the same as that of the original mineral, and the double refraction is slightly weaker. The acute bisectrix is X , and the dispersion is weak $\rho < v$. The axial angle is large.

Chemical Composition:—The theoretical composition of glaucophane is represented, according to Dana, by the formula $\text{Na}_2\text{Al}_2\text{Si}_4\text{O}_{12}$, $(\text{FeMg})\text{SiO}_3$. This molecule is susceptible of many variations, and by the gradual replacement of Fe''' for Al in an isomorphous mixture of $\text{Na}_2\text{Al}_2\text{Si}_4\text{O}_{12}$ with $\text{Na}_2\text{Fe}_2\text{Si}_4\text{O}_{12}$ glaucophane passes through a series of compounds, crossite, rhodusite (abriachanite), to a non-aluminous iron amphibole series, crocidolite-riebeckite, in which the magnesium of the ferro-magnesian oxide is replaced by ferrous iron. This variation in composition is shown in the following table which represents the constitution of the glaucophane-riebeckite series.

Table I.

Al	Glaucophane	$\text{Na}_2\text{O}, \text{FeO}, 2(\text{MgCa})\text{O}, (\text{AlFe}''')_2\text{O}_3, 7\text{SiO}_2.$
	Uniaxial Glaucophane	$\text{Na}_2\text{O}, \text{FeO}, 2(\text{MgCa})\text{O}, (\text{AlFe}''')_2\text{O}_3, 7\text{SiO}_2.$
Fe''		where $\text{Al} : \text{Fe} = 3 : 1$ $\text{Mg} : \text{Ca} = 6 : 1$
	Crossite	$\text{Na}_2\text{O}, \text{FeO}, (\text{MgCa})\text{O}, (\text{AlFe}''')_2\text{O}_3, 18\text{SiO}_2.$
		where $\text{Al} : \text{Fe} = 3 : 4$ $\text{Mg} : \text{Ca} = 6 : 1$
Mg	Rhodusite (Abriachanite)	$\text{Na}_2\text{O}, \text{FeO}, 2\text{MgO}, \text{Fe}_2\text{O}_3, 7\text{SiO}_2.$
	Crocidolite	$\text{Na}_2\text{O}, 3(\text{FeMg})\text{O}, \text{Fe}_2\text{O}_3, 5\text{SiO}_2.$
		where $\text{Fe}'' : \text{Mg} = 4 : 1.$
Fe''	Riebeckite	$\text{Na}_2\text{O}, \text{FeO}, \text{Fe}_2\text{O}_3, 5\text{SiO}_2.$

Table II.

	I	II	III	IV	V	VI
SiO ₂	56.49	57.81	54.52	52.39	55.02	59.41
Al ₂ O ₃	12.23	12.03	9.25	11.29	4.75	0.22
Fe ₂ O ₃	....	2.17	4.44	3.74	10.91	9.47
FeO	10.91	5.78	9.81	9.13	9.46	5.92
MgO	7.97	13.07	10.33	11.37	9.30	17.40
CaO	2.25	2.20	1.98	3.03	2.38	0.33
Na ₂ O	9.28	7.33	7.56	6.14	7.62	3.67
K ₂ O	....	....	0.16	....	0.27	0.14
H ₂ O	....	....	1.78	2.57	....	4.14
TiO ₂	....	....	0.39	0.14	....	....
P ₂ O ₅	....	....	....	....	....	....
MnO	0.50	....	0.46	....	....	....
	99.63	100.39	100.68	99.80	99.71	100.70
	VII	VIII	IX	X	XI	XII
SiO ₂	52.40	51.89	52.13	49.83	49.65	50.01
Al ₂ O ₃	....	....	....	....	1.34	....
Fe ₂ O ₃	9.34	19.22	15.93	14.87	17.66	28.30
FeO	15.17	17.53	21.25	18.86	19.55	9.87
MgO	10.50	2.43	0.22	0.41	....	0.34
CaO	1.17	0.40	....	....	3.16	1.32
Na ₂ O	7.11	7.71	6.26	8.33	1.61	8.79
K ₂ O	0.61	0.15	....	1.44	....	0.72
H ₂ O	2.97	2.36	3.95	0.20	1.67	....
S	1.00	....	.... TiO ₂	1.43	....	....
ZrO ₂	....	....	....	0.75	....	....
MnO	0.40	....	....	1.75	....	0.63
	100.67	101.69	99.74	97.87	100.64	99.98

- I. Glaucothane from Syra. Analyst:— Schnederman. Jour. pr. Chem., XXXIV, 240, 1845.
- II. Glaucothane from Zermatt. Analyst:— Bodewig. Ann. der Phys. und Chem. Pogg., CLVIII, 224, 1876.
- III. Glaucothane from San Pablo, California. Analyst:— Blasdale. Bull. Dept. Geol. Un. of Cal., II, No. 11, p. 338, 1901.
- IV. Uniaxial glaucothane from San Pablo. Analyst:— Blasdale, *loc. cit.*
- V. Crossite, from North Berkeley, California. Analyst W. S. T. Smith. Bull. Dept. Geol. Un. of Cal., I, p. 188, 1894.
- VI. Rhodusite from Island of Rhodes. Analyst:— Foullon. Sitzungsberichte Akad. Wien, C, 172, 1891.
- VII. Abriachanite from Scotland. Analysts— Jolly and Cameron. Quart. Jour. Geol. Soc., XXXVI, 109, 1880.

- VIII. Crocidolite from Orange River, Africa. Analysts:—Renard and Klement. Bull. Ac. Belg., VIII, 530, 1884.
- IX. Crocidolite from Rhode Island. Analysts:—Chestner and Cairns, Am. Jour. of Sci., XXXIV, 108, 1887.
- X. Riebeckite from Colorado. Analyst:—Koenig. Zeitschrift für Krystallographie, I, 430, 1877.
- XI. Riebeckite from Quincy, Mass. Analyst:—Gregory. Am. Jour. of Sci., VI, 180, 1889.
- XII. Riebeckite from Sokotra. Analyst:—Sauer. Zeit. deut. geol. gesell., v. 40, 139, 1888.

Gastaldite:—Strüver¹ has described from Piedmont, Italy, a variety of blue amphibole which he calls gastaldite in honor of Professor Gastaldi. The optical properties of gastaldite are almost the same as those of glaucophane except for the fact that the extinction angle in gastaldite is smaller; $Z \wedge c = 0^\circ$ to 6° for gastaldite while Z makes an angle with c in glaucophane that runs as high as 16° . The difference lies in the chemical constitution, since two parts of alumina with one part of lime-magnesia enter into the formula of gastaldite while the glaucophane molecule contains one part of alumina to two parts of lime-magnesia. The following formulas show this difference in constitution.

Table III.

Gastaldite	$\text{Na}_2\text{O}, \text{FeO}, (\text{MgCa})\text{O}, 2(\text{AlFe}''')_2\text{O}_3, 9\text{SiO}_2$ where $\text{Mg}:\text{Ca}=5:2$
Glaucophane	$\text{Na}_2\text{O}, \text{FeO}, 2(\text{MgCa})\text{O}, (\text{AlFe}''')_2\text{O}_3, 7\text{SiO}_2$ where $\text{Mg}:\text{Ca}=6:1$

Columns I, II and III of Table IV show the chemical composition of gastaldite as compared with that of normal glaucophane and from these figures it is apparent that gastaldite represents the aluminous end of the glaucophane series.

Table IV.

	I	II	III
SiO_2	58.55	56.71	57.81
Al_2O_3	21.40	15.14	12.03
Fe_2O_3	....	9.78	2.17
FeO	9.04	4.31	5.78
MgO	3.92	4.33	13.07
CaO	2.07	4.80	2.20
Na_2O	4.77	4.83	7.33
K_2O}	....	0.25	....
	99.75	100.15	100.39

¹ Strüver. Mem. Acc. Lincei, II, 333, 1875.

- I Gastaldite from Aosta; analyzed by Cossa. *Mem. Acc. Linc.*, II, 33, 1875.
- II Gastaldite from Shikoku; analyzed by Yoshida. *Jour. Coll. Sci. Tokyo*, I, 85, 1886.
- III Glaucophane from Zermatt; analyzed by Bodewig. *Ann. der Physik und Chemie Pogg.*, CLVII, 224, 1876.

Two analyses have been made of the blue amphibole from Pennsylvania. A specimen from the Oley Valley Electric Railway about $\frac{3}{4}$ mile east of Shanesville (Locality 4) was analyzed by Dr. Edwin DeBarr, University of Oklahoma, Norman, Oklahoma, with the results shown in column I, Table V. A glance at this analysis shows that the Shanesville amphibole corresponds to the constitution of a gastaldite rather than to that of glaucophane. The amount of alumina which enters into the composition of the mineral is in excess of the amount of lime-magnesia. The ratio of magnesia to lime in the Shanesville analysis corresponds to the ratio of magnesia to lime in gastaldite. The mineral from the Oley Valley Railway may be described as a lime-free gastaldite, low in magnesia and deficient in alkalies, in which the Al:Fe=2:1. In this connection it is interesting to compare the lime-free gastaldite analyzed by A. Johnsen¹ from Miask. (See column II, Table V.) Column III shows the results of recalculating the analysis shown in column I to the composition of a gastaldite molecule whose theoretical composition is shown in column IV.

Table V.

	I	II	III	IV
SiO ₂	83.30	58.50	60.83	60.06
Al ₂ O ₃	6.00	12.38	16.90	9.84
Fe ₂ O ₃	5.10	14.32	9.46	8.46
FeO	2.90	4.79	8.17	8.01
MgO	1.20	4.30	3.38	3.68
CaO	trace	0.92	....	3.05
Na ₂ O	.30	4.09	0.84	6.90
K ₂ O	.15	0.48	0.42	....
MnO	....	3.16	....	....
	98.95	102.94	100.00	100.00

An analysis of a specimen from Hill Church, Pennsylvania, made by Mr. A. S. McCreath² is given in column I, Table VI. It shows, as compared with the Shanesville analysis an increase in the proportion of lime-magnesia to alumina. A recalculation of this analysis (see column II, Table VI), shows a correspondence to glaucophane whose theoretical composition is

¹ A. Johnsen. *Neues Jahrbuch*, II, p. 121, 1901.

² Rept. of Second Geol. Surv. of Pa., D3, II, 94, 1883.

given in column III, Table VI. The Hill Church mineral may be described as a glaucophane which is rich in iron and magnesia, low in lime and deficient in alkalis.

Table VI.

	I	II	III
SiO ₂	51.70	61.55	50.03
Al ₂ O ₃	17.54	14.94	10.54
Fe ₂ O ₃	....	....	9.05
FeO	9.22	10.55	8.58
MgO	8.76	8.62	7.89
CaO	5.06	4.34	6.53
Na ₂ O	....	....	7.38
K ₂ O	....	....	....
MnO	....	....	....
	92.28	100.00	100.00

A striking feature in both of the Pennsylvania analyses is a deficiency in the soda content which is unusual for any member of the soda-aluminous series. In this connection it is interesting to note the observations of Murgoci¹ on the relation between the Al: Fe ratio and the optical properties of the glaucamphibole series. He emphasizes the fact that the intensity of color and pleochroism, size of extinction angle, axial angle, amount of birefringence, etc., are functions, not of the soda content, but of the ratio Al: Fe. The fact that the small percentage of soda in the Pennsylvania amphiboles is not accompanied by a decrease in the intensity of color, size of extinction angle or axial angle, is in accord with the conclusions of Murgoci.

A deficiency in soda content, such as noted in the Pennsylvania minerals, is however what would be expected from a consideration of the magmatic composition of the igneous rocks of the eastern belt of the Piedmont Plateau. The igneous types of the region are alkali-calcic, dolcalcic, and percalcic, but never peralkalic or domalkalic. In other words the ratio of lime to alkalis, in the composition of the eastern Piedmont rocks, is always greater than the ratio of alkalis to lime.

A mineral having the composition of the Pennsylvania glaucophane might result from the replacement of the lime in an actinolite or hornblende molecule, by an infiltration of iron from a country rock which is rich in iron. That the region of the Boyertown quadrangle is rich in iron is evidenced by the frequent occurrence of iron ore deposits. The manner of occurrence of the glaucamphiboles of this region together with their secondary nature as observed under the microscope would at least suggest the possibility that in some cases glaucophane may be derived from hornblende by a process of weathering.

¹ Murgoci. Bull. Dept. Geol. Un. of Cal., IV, 371, 1906.