ASSOCIATION OF HARMOTOME AND BARIUM FELDSPAR AT GLEN RIDDLE, PENNSYLVANIA

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ABSTRACT

Small crystals of harmotome with a cruciform penetration twinning habit were found on the joint surfaces of a dike of anorthositic gabbro flanked by serpentine at Glen Riddle, Delaware County, Pennsylvania.

The dike is composed of two distinct rock types. (1) A hard gabbroic border phase consisting chiefly of sodic labradorite and 25 per cent biotite. (2) A crumbly central portion consisting chiefly of sodic oligoclase and 10 per cent biotite. Irregularly spaced crush zones parallel to the vertical foliation in the border rock contain corundum, hyalophane (Cn_{15}) and andesine (An_{40}). Similar zones occurring chiefly along the margins of the central portion contain hyalophane (Cn_{10}) and oligoclase (An_{15-20}).

The feldspars in the border rock show strain effects, and the crush zones contained therein show evidence of hydrothermal reaction and replacement such as hyalophane-plagioclase antiperthites. Similar zones in the central portion show little evidence of strain and contain patchy aggregates of hyalophane and albite-oligoclase. The most alkaline zones in the central portion reveal no evidence of strain. In these zones, sparsely distributed grains of hyalophane with indented and frayed borders are surrounded by albite-oligoclase.

The contemporaneous deposition of the hyalophane and corundum and the later deposition of the harmotome is considered to be the result of (1) deformation of a three foot wide dike of anorthositic gabbro, emplaced in pyroxenite, by forces accompanying the intrusion of a hornblende granite close by, and (2) infiltration of hydrothermal solutions (or superheated vapors) rich in potash, barium and soda, which emanated from the granite at an advanced stage of cooling, and which initiated a series of reactions along favorable channels within the dike rock, resulting in the deposition of the mineral suites described.

The hyalophane-andesine antiperthites with corundum are considered to have been formed at relatively high temperatures; the hyalophane-albite-oligoclase patch perthites without corundum, at lower temperatures; and the association of albite-oligoclase with indented grains of hyalophane, as representing partial resorption of previously formed hyalophane by late soda-rich solutions which deposited the resorbed potash and barium as harmotome in the joints and fissures of the dike rock.

The value of 2V for harmotome of 79°50′ (described in Section 2) is at variance with figures given in standard texts, and suggests possible oversight on the part of workers to note the effect of ordinary heat of grinding on the optical properties of the mineral.

INTRODUCTION

The barium zeolite harmotome has been reported from so few American localities[1] that its occurrence in a gabbroic dike at Glen Riddle, Pa.,

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[1] Manhattan Island, and near Port Arthur, Lake Superior: Ford, W. E., *Dana's Textbook of Mineralogy*, 2d ed., 551 (**1922**). Sing Sing, N. Y.: Specimen in the collection of Mr. Hugo Bilgrim, Philadelphia, Pa. Thunder Bay, Canada: Doelter, C., *Handbuch der Mineral Chemie*, Band **II**, 404 (1919).

in close association with barium feldspar and corundum has been considered of sufficient importance to merit a detailed description. The dike is exposed in a railroad cut along the Octoraro Branch of the Pennsylvania Railroad, just west of the Glen Riddle station, about 17 miles southwest of Philadelphia. The harmotome crystals are scattered over the joint surfaces of the dike rock, while the barium feldspars occur chiefly as separate grains, or as hyalophane-plagioclase antiperthites, along crush zones or solution cracks in the rock matrix. Two distinct types of hyalophane are present: one whose composition is $Or_{90}Cn_{10}$, and a second whose composition is $Or_{85}Cn_{15}$. So far as is known, no occurrence of the second type has been reported thus far in the literature.

The first part of this paper describes a petrographic study of important variations in the dike rock and of closely related major formations in the vicinity. From the results obtained, an interpretation of the probable paragenetic sequence is offered. The second part describes the crystallography, physical properties and chemical analysis of the harmotome found at Glen Riddle, together with physical changes induced by heating the mineral. The method used for the identification of the barium feldspar is also described.

The writer has made a joint study of the Glen Riddle dike with Mr. W. Harold Tomlinson, who has described the paragenesis of the corundum in a separate paper.[2]

I

Geology of the Glen Riddle Area

The geology of the immediate vicinity is shown on the map (Fig. 1). The black wavy line marked *H* is the dike where the harmotome was found. It is flanked on either side by serpentine (an altered pyroxenite). A slightly gneissic hornblende granite lies in contact with the serpentine about eight feet east of the dike, and for the next 200 feet eastward granite and serpentine alternate with one another in close succession. To the west of the dike the rock exposed in the railroad cut is dominantly serpentine with a few narrow bands of granite exposed at broadly spaced intervals. Three hundred feet northwestward, across the strike, a body of metamorphosed gabbro about one hundred feet wide is exposed in a creek valley. Good exposures of meta-gabbro may be found on all sides of the mapped area. All the formations including the dike have a rough schistosity or gneissic structure which trends in a general NE-SW direction and dips steeply to the SE. The gabbro and granite have been

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[2] Tomlinson, W. Harold, Corundum in a dike at Glen Riddle, Pa.: *Am. Mineral.*, **24**, 339–43 (1939).

considered to be intrusive into the serpentine,[3] and the latter into the Wissahickon gneiss.[4]

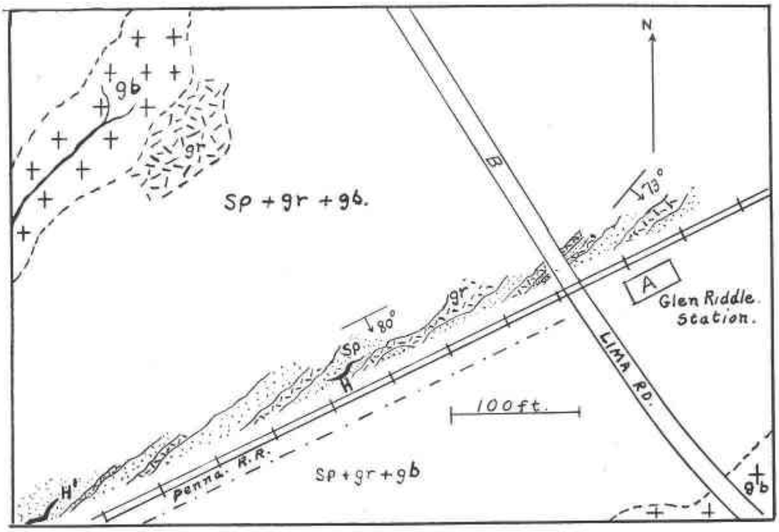

FIG. 1. Map of Formations at Glen Riddle, Pa.

H. Gabbroic dike where harmotome, corundum and barium feldspars were found.
H.′ Gabbroic dike similar to H containing barium feldspar, and corundum, but without harmotome, and without the crumbly central portion peculiar to H.

Serpentine (Meta-pyroxenite)	Sp
Granite	Gr
Metagabbro	Gb
Serpentine, granite, metagabbro (contacts poorly defined)	Sp+Gr +Gb

A. Glen Riddle station. Pennsylvania Railroad, Octoraro Branch.
B. Lima road. Penna. route 452.

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[3] Watson, E. H., *Report of the Fifth Annual Field Conference of Pennsylvania Geologists,* 32 **(1935)**.

[4] Bascom F., *U. S. Geol. Survey, Geol. Atlas, Philadelphia Folio* (No. **162**).

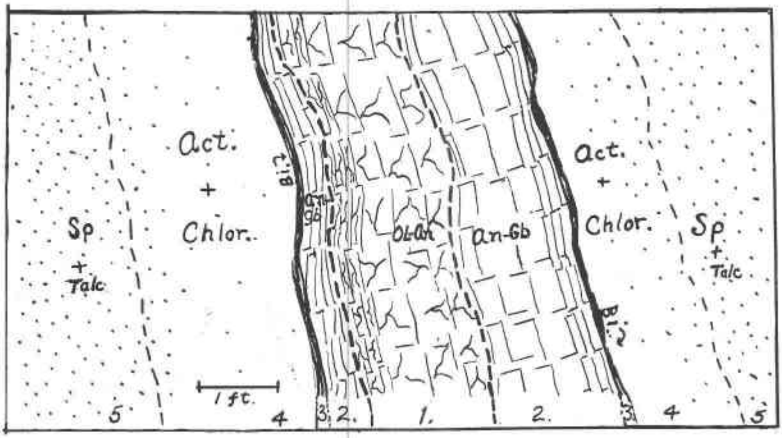


FIG. 2. Cross Section of Dike.

1. Friable central portion. Ol–An—Oligoclase-anorthosite. (See types E and F in text.)
2. Hard border rock. An-Gb—Anorthositic gabbro. (Types C and D.)
3. Thin biotite or vermiculite contact layer.
4. Actinolite and chlorite zone of "contact" minerals.
5. Serpentine wall rock containing occasional talc and tremolite.

Scheme of marking zones 1 and 2.

Vertical lines, foliation.
Horizontal lines, jointing (prominent direction).
Irregular wavy lines in zone 1, random cracks or veins.
Broken vertical lines, transitional zones between 1 and 2.

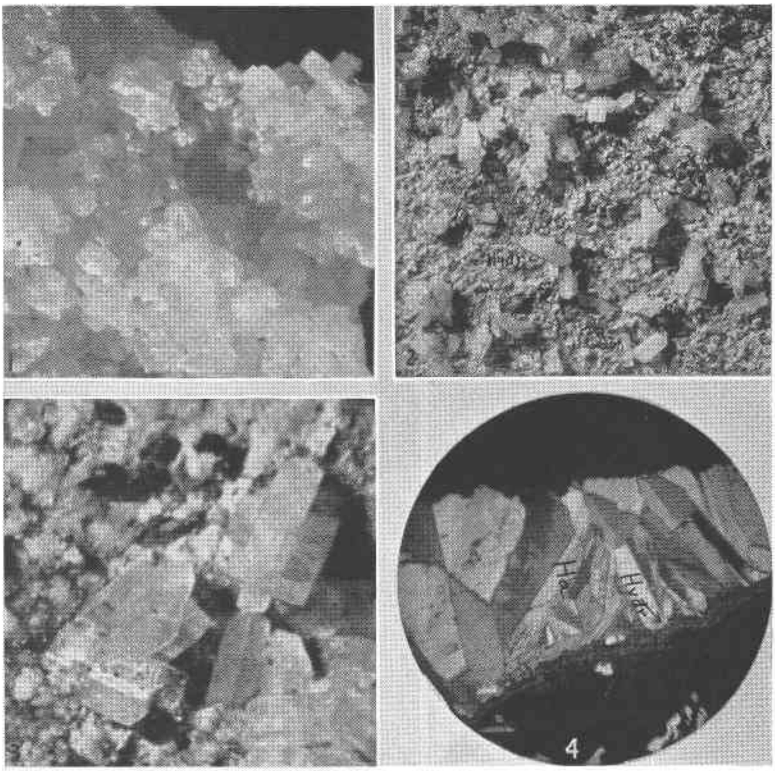
HARMOTOME CRYSTALS

The harmotome crystals found at Glen Riddle are well developed cruciform penetration twins measuring from 3–5 mm. in length and 2–3 mm. in width. They are cream colored or white to crystal clear with a pearly to glassy luster. (Figs. 1–3, Pl. 1.) They are generally found resting on a semi-transparent film of crystalline hydrargillite (Figs. 2 and 4, Pl. 1). Separate crystals or thin drusy coatings are rather sparsely distributed along the joints of the dike which lie in a nearly vertical position against serpentine (altered pyroxenite) wall rock.

STRUCTURE AND GENERAL COMPOSITION OF THE DIKE

The structure of the dike, a cross section of which is shown in Fig. 2, suggests that it has undergone considerable deformation as well as later injection since the time of its original emplacement. The foliation is well marked by thin layers of biotite or vermiculite, which are closely spaced at the borders (one half inch), and more broadly spaced toward the center of the dike (4–6 inches). Small-scale horizontal faulting has broken the rock into a number of loosely fitting blocks of various sizes. A narrow zone of biotite or vermiculite sharply delimits the greyish black border rock of the dike from the bluish green highly altered pyroxenite on either side. The blue green color is caused by a mixture of actinolite and chlorite which grades off into a mixture of serpentine and talc with occasional tremolite.

Plate 1



Glen Riddle Harmotome.

1. Harmotome crystals showing cruciform penetration twins. ×4 diam.
2. Harmotome crystals resting on hydrargillite (Hydr.). ×4 diam.
3. Same as 2. Mag. about 8 diam.
4. Thin section of harmotome (Ha) resting on hydrargillite (Hydr.) ×nicols. Mag. about 20 diam.

Within the dike itself the rock immediately adjacent to the biotite contact is extremely hard. In composition and texture it resembles most closely the local gabbro, although slightly more anorthositic. It consists of approximately 75 per cent of felsic minerals, chiefly sodic labradorite, and 25 per cent biotite. The central portion of the dike (bounded by the two heavy broken lines in Fig. 2) is light grey in color and crumbles easily. It consists of 90 per cent of felsic minerals, chiefly albite-oligoclase and hyalophane, and 10 per cent biotite. The broken lines (Fig. 2) represent a 2–3 inch wide transitional zone between the two more extreme types. These zones are rich in corundum (11 per cent), hyalophane and andesine.

The short horizontal lines in Fig. 2 represent cross joints in which the harmotome was found. The parallel vertical lines represent directions of easy cleavage along foliation planes. The random lines in the central portion represent countless cracks which have apparently served as channels for the flow of solutions through this part of the dike.

Lense-like masses in the central portion.

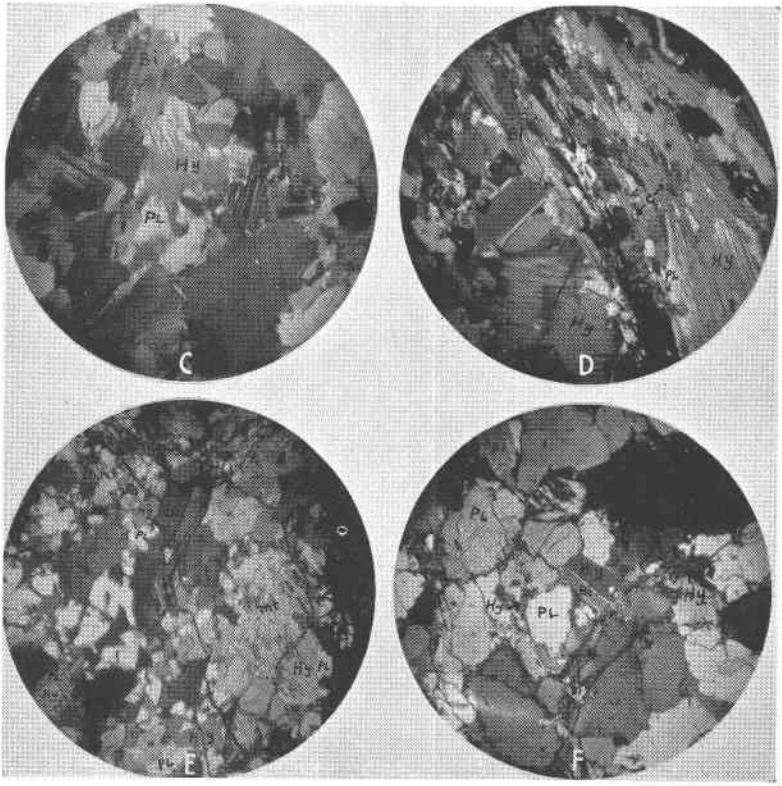
Relatively hard lense-like masses appear along the western border of the crumbly central portion of the dike. They are from 3–5 inches in length and possess a different composition from the soft crumbly rock which partly or completely surrounds them. They are of two types. The first type consists chiefly of hornblende and oligoclase. The composition of the second type is identical with that of the transitional zones,—*i.e.*, rich in corundum, andesine and hyalophane. Their probable bearing on the history of the dike will be discussed in connection with the paragenetic sequence.

PETROGRAPHIC ANALYSIS

Under the microscope irregularly spaced crush zones about 1–2 mm. wide appear parallel to the visible foliation in almost every phase of the dike rock. They are spaced from 4 mm. to 75 mm. apart. It is along such crush zones—sharply defined in the hard border rock, and partly obliterated in the central portion—that the potash-barium feldspars and corundum are found. Except for its presence in the lense-like masses already mentioned, the corundum is confined exclusively to the narrow crush zones in the border rock and to the transitional zones between the border and center. The minerals in the crush zones make up about 15 per cent of the bulk composition of the dike rock.

Photomicrograph *C* (Pl. 2) represents a typical section of the border rock; *D*, a typical crush zone in the border rock; *E*, a typical crush zone in the central portion,—lacking the sharp boundaries of *D*, and most abundant along the outer margins; and *F*, a typical section of the rock which makes up the greater percentage of the central portion of the dike. All photographs were taken under the same magnification in order to illustrate relative differences in grain size. Type *C* (with alternate zones *D*) to *E* and *F* represent a typical cross section traverse from the border to the center of the dike.

Plate 2



Important Rock Types in Glen Riddle Dike where Harmotome Was Found.

C and *D*, Border Phase. *E* and *F*, Central Phase.

X Nicols. Mag. about 24 diam.

Pl—Plagioclase. Hy—Hyalophane. Bi—Biotite. C—Corundum. mt—montmorillonite.

C. Dominant type in border phase. Single grain of antiperthite in center of field composed of plagioclase (An_{40}) and hyalophane (Cn_{20}).

D. Mylonitized zones in border phase. Two large grains of antiperthite in lower half of field. Separate grains of hyalophane in center. Small seed-like xls. of high relief are corundum.

E. Mylonitized zones in central phase, top left, with patch-work mosaic at bottom center of field. Large grain of antiperthite, lower right with part of plagioclase altered to montmorillonite (mt).

F. Dominant type in central phase. Shows a few small grains of hyalophane in center of field.

TABLE 1. MINERALOGIC COMPOSITION OF GLEN RIDDLE METAGABBRO AND VARIOUS PHASES OF THE DIKE ROCK

			Border Phase		Central Phase		Av. Grain Size*	
	A	B	C	D	E	F	mm.×mm.	
Hornblende	51	20					1.0	.80
Biotite		5	26	31	7	10	.33	.14
Quartz	10.5							
Plagioclase								
An_{50}	36		60	5			.77	.58
An_{40}			4	30				
An_{20}		49			24	20		
An_{15}					8	36		
Hyalophane								
Cn_{15}			2	9			.20	.12
Cn_{10}		16			26	7		
Antiperthite								
$An_{40}+Cn_{15}$			5	12–19			1.00	.81
$An_{20}+Cn_{10}$		8			11	5		
Corundum			1	4–11			.04	.02
Accessories								
Apatite	1.5						.22	.16
Zircon								
Titanite	*m* 1.0	2	2	2	1	2	.02	.01
Secondary Montmorillonite, clay, etc.					23	20	n.d.	
Av. grain size in mm. *l.***	Same as C.	.89	.54	.37	.55	.63		
w.		.67	.38	.20	.40	.43		

A. Local metagabbro. *m* = magnetite—present in A only.
B. Lense-like inclusions found in type E of central phase.
C. Dominant type in border phase.
D. Mylonitized zones in border phase.
E. Mylonitized zones in central phase bordered by patch-work mosaic.
F. Dominant type in central phase.

* Average dimensions of each mineral for all phases in which it is present.

** Average grain size of each phase excluding corundum, accessories and secondary minerals. 18 to 35 grains were measured on each slide. *l.* = length. *w.* = width.

Summary

A summary of the study of the photomicrographs and of the data presented in Table 1 and Fig. 3 reveals that as we pass from the border to the center of the dike the plagioclase becomes more sodic, the hyalophane becomes more potassic, grain size increases, evidence of strain diminishes, crush zones (reaction zones) become broader, antiperthites decrease, separate grains of hyalophane increase in number and finally decrease notably in the most sodic central part of the dike.

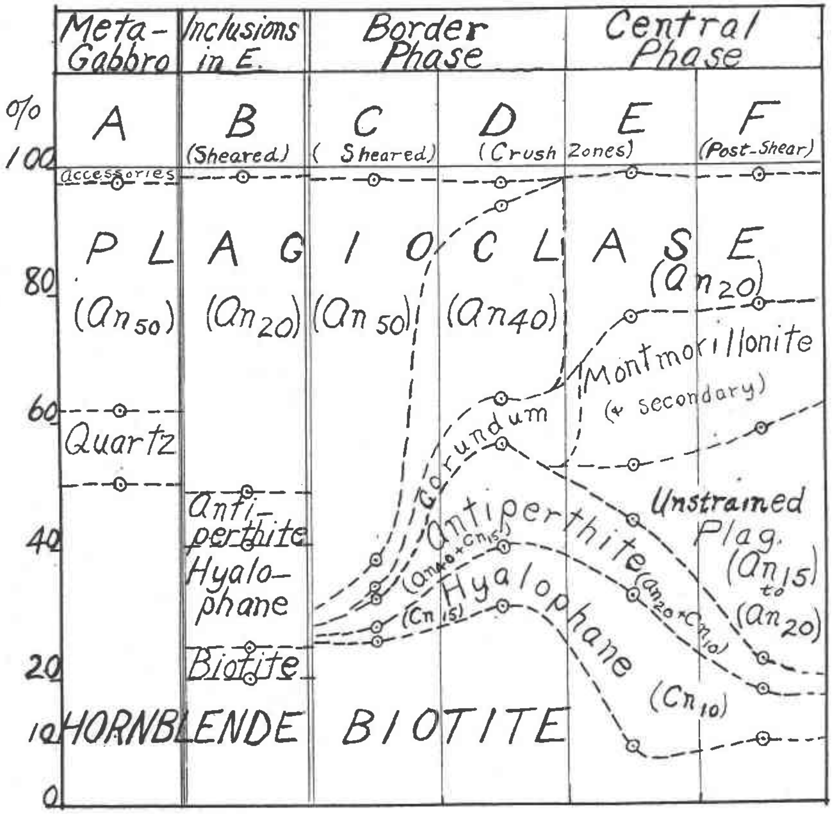


FIG. 3. Variation Diagram. Constructed from Analyses in Table 1.

Table 1 represents an analysis of the mineral content and grain size of the local metagabbro and outstanding types found in the Glen Riddle dike. Types *C*, *D*, *E* and *F* correspond to photomicrographs (Pl. 2) bearing the same letters and represent a cross section from the border (*C* and *D*) to the center (*E* and *F*). In the variation diagram (Fig. 3) columns *C*, *D*, *E* and *F* show the progressive appearance and disappearance of the components of each phase from the basic border to the more alkaline center of the dike.

Mineral percentages were determined by the Rosiwal method with the Wentworth integrating stage. Five to seven traverses were made on each slide. *D* and *F* represent the average of two slides for each type. Count was made on one slide only for each of the remaining types. Additional slides and crushed samples were examined in order to insure a reasonably dependable degree of accuracy. The plagioclase feldspars were determined by measurement of refractive indices on {010} and {001} cleavage plates, and by referring to curves in standard textbooks. The method for the determination of the hyalophane is described in section 2 of this paper.

Paragenetic Sequence of Barium Minerals

Since the relations obtaining in the dike are not nearly so simple as might be gathered from the foregoing description, the interpretation which follows is presented in the form of a discussion rather than as a positive interpretation.

Source of the magma of the dike minerals.

1. The local gabbro is considered the most probable source magma of the dike as originally emplaced. This is suggested by the anorthositic composition of the hard border rock. The anorthite content of its labradorite is similar to that of the gabbro (45–50 per cent). Its content of mafic minerals (26 per cent) is much higher than that of the local granite (10 per cent). Accessory minerals also correspond to those present in the gabbro.
2. The local granite is the most probable source of the barium.
    - (a) Hyalophane-plagioclase antiperthites similar to those in the dike rock were found in granite near Lenni Mills, Pa., about one half mile west of Glen Riddle.
    - (b) Evidence of strain or shear in the dike rock wherever hyalophane-plagioclase antiperthites are found suggests that the original gabbroic rock of the dike was sheared by forces attending the intrusion of the granite magma, and that during or shortly after deformation highly mobile solutions emanated from the granite mass at an advanced stage of cooling, and soaked into the dike rock along microscopic cracks or crush zones.

Evidence of hydrothermal reaction from high to progressively lower temperatures, in the form of a reaction series.

(a) Chemical evidence. There is a progressive increase in the sodic content of the plagioclase from the border to the center of the dike. The anorthite content decreases from 50 to 15 per cent.

As the plagioclase becomes more sodic its associated hyalophane becomes more potassic. Where associated with labradorite and andesine the composition of the hyalophane is $Or_{85}Cn_{15}$; where associated with albite-oligoclase its composition is $Or_{90}Cn_{10}$.

(b) Physical evidence of progressively lower reaction temperatures from border to center.

1. Changes in texture of replaced rock and replacing minerals. In the resistant border rock where traces of the first attack of granitic volatiles are well preserved, the texture is dominantly antiperthitic. In the reaction zones which border the most sodic central portion, antiperthites have given way to an irregular patchy mosaic pattern of hyalophane and albite-oligoclase. (See Pl. 2, *D* and *E*.) Andersen[5] suggests that antiperthites indicate reaction at relatively high temperatures, whereas patch perthites are formed at relatively low temperatures. If his conclusions be applied here, hydrothermal reaction and replacement persisted down through a lower temperature in the central than in the more resistant border rock of the dike.
2. Formation temperature of the harmotome. The lowest temperature in the hyalophane-harmotome sequence would be represented by the appearance of the barium zeolite. At this stage the rock would have cooled sufficiently to form contraction joints into which the excess liquid would find its way. The formation temperature of the harmotome, as suggested by its behavior on heating (Section 2 of this paper) may have been as low as 180–200°C.

Transition from hyalophane to harmotome.

While the record of changing composition and temperature is rather clearly preserved in the case of the hyalophane and plagioclase feldspars, the intermediate steps between the lowest temperature of formation of hyalophane and that of harmotome are not so clearly marked. The explanation which appears to be most in keeping with the evidence at hand, is that after the deposition of the last formed hyalophane the granitic solutions became progressively richer in soda, and by a process of metasomatic replacement resorbed an amount of hyalophane equivalent to the relatively small amount of harmotome which is now sparsely distributed along the joints of the dike rock. This resorption appears to have taken place along the central channels of the dike where the rock (type *F*) most nearly resembling the granite is found.

An alternative explanation would be that as the solutions cooled down they became progressively richer in barium, potash and water, and at the proper conditions of equilibrium produced the crystals of harmotome.

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[5] Andersen, O., The genesis of some types of feldspar from granite pegmatites: *Norsk geol. tidsskr.*, B. X. h. 1–2, 151–204 (1928).

The great excess of soda over potash in the latest formed phases of the dike, together with certain considerations enumerated below, mitigates against this relatively simple explanation.

Metasomatic replacement of central portion of dike by late soda-rich granitic injections.

(a) Chemical evidence. In the central portion of the dike (type *F*) the ratio of soda to potash feldspar is as 8:1, whereas in the local granite it is as 1:3.

(b) Evidence of prolonged and intense soaking in the central portion. Reaction between granitic volatiles and original dike minerals is not confined to narrow crush zones, as in the hard border rock, but has spread out in a haphazard fashion, forming zones of extended reaction. (Compare Pl. 2 Figs. *D* and *E*.) The lense-like masses, some containing hornblende as the mafic mineral, and others rich in corundum, appear to be remnants of more extensive zones which were either present in the original gabbroic dike or were formed at an early stage of the granitic sequence.

   1. The hornblendic masses are believed to be a part of the original gabbro dike. Their content of hornblende is equivalent to the biotite content of the border rock. Like the border rock they also contain antiperthites which show distinct evidence of strain. This should place them in the pre-granitic gabbro sequence.
   2. The corundum-rich masses. Since corundum is always associated with hyalophane, the corundum-rich masses must belong to the early high temperature granitic sequence best preserved in the hard border rock.

(c) Absence of strain in the central portion. Marked evidence of strain in the hard border rock and in the hornblendic masses, such as strain shadows, curved twin lamellae and granulation, is only partially present in the reaction zones bordering the central portion; and disappears almost completely in the most sodic central zone of the dike. In the latter the twin lamellae of the feldspars are perfectly straight (see Pl. 2, type *F*). Almost complete absence of antiperthites, which are generally associated with stress phenomena in the dike, suggests a late period of formation for the most sodic central portion of the dike.

(d) Attack of minerals formed early in sequence by later solutions.

   1. Borders of hyalophane grains are frayed and indented (see Pl. 2, type *F*).
   2. Crosscutting tendency of invading minerals. Hyalophane intergrowths crosscut the cleavage traces of the plagioclase in the

hard border rock. In the central portion (type *E*) intergrowths of albite-oligoclase crosscut the cleavage traces of hyalophane.

SUMMARY OF EVIDENCE OF REPLACEMENT IN CENTRAL PORTION OF DIKE BY LATE SODA-RICH SOLUTIONS

From the evidence given above it appears that the potash-barium feldspars kept forming for some time after the relaxation of stress, but that the solutions finally became impoverished in barium and potash, and richer in soda and water. Increase in water may have facilitated diffusion along favorable passages and appears to have effected local replacement of some of the earlier reaction products. Some of the hyalophane appears to have been resorbed to form harmotome, while some of the corundum may have been resorbed to form hydrargillite, thus explaining the close association of harmotome and hydrargillite on the joints of the dike rock. The presence of 1.2 per cent of soda in the harmotome also suggests that soda was present in the solutions which deposited the barium zeolite.

If interpreted correctly, this evidence of replacement by soda-rich solutions confirms the work of Noll,[6] whose study on artificial hydrous silicate melts indicates that soda-rich solutions promote the formation of zeolites, whereas potash-rich solutions aid in the formation of such minerals as sericite. He also finds that an excess of alumina in water rich melts will produce corundum between 400–600°C. and böhmite (hydrargillite) at 300°C. or less.

The combined evidence of reaction and replacement in the dike rock as a whole is also in accord with the reaction principle of Bowen, and with the views of Butler, who extends the reaction series to include deuteric and hydrothermal phases. The results also confirm the views held by Schaller and Andersen, who investigated hydrothermal replacement phenomena in lithium and microcline pegmatites. Although the chief difference lies in the more basic nature of the replaced dike minerals at Glen Riddle, and the chemical nature of the granitic exudates which replaced them, the actual processes involved are essentially the same.[7]

SUMMARY OF PARAGENETIC SEQUENCE OF GLEN RIDDLE DIKE MINERALS

A. Emplacement of a dike of anorthositic gabbro in pyroxenite at near

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[6] Noll, W., Über die Bildungsbedingungen von Kaolin, Montmorillonit, Sericit und Analcim: *Min. pet. Mitt.*, *Band* **46** Heft 3–4, 221–224 (1936).

[7] Bowen, N. L., The reaction principle in petrogenesis: *Jour. Geology*, **30**, 177–198 (1922).

Butler, B. S., Influence of replaced rock on replacement minerals associated with ore deposits: *Econ. Geology*, **27**, 1–24 (1932).

Schaller, W. T., The genesis of lithium pegmatites: *Am. Jour. Sci.*, **10**, 269–279 (1925).

Andersen, O., *Loc. cit.*

magmatic temperatures. This sequence is now represented by (1) the hard border rock, and (2) by the hornblendic masses which may have once extended as thin bands up the center of the dike.

B. Structural deformation of dike rock attended by the introduction of late-stage granitic exudates rich in potash, barium and soda. Reaction of solutions (or superheated vapors) with original dike minerals to form:

  1. An early relatively high temperature stress sequence consisting of hyalophane (Cn_{15}), andesine (An_{40}) and corundum in the border rock, and of hyalophane (Cn_{10}) and oligoclase (An_{20}), without corundum, in the portions represented by the hornblendic inclusions. The temperature range was probably from 500–600°C. There were relatively equal amounts of soda, potash and barium in the invading solutions.
  2. Low stress intermediate temperature sequence consisting of relatively large grains of hyalophane (Cn_{10}) and albite-oligoclase (An_{15}). This stage represented maximum potash and barium content in solutions with increase in water vapors. This was followed by:
     (a) Increase in soda content of solutions and local replacement of previously formed hyalophane by albite-oligoclase in the center of the dike.
  3. Low temperature zeolitic sequence composed of harmotome and hydrargillite. Solutions rich in water resorbed potash, soda, barium and alumina. Temperatures approximately 200°C.

The change in the celsian content of the hyalophane from 10 per cent where associated with albite-oligoclase (An_{15}) to 15 per cent where associated with andesine (An_{40}) may be the manifestation of a possible established equilibrium. In his work on myrmekites Becke[8] found that the amount of quartz formed during the replacement of orthoclase by plagioclase increased in direct proportion to the increase in lime content of the invading feldspar. In the Glen Riddle occurrence the barium content of the hyalophane intergrowth appears to be controlled by the lime content of the invaded plagioclase. It is not known whether the lime or the alumina in the plagioclase is the actual controlling factor which determines how much barium will appear in the hyalophane, but since both calcium and barium belong to the alkaline earth group it is quite probable that where stoichiometric relations are involved these elements are interdependent. Because of close correspondence in the size of their atomic radii, however, the barium is able to replace potassium in the lattice

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[8] Becke, F., Über Myrmekit: *Min. pet. Mitt.*, **27**, 377–390 (1908).

structure, and thus form hyalophane. It is worthy of note that hyalophane which occurs in limestone districts has a still higher barium content than any of the types found at Glen Riddle. Hyalophane reported from Franklin, N. J., has a celsian content of approximately 25 per cent.[9] Since the actual processes involved in the formation of simplectites are not very well understood, a mere mention has been made of this relationship without attempting to interpret its possible significance.

II

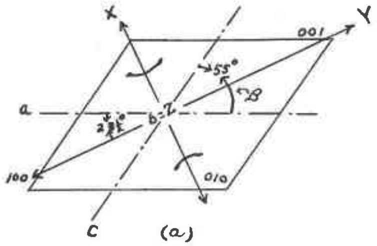
CRYSTALLOGRAPHIC, PHYSICAL, AND CHEMICAL PROPERTIES OF HARMOTOME FROM GLEN RIDDLE, DELAWARE CO., PENNSYLVANIA

FORMULA: $K_2Ba(Na_2Ca)O \cdot Al_2O_3 \cdot 5\ SiO_2 \cdot 5\ H_2O$. Monoclinic.

FORMS OBSERVED: *a*(100), *b*(010), *c*(001), *m*(110), see Fig. (5). *e*(011) present as twinning plane only.

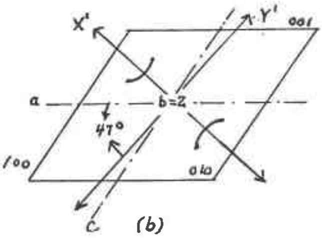
TWINNING: On the base *c*(001) and on the clinodome *e*(011).

HABIT: Cruciform penetration twins. In Fig. 5 the prism and the front pinacoid are about equally developed. In some crystals the prism face is absent; in others it has partially or completely replaced the front pinacoid.[10]



$Y \wedge a = 23\frac{1}{2}°$

FIG. 4. Optical Orientation of Harmotome below 100°C. on *b*(010).



$Y' \wedge a = 47°$.

Optical Orientation of Harmotome at 130°C. on *b*(010).

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[9] Palache, Charles, The minerals of Franklin and Sterling Hill, Sussex County, N. J.: *U. S. Geol. Survey, Prof. Paper*, **180,** 60 (1935).

[10] The one crystal measured on a Goldschmidt two-circle goniometer had poor reflecting faces because of striations. The axial ratio, and the facial intercepts which are given above are in agreement with those given in *Goldschmidt's Winkeltabellen.*

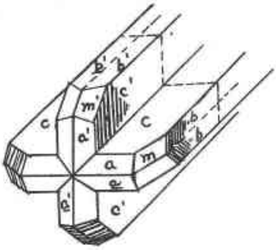

Fig. 5. Interpenetration Twins of Harmotome.

1. Showing forms observed.
2. Type of twinning.
3. Direction of striations observed on prism faces, $c(001)$ and $b(010)$.

Crystallographic Angle: Beta = 55°* (measured on thin section ‖ to $b(010)$.

Physical Properties: Cleavages: $b(010)$ good, $c(001)$ fair. Gr. = 2.47 H. = 4.5.

Optical Properties: Biaxial positive. $Z=b$. Axial Plane and $Bx_a \perp b(010)$. See Fig. 4(a). $\alpha=1.506$* $\beta=1.509$ $\gamma=1.514$ at 24°C.

Dispersion crossed; increases with heating.

$$2V_\gamma = 79°50'†$$

* All readings marked * were made in yellow light with a Lifa Filter 395 D Na.

† Calculated from refractive indices. Values of $2V_\gamma$ obtained by measurements on separate grains on the Universal Stage were 78, 80, 81, and 82 degrees.

Change in Optical Properties on Heating:[11] The extinction angle $Y\wedge a$, and the optic axial angle over Z vary with change in temperature as shown in Figs. 4 (a) and (b) and in Table 2 which also includes water loss on heating.

Table 2. Optical Changes and Water Loss on Heating of Harmotome from Delaware Co.

Temp. °C.	$Y\wedge a$	$2V_\gamma$	Temp. °C.	Water Loss	Hours Heated
24	*23½°	79°50′	24	n.d.	
90–100	*24	*69°	105	4.9%	12
130	47	*32	140	6.8	15
180	55±4	n.d.	190	10.3	4
**240	37–45	n.d.	240	11.6	3
**Red heat	37	n.d.	Red heat	14.8	1

** Extinction angles were read with difficulty above 180°C., owing to strain in the crystal fragments.

The changes in optical properties which attend the loss of water on heating are shown in Table 2. Similar changes in water loss have been noted previously by Fresenius (1879) and Stoklossa (1918). Optical

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[11] Lack of agreement of optical data in various textbooks may be due to oversight on the part of workers to note the effect of heat. A thin section ground in the ordinary manner and mounted in balsam showed an optic angle of 32°.

changes have been observed by Des Cloizeaux (1868) and by Rinne (1890).[12] Approximately one third of the water is lost at 140°C. and an additional third at 190°. The optical angle $2V_\gamma$ becomes smaller, and the extinction angle $Y \wedge a$ becomes larger until its value coincides approximately with that of the crystallographic angle beta (55°). This coincidence takes place very close to 180°C. Further increase in temperature induces a reversal in the swing of the *Y* direction causing the extinction angle to become smaller again. Weigel has noted similar changes in the behavior of heulandite, another member of the desmine group, to which harmotome belongs.[13] The temperature at which coincidence and then reversal takes place is also in the neighborhood of 180°C. The point at which optical and crystallographic directions coincide is considered by Weigel to be the temperature at which the zeolite was originally formed.[14] Such a relationship in the case of harmotome could only be established by much more detailed work than appears in the above table. The value of 180°C. seems, however, to correspond fairly well with the low range of formation indicated by the petrographic study cited previously.

CHEMICAL ANALYSIS OF HARMOTOME

As the number of available crystals was rather small, the analysis in Table 3, column A, was made on the purest fragments of the mineral found in the form of thin seams or crusts. After separation from impurities, mainly hydrargillite, the ground specimen was examined under the microscope. The amount of impurities was estimated to be not more than 1.5 to 2.0 per cent. Thin sections of harmotome oriented parallel to *b* (010) revealed tiny groups of acicular crystallites arranged in bundles. These were taken to be either thomsonite or natrolite.

TABLE 3. ANALYSIS OF HARMOTOME

	A	B	C	C′	E	F
SiO_2	45.51	47.1	46.15	.765	4.87	5
Al_2O_3	16.50	16.0	16.03	.157	1.00	1
MgO	0.27					
CaO	0.12		0.13	.003	1.10	1
BaO	19.89	20.6	20.17	.131		
K_2O	1.77	2.1	1.81	.019		
Na_2O	1.18		1.21	.020		
H_2O 110°C.	14.74	14.1	14.50	.806	5.13	5
Total	99.98	100.0	100.00			

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[12] Doelter, *Handbuch der Mineral Chemie, Bd.* **II,** 404 and 406 (1919).

[13] *Doelter, Ibid.* 300 et seq.

[14] Angel and Scharizer, *Grundriss der Mineralparagenese,* 76–95 (1932).

A. Harmotome from Glen Riddle. Analyst A. E. Meier.

B. Theoretical composition of harmotome (*Dana's Textbook of Mineralogy*, 3rd ed., p. 551).

C. Analysis A calculated to 100 per cent after deducting an estimated 1 per cent of hydrargillite and an amount of hydrous magnesium silicate (white chlorite) equivalent to 0.27 per cent of MgO.

C′. Molecular proportions of C.

E. Molecular ratio of harmotome from Glen Riddle, computed from C. and C′.

F. Molecular ratio of theoretical harmotome, computed from B.

Analytical notes

The usual procedures recommended for silicate analysis by Washington and Hillebrand were followed. Barium was determined on a separate sample by the HF–H_2SO_4 method. The silica, alumina and lime precipitates were all purified and tested in order to correct for any occluded barium.

On a sample of harmotome weighing 0.3006 gms. the Al_2O_3 precipitate yielded 0.0017 gms. $BaSO_4$ (after double precipitation of Al_2O_3). HF residue from SiO_2 yielded 0.0015 gms. $BaSO_4$. Calcium oxalate ppt. was free from barium.

Magnesium ammonium phosphate brought down approximately 75 per cent of the barium. This precipitate was dissolved in HCl and the barium removed with H_2SO_4.

The filtrate from the main portion after all the other elements had been determined yielded 19.51 per cent BaO, against 19.89 per cent BaO obtained on a separate sample by the HF–H_2SO_4 method.

IDENTIFICATION OF BARIUM FELDSPAR AS HYALOPHANE

The presence of a number of mineral grains in type *D* (the mylonitized zones of the resistant border phase), whose highest interference color in thin section was a first order grey, and whose refractive indices were too high for orthoclase and too low for cordierite, suggested the possible presence of hyalophane in the dike rock. A chemical test made on the rock similar to photomicrograph *D* revealed a BaO content of 1.5 per cent. The refractive indices fell within the range of those given by Winchell[15] for hyalophane, and were halfway between those corresponding to a composition of $Or_{90}Cn_{10}$ and $Or_{80}Cn_{20}$. No composition was listed, however, which corresponded to the indices obtained.

In order that the exact composition of the unknown feldspar might be determined, an attempt was made to isolate the feldspar in question by means of heavy liquids. The first separation was made on unsized grains that passed through a 120 mesh sieve, and with potassium mercuric iodide as the heavy liquid. Gravity adjustments were made by means of a pycnometer and a standard analytical balance. After all the minerals heavier or lighter than sp. gr. 2.685 had been removed, there remained a mixture of almost equal parts of andesine (An_{40}) and an unknown feldspar. Portions of this mixture would either float or sink in a liquid of sp. gr. 2.685, the coarser particles tending to sink whereas the finer

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[15] *Loc. cit.*, 360.

grains floated, or remained suspended. A second test was made on sized grains using bromoform, but no better separation was obtained. The fractions collected from each test were kept separate. Slides were made by immersing representative samples in liquids of suitable index, and the percentage of the unknown feldspar was determined by counting the grains. In the first test a number of grains (about 25 per cent of those counted) were measured, and the relative proportion of each feldspar present in the mixture computed by multiplying the number of grains counted on each slide by the average diameter. This procedure was not considered necessary in the second test since the grains had already been screened to size. No allowance was made for possible difference in vertical thickness of grains on the slides. Since both components of the mixture were practically inseparable in heavy liquids, per cent by volume and by weight were considered to be identical.

TABLE 4. IDENTIFICATION OF HYALOPHANE BY GRAVITY SEPARATION AND CHEMICAL ANALYSIS

	Test 1	Test 2
Liquid used	$KHgI_2$	Bromoform
Sp. gr. of liquid	2.685	2.686 at 20–25°C.
Screen sizes	through 120 mesh	55% through 120 on 140 45% through 140 on 170
Grains counted:		
Ba feldspar	243	689
Andesine (An_{40})	171	721
No. of grains measured:		
Ba feldspar	66	not measured
Andesine	60	not measured
Av. grain diameter:		
Ba feldspar	0.17 mm.	not measured
Andesine	0.20 mm.	not measured
Per cent present:		
Ba feldspar	55	47
Andesine	45	53
Wt. sample for anal.	0.1745 gs.	0.4012 gs.
Per cent BaO found:		
In mixture by analysis	3.76	3.08
In 100% Ba feldspar	6.46	6.55
In theoretical celsian	40.8	40.8
Per cent Cn in Ba feldspar	15.83	16.05
Per cent $Or_{85}Cn_{15}$ sol. in andesine (An_{40}) approx.		10*
Per cent celsian sol. in andesine (An_{40}) approx.		1.5
Per cent celsian remaining for free Ba feldspar		14.5
Approximate celsian content of Ba feldspar present in the border phase (type *C*) of dike		Cn_{15}

* This value was obtained by substituting hyalophane $Or_{85}Cn_{15}$ for orthoclase in the ternary diagram of Winchell, *loc. cit.*, 319.

Each of the two mixtures were analyzed separately for barium. The results are given in Tables 4 and 5. The computations are based on the assumption that all the barium found in the mixture is contained in the unknown feldspar, and none in the other component of the mixture *i.e.*, andesine. (The mixtures analyzed contained not more than 1 per cent of foreign minerals such as biotite, corundum, etc.) From the BaO content found by analysis the percentage of BaO was calculated in a sample which would consist of 100 per cent of barium feldspar. The amount of celsian equivalent to the percentage of barium present was then computed. The theoretical barium content of celsian was used as a standard. The celsian content of the unknown barium feldspar, thus computed, proved to be 14.5 per cent, or very close to 15 per cent, a figure which corresponds to the composition indicated by its refractive indices, and indicates that it is an intermediate type between Winchell's hyalophane (Cn_{10}) and (Cn_{20}). In making the computations a deduction was made for the amount of hyalophane which might possibly occur in solid solution with the associated andesine. This correction is included in Table 4.

A standard specific gravity determination was made on the 2.686 g. fraction separated in bromoform. This was done by employing the pycnometer method; boiling the fragments in water, removing the air and making up to volume at 20°C. The value obtained was 2.697, which is slightly higher than that of the liquid in which the grains just floated (2.686), and indicates the inadvisability of depending on heavy solutions for accurate gravity determinations.

The barium feldspar in the central portion of the dike, (types *E* and *F*) was identified as a more alkaline type of hyalophane ($Or_{90}Cn_{10}$) than that found associated with andesine in the border phase. This was done by checking the refractive indices with those given by Winchell, and verifying by a test for barium on a representative sample without making a detailed separation as above. Optical and chemical tests were made on a fraction which floated in bromoform of sp. gr. 2.675. The refractive indices and specific gravity of the two types of hyalophane present in the dike rock are shown in the following table. Three types listed by Winchell have been inserted for the sake of comparison.

TABLE 5. PHYSICAL PROPERTIES OF HYALOPHANE

Composition	$Or_{90}Cn_{10}$		$Or_{85}Cn_{15}$		$Or_{80}Cn_{20}$
Type	A	B	A	C	A
Optic Sign	—	—		—	—
N_g	1.534	1.532	not	1.539	1.541
N_m	1.531	1.530	given	1.535	1.538
N_p	1.528	1.527		1.532	1.535
Sp. Gr.	2.65	2.675		2.697	2.73

A. Taken from Winchell, *loc. cit.*, 360.
B. Type found in central portion of dike (types *E* and *F*).
C. Type found in border portion of dike (types *C* and *D*).

Index determinations were made with the immersion method in white light. Because of poor cleavage traces the extinction angles of the hyalophane could not be determined with any degree of certainty. The mineral exhibited no signs of twinning when tested on the universal stage.

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