CORDIERITE-GARNET GNEISS AND ASSOCIATED MICRO-CLINE-RICH PEGMATITE AT STURBRIDGE, MASSA-CHUSETTS AND UNION, CONNECTICUT[1]

FRED BARKER, *U. S. Geological Survey, Washington, D. C.*

ABSTRACT

Gneiss of argillaceous composition at Sturbridge, Massachusetts, and at Union, Connecticut, 10 miles to the south, consists of the assemblage biotite-cordierite-garnet-magnetite-microcline-quartz-plagioclase-sillimanite. The conclusion is made that this assemblage does not violate the phase rule. The cordierite contains 32 mole per cent of Fe-end member, the biotite is aluminous and its ratio $MgO:(MgO+FeO)$ is 0.54, and the garnet is $alm_{69.5}$ $pyr_{26.4}gro_{2.9}spe_{1.2}$. Lenses of microcline-quartz pegmatite are intimately associated with the gneiss; some are concordant, others cut across the foliation and banding of the gneiss. The pegmatites also contain small amounts of biotite, cordierite, garnet, graphite, plagioclase, and sillimanite; each mineral is similar in optical properties to the corresponding one in the gneiss. It is suggested that muscovite was a former constituent of the gneiss at a lower grade of metamorphism, and that it decomposed with increasing metamorphism, and reacted with quartz to form sillimanite *in situ* and at least part of the microcline of the gneiss and pegmatites. These rocks are compared with similar rocks of Fennoscandia and Canada.

INTRODUCTION

Cordierite-garnet-sillimanite gneisses that contain microcline-quartz pegmatite are found in Sturbridge, Massachusetts, and Union, Connecticut. The locality (Fig. 1) at Sturbridge is on the south side of the Massachusetts Turnpike at the overpass of the New Boston Road; this is about 1 mile west of the interchange of Route 15 with the Turnpike. The other locality is about $1\frac{1}{4}$ miles east of the village of Union, on the north side of Bigelow Hollow Road, Connecticut Route 198, about 100 feet west of Bigelow Pond. These gneisses are part of the widespread Brimfield Schist (Emerson, 1917, p. 68–72; and Rodgers and others, 1959, p. 46 and map). The two localities are about 10 miles apart.

DESCRIPTION OF ROCKS

The gneiss at Sturbridge is gray, medium- to coarse-grained, and shows a rough compositional banding of mafic and quartzo-feldspathic units from a few millimeters to a few inches in thickness. Irregular folia of intergrown biotite and sillimanite with scattered anhedral garnet and cordierite are set in a matrix of massive aggregates of plagioclase, quartz, microcline, and minor amounts of biotite. Muscovite is absent. Magnetite, graphite, and pyrite are present in small amounts. Proportions of the minerals vary considerably from one part of the gneiss to another.

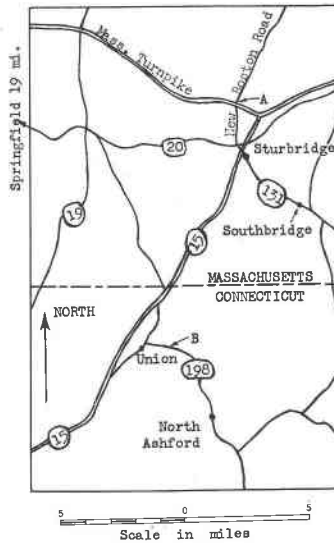[1] Publication authorized by the Director, U. S. Geological Survey.

Fɪɢ. 1. Map showing locations of cordierite-garnet-sillimanite gneiss in Sturbridge, Massachusetts, at A, and in Union, Connecticut, at B.

An analysis of typical gneiss, free of pegmatite, from Sturbridge was made by chemists of the U. S. Geological Survey using the rapid methods of Shapiro and Brannock (1956):

SiO_2	53.1		Na_2O	1.7
TiO_2	1.2		K_2O	3.5
Al_2O_3	24.1		H_2O	1.4
F_2O_3	1.4		P_2O_5	0.06
FeO	8.4		MnO	0.10
MgO	3.7		CO_2	0.05
CaO	1.5		Total	100.2

The composition of the gneiss is comparable to that of a shale, except for its low content of H_2O and its high ratio of $FeO:Fe_2O_3$. The low content of H_2O probably is due to dehydration during metamorphism. The original sediment may have contained enough ferrous clay to account for the 8.4 per cent of FeO, but it is more probable that original Fe_2O_3, in hydrous iron oxides, was partially reduced to FeO during metamorphism, perhaps by carbonaceous material.

The gneiss at Union is similar to that at Sturbridge, except that the folia of biotite and sillimanite form only 10 to 20 per cent of the rock; cordierite and garnet are much more abundant; and both garnet and cordierite occur in the quartzo-feldspathic portions. There is a gradation
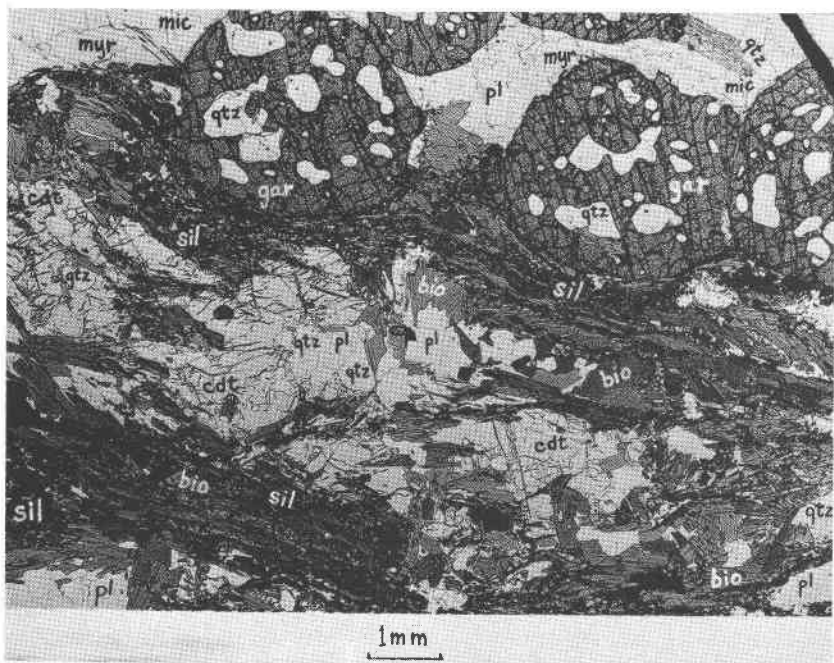
Fɪɢ. 2. Mafic band in gneiss from Union, Connecticut. Biotite, bio; cordierite, cdt; garnet, gar; microcline, mic; myrmekite, myr; plagioclase, pl; quartz, qtz; and sillimanite, sil.

from scattered grains and clusters of microcline to small, lenticular and blob-like pegmatites that appear to have replaced the gneiss. An example of the latter is shown in Fig. 4.

In thin section the folia of biotite and sillimanite in the gneiss at Union wrap around equant, anhedral garnets and irregular grains of cordierite. Small amounts of plagioclase and quartz are interstitial to these folia; microcline rarely occurs inside them, but commonly embays their margins. A typical view is given in Fig. 2. The quartzo-feldspathic aggregates are granular mosaics of andesine, quartz, microcline microperthite, and biotite, with occasional cordierite, garnet, and sillimanite. Rims of myrmekite lie between plagioclase and microcline; they are similar to ones in migmatite pictured by Schreyer (1958, Taf. 10, Abb. 2). The volumetric ratio of myrmekite to the adjacent microcline is about 1:10. The amount of microcline varies greatly from place to place, even as seen in thin section. The relative amounts of microcline and plagioclase commonly vary inversely; the feldspar in one thin section may be almost all plagioclase, whereas that in a section cut from adjacent rock may be
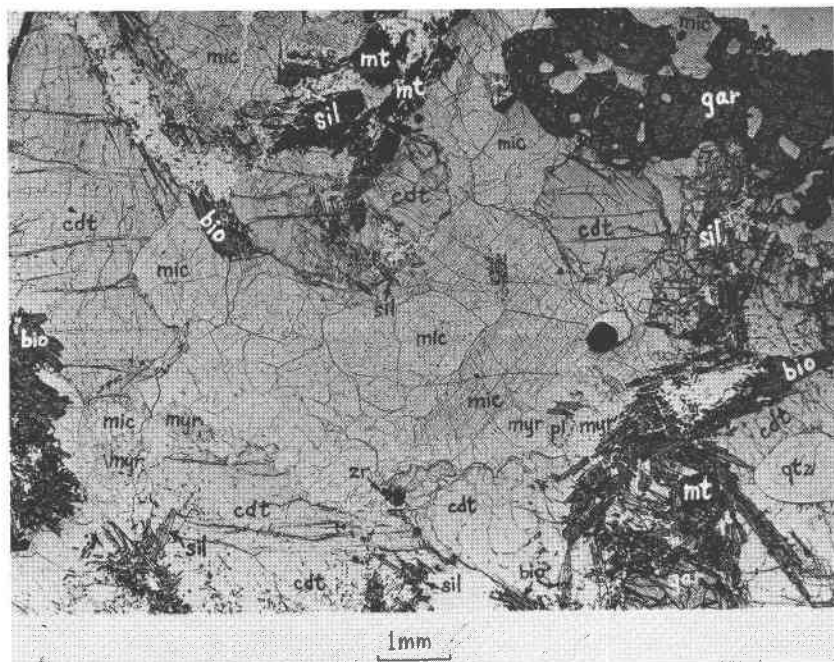
Fig. 3. Small aggregate of microcline in cordierite-rich gneiss, Union Connecticut. The grain of myrmekite in right center has only a core remaining of the original grain of andesine. Biotite, bio; cordierite, cdt; garnet, gar; microcline, mic; myrmekite, myr; plagioclase, pl; quartz, qtz, sillimanite, sil; magnetite, mt; and zircon, zr. Plane light.

nearly all microcline. Some grains of microcline interfinger into grains of biotite as thin sheets parallel to the cleavage of the latter. Grains of garnet and cordierite that are embayed by microcline are seen in thin section, as in Fig. 3. Thin shells of sillimanite are present between much of the microcline and embayed garnet.

DESCRIPTION OF MINERALS

Analyses of biotite, cordierite, and garnet from the gneiss at Sturbridge are given in Table 1. The formula of the biotite, calculated on a basis of 24 anions, is:
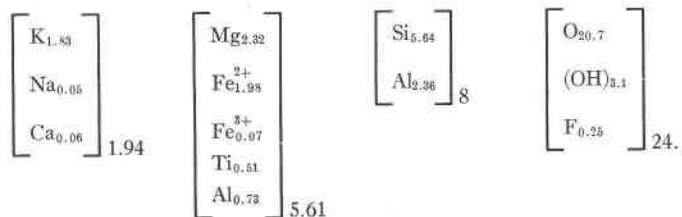
$$\begin{bmatrix} K_{1.83} \\ Na_{0.05} \\ Ca_{0.06} \end{bmatrix}_{1.94} \begin{bmatrix} Mg_{2.32} \\ Fe^{2+}_{1.98} \\ Fe^{3+}_{0.07} \\ Ti_{0.51} \\ Al_{0.73} \end{bmatrix}_{5.61} \begin{bmatrix} Si_{5.64} \\ Al_{2.36} \end{bmatrix}_{8} \begin{bmatrix} O_{20.7} \\ (OH)_{3.1} \\ F_{0.25} \end{bmatrix}_{24.}$$

	Biotite[1]	Cordierite[2]	Garnet[2]
SiO_2	37.3	48.2	39.1
TiO_2	4.5	0.00	0.03
Al_2O_3	17.3	32.9	22.2
Fe_2O_3	0.71	0.00	0.00
FeO	15.5	7.4	30.8
MgO	10.3	8.78	6.58
CaO	0.42	0.05	1.04
Na_2O	0.19	n.d.	n.d.
K_2O	9.6	n.d.	n.d.
H_2O[3]	3.1	1.66	n.d.
F	0.54	n.d.	n.d.
MnO	(0.019)[4]	0.06	0.56
Sum[5]	99.3	99.05	100.3

[1] Analysis by B. L. Ingram.

[2] Analysis by C. A. Kinser.

[3] Determined by Penfield method.

[4] Determination by semiquantitative spectrographic analysis.

[5] Oxygen equivalent for fluorine subtracted from total.

n.d.: not determined.

That of cordierite, on a basis of 18 atoms of oxygen, is:

$$Mg_{1.36}Fe_{0.64}Al_{4.00}Si_{4.99}O_{18} \cdot 0.57H_2O$$

Schreyer and Yoder (1960, p. 94) have suggested that H_2O may be present in molecular form in interstices in the cordierite structure, and so the formula of cordierite is given with H_2O as water of hydration. The formula of the garnet on a basis of 24 atoms of oxygen is:

$$Fe_{4.0}Mg_{1.52}Ca_{0.17}Mn_{0.07}Al_{4.07}Si_{6.07}O_{24}$$

The molar ratios $MgO:(MgO+FeO)$ of these minerals are: biotite, 0.54; cordierite, 0.68; and garnet, 0.28. Formula of the garnet in terms of end numbers is:

$$alm_{69.5}pyr_{26.4}gro_{2.9}spe_{1.2}$$

The β and γ indices of refraction in sodium light of biotite at both Sturbridge and Union are about 1.640. The biotite is pleochroic from pale yellowish brown to red-brown. Indices of the cordierite from Sturbridge are: $\alpha = 1.541$, $\beta = 1.547$, and $\gamma = 1.553$, all ± 0.002; those of Union cordierite are similar except that $\alpha = 1.542$. For garnet at Sturbridge $n = 1.795$, ± 0.004, and that from Union is 1.792.

The distortion index of the cordierite, as defined by Miyashiro (1957, p. 44–45), is 0.25 ± 0.02. Garnet was x-rayed by R. O. Fournier; the averages of four determinations (hkl: $12 \cdot 2 \cdot 0$, $11 \cdot 5 \cdot 2$, $12 \cdot 6 \cdot 0$, and $10 \cdot 9 \cdot 3$) from Sturbridge garnet and of five determinations (hkl: $12 \cdot 2 \cdot 0$, $11 \cdot 5 \cdot 2$, $12 \cdot 6 \cdot 0$, $12 \cdot 6 \cdot 2$, and $10 \cdot 9 \cdot 3$) of Union garnet were each $a = 11.49 \pm 0.05$ Å.

Most grains of microcline show grid twinning, but some do not. About half of the grains of this mineral are microperthitic with fine filaments or irregular patches of sodic plagioclase. The volume of plagioclase in the perthite ranges from a trace to about 20 per cent. Microcline from a large crystal in pegmatite at Sturbridge was homogenized by heating at 900° C. for 60 hours and then x-rayed. The $(\bar{2}01)$ method with $KBrO_3$ as an internal standard was used (Orville, 1958, p. 208) and indicated a composition of 82 weight per cent of $KAlSi_3O_8$.

The plagioclase is sodic andesine. Gradationally zoned grains are not uncommon; these have rims of calcic andesine or sodic labradorite.

METAMORPHIC PEGMATITES

Lenses of pegmatite from a fraction of an inch to about 10 feet in thickness lie scattered in the gneiss. The lenses commonly lie parallel to the foliation of the gneiss, which locally wraps around them. A few lenses, however, transect the foliation. Blobs or blotches of pegmatite of very irregular shape, from an inch to about 10 feet in maximum dimension, are also found in the gneiss. These latter pegmatites mostly transect the foliation of the gneiss without displacing it, and many of them decrease in grain size toward the margins and fade into the quartzo-feldspathic aggregates of the gneiss. Typical examples are shown in Fig. 4. These blobs are interpreted to have replaced the gneiss. Both forms of pegmatite consist of about 80 to 95 per cent by volume of microcline, with the remainder quartz, biotite, and accessory minerals. Cordierite, garnet, graphite, and rarely plagioclase and sillimanite are found along the margins of the pegmatite. The optical properties of these minerals are virtually identical to their counterparts in the gneiss. Muscovite is not present in these pegmatites. Margins of many of the pegmatites are granulated. In thin section the microcline microperthite, quartz, and cordierite of a marginal specimen are seen to be closely fractured and show pronounced undulatory extinction. Much of the microcline in the larger bodies, however, is in translucent grains of maximum dimension 1 to 4 inches.

The pegmatites do not show chilled zones, internal zoning, or reaction zones with the enclosing gneiss. The same suite of minerals of like compositions is found in the pegmatites as in the adjacent gneiss. Furthermore, the experimental studies of Tuttle and Bowen (1958, p. 54–75) on the system $KAlSi_3O_8$-$NaAlSi_3O_8$-SiO_2-H_2O indicate that microcline-rich
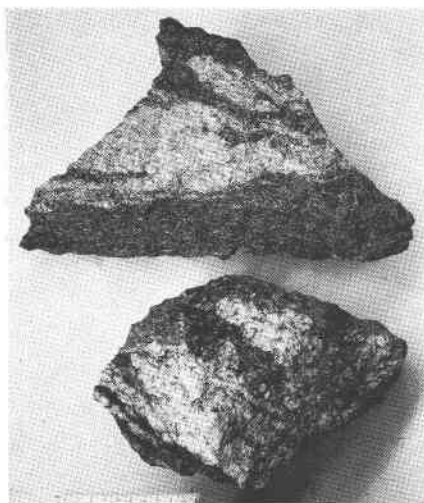
Fig. 4. Specimens of gneiss with small microcline-quartz pegmatites from Sturbridge, Massachusetts (upper), and Union, Connecticut (lower).

pegmatite magma would be far removed from the minimum-melting composition of this system, would be molten at temperatures of about 800°–900° C. (depending on the water pressure), and thus such a melt would be expected to react strongly with the abundant plagioclase of the gneiss. Absence of such reaction, together with the field and textural relations of the pegmatites, suggests that they are not of magmatic, but of metamorphic origin. One probable source of their potassic feldspar is found in the gneiss itself, in the reaction of muscovite and quartz to sillimanite and microcline. Solutions derived from granitic magmas are another possible, but problematical, source of the potassic feldspar in the pegmatites.

The sillimanite of the gneiss is believed to have formed largely from muscovite. The gneiss contains abundant Al_2O_3 and K_2O, and is of a proper bulk composition for growth of muscovite at lower metamorphic rank. The transformation of muscovite to sillimanite and potassic feldspar may be represented by the well-known equation (see Heald, 1950, p. 74–75):

MUSCOVITE + QUARTZ = SILLIMANITE + K-FELDSPAR (+ H_2O),

where the substitution of Na for K in muscovite and feldspar is neglected. This reaction has temperature, rock pressure, and activity of H_2O as external variables. At Sturbridge and Union this reaction is believed to have taken place, with sillimanite formed *in situ*, and with the constitu-

ents of microcline perhaps first dissolved in an aqueous phase, transported a short distance, and then deposited as pegmatite.

APPLICATION OF THE PHASE RULE

The fact that gneiss and pegmatite of virtually identical mineralogy formed at Sturbridge and at Union, 10 miles apart, implies that the grade of metamorphism was the same at the two localities, and also that equilibrium was reached at each place. These rocks, as now seen, are believed to represent a stable assemblage, one probably formed at or very near the peak of the metamorphism.

The phase rule may be applied to these rocks. There are 9 components present in significant amounts; these are: Al_2O_3, CaO, H_2O, FeO, Fe_2O_3, K_2O, MgO, Na_2O, and SiO_2. The component H_2O probably was mobile to the extent that its activity was constant throughout the rock mass under discussion. The remaining 8 components would be "fixed" or "inert" (Thompson, 1955, p. 81; Korzhinskii, 1959, p. 17). The phase rule thus allows 8 minerals to be stable at arbitrary rock pressure, activity of H_2O, and temperature. Eight minerals are present: biotite, cordierite, garnet, magnetite, sodium-bearing microcline, plagioclase, quartz, and sillimanite. The phase rule is not violated.

The assemblage may be viewed as forming an 8-phase region in 8-component space, with the independent variables temperature, rock pressure, and activity of H_2O externally applied. Small variations of the 8 "fixed" components would not change the assemblage of minerals, but would merely change their relative proportions. The slightly higher proportions of cordierite and garnet in the gneiss at Union are a reflection of slightly greater proportions of MgO and FeO than in the gneiss at Sturbridge.

The two accessory phases graphite and pyrite, and their associated components carbon and sulfur deserve special comment. The presence of graphite and pyrite in the gneiss suggests that reactions of C and S with oxygen-bearing components to form CO_2 and SO_2 have not occurred to any noticeable extent at the present high metamorphic grade. Any earlier reactions cannot be traced. In application of the phase rule C and S are classed as inert components, and the system is considered closed to CO_2 and SO_2. The activities of any CO_2 or SO_2 formed in these rocks would be both negligibly small and variable from place to place. This is in contrast to metamorphism of carbonate-bearing rocks, which have much higher activities of CO_2, and which may have CO_2 (or C) as a mobile component (Thompson, 1955, p. 79; Korzhinskii, 1959, p. 117–135).

These rocks may be partially represented in an AFM diagram, as shown in Fig. 5. The ratios of $MgO:FeO$ in the biotite, cordierite, and garnet

are shown. This diagram, of course, is not a ternary phase diagram, and the four minerals shown on it may coexist stably. The garnet and cordierite are the most magnesian and most ferrous, respectively, that would be expected in assemblages with biotite and sillimanite. In an assemblage free of cordierite, with similar external conditions but different composition, both garnet and biotite would be more ferrous. Similarly, in a garnet-free assemblage the cordierite and biotite would be more magnesian. An interesting paper by Chinner (1959, p. 112–114) discusses the stability
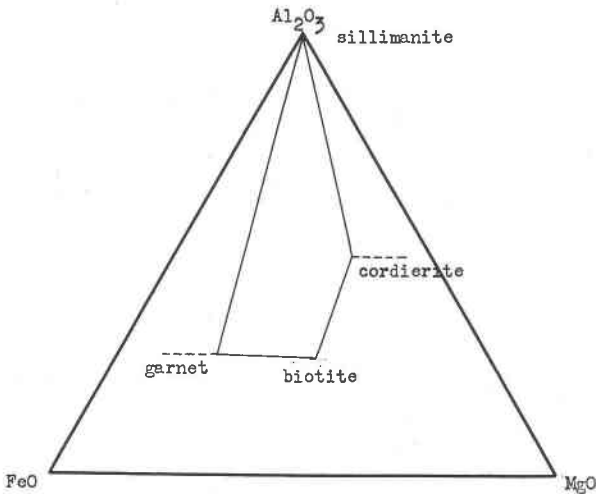

FIG. 5. AFM diagram for gneiss at Sturbridge, Massachusetts, and Union, Connecticut, showing compositional relations of biotite, cordierite, garnet, and sillimanite. Other minerals of the assemblage are graphite, magnetite, sodium-bearing microcline, plagioclase, pyrite, and quartz.

of garnet, cordierite, and biotite in regional versus thermal environments, and shows tie lines of 7 cordierite-garnet pairs on the diagram Mg cordierite-Fe cordierite-almandite-pyrope.

OTHER OCCURRENCES

Cordierite-garnet-bearing gneiss similar to the ones described above are found in northwestern Canada, Finland, Sweden, and Norway.

A gneiss north of Great Slave Lake, N. W. T., Canada, consists of andesine, biotite, cordierite, garnet, graphite, microcline, sillimanite, green spinel, and tourmaline (Folinsbee, 1940, 1941). The green spinel (pleonaste) presumably is not stable with quartz. Folinsbee analyzed the cordierite and garnet, and found that the cordierite contains 39 mole

per cent of Fe-end member, and the garnet 24 mole per cent of pyrope. Pegmatites are closely associated with this gneiss and contain cordierite and garnet.

Cordierite-garnet gneisses are found interlayered with the granulites of Finnish Lapland, as described by Eskola (1952). Some of these gneisses are migmatitic. A gneiss from the mouth of Sotajoki consists of the same assemblage as the rocks at Sturbridge and Union, except that graphite is absent. The cordierite has 31 mole per cent of Fe-end member, and the garnet is 39 per cent pyrope (Eskola, 1952, p. 149, 153). Associated rocks contain hypersthene.

Cordierite-garnet gneiss is found over a wide area in southern Finland. Hietanen (1943, p. 12–17) described a biotite-cordierite-garnet-ilmenite-microcline-oligoclase-quartz-sillimanite gneiss from Häähäjärvi, Kalanti, area, southwestern Finland. The indices of refraction are given (Hietanen, 1943, p. 12, 14):

$$
\begin{array}{lll}
\text{biotite:} & \beta = \gamma = 1.647 \\
\text{cordierite:} & \alpha = 1.547 \\
& \beta = 1.552 \\
& \gamma = 1.557 \\
\text{garnet:} & n = 1.805
\end{array}
$$

These indices suggest that the compositions of these three minerals are similar to those of the cordierite-garnet gneisses of Sturbridge and Union. Hypersthene was not found in the Kalanti area (Hietanen, 1943).

In the Turku area Hietanen (1947, pl 1023–1026, 1071) found cordierite-garnet rocks like those at Kalanti, to the northwest. Migmatites are abundant here; those in cordierite-garnet gneiss consist largely of quartz, microcline, and plagioclase, and also contain cordierite and garnet (Hietanen, 1947, p. 1071). These rocks differ from those of New England in several respects. First, the Finnish rocks commonly show an interlayering of thin bands of cordierite gneiss, garnet gneiss, and cordierite-garnet gneiss. In thin section, cordierite and potassic feldspar show a reaction texture, having formed biotite and sillimanite. In addition, a second generation, or later growth of cordierite is seen, in which large grains of this mineral contain many inclusions of quartz, and of biotite, in parallel arrangement (Hietanen, 1947, p. 1025–1026). Hypersthene-bearing rocks were found in this area.

The West Uusimaa complex of crystalline rocks, which lies 70 to 130 km east of Turku, has been described by Parras (1958). Cordierite-garnet gneisses here are coarse grained, are intimately mixed with veins and lenses of quartz-microcline pegmatite, and contain layers of garnet-hypersthene gneiss. Specimen no. 53 of Parras (1958, p. 119) consists of the same assemblage as the gneiss at Sturbridge and Union. The garnet

of no. 53 contains 26 mole per cent of pyrope; the β-index of the biotite is 1.644, very close to the 1.640 value of the New England biotite; and the cordierite was not studied. The associated plagioclase is An_{20}. Specimen no. 60 of Parras is the same assemblage; its plagioclase is An_{25}, and the other minerals were not studied.

Cordierite-garnet gneisses also crop out in southern Finland near Mikkeli and Lake Laatokka (Parras, 1946), and near Porkala (Kranck, 1937, p. 77–78). Parras, Hietanen, and Eskola (see references as given) believe that metamorphism of argillaceous rocks has produced the cordierite-garnet gneisses.

The Sörmland gneisses, southwest of Stockholm, Sweden, contain cordierite-garnet gneiss, with intimately mixed microcline-rich pegmatite (Magnusson, 1950, p. 17). J. A. W. Bugge (1943, p. 16) has described similar rocks from the vicinity of Risör and Kragerö, southern Norway. Anthophyllite, rather than hypersthene, is associated with these Swedish and Norwegian rocks.

Several remarks may be made in summary. The association of cordierite-garnet gneiss and microcline-rich pegmatite, both free of primary muscovite, is a common one. The author follows Holmquist's (1921) assertion that these are "venitic" pegmatites, *i.e.*, formed by segregation of material originally contained in the gneiss itself. Formation of microcline-quartz pegmatite in these localities perhaps may be related to the decomposition of muscovite, as suggested above for those of Sturbridge and Union.

Cordierite-garnet gneisses are associated with anthophyllite (gedrite)-bearing rocks in some localities, with hypersthene-bearing rocks in others. The compositions of biotite, cordierite, and garnet in these gneisses are much the same in either case, except for the pyropic garnet described by Eskola. The assemblage biotite-cordierite-garnet-microcline-magnetite-plagioclase-quartz-sillimanite is stable through the range of external conditions (temperature, rock pressure, and activity of H_2O) over which the transition: anthophyllite→hypersthene takes place (in rocks of appropriate composition, of course). Thus this assemblage spans the amphibolite-granulite facies boundary of Eskola; this point has been discussed by Eskola (1952, p. 162–169) and briefly by Fyfe and Turner (1958, p. 159). Much detailed work must be done to determine the extent of stability of biotite and of cordierite in the so-called "granulite" facies.

REFERENCES

BUGGE, J. A. W. (1943), Geological and petrographical investigations in the Kongsberg-Bamble formation. *Norges Geol. Unders.*, **160.**

CHINNER, G. A. (1959), Garnet-cordierite parageneses. *Carnegie Inst. Wash., Year Book,* **58,** 112–114.

EMERSON, B. K. (1917), Geology of Massachusetts and Rhode Island. *U. S. Geol. Survey Bull.*, **596.**

ESKOLA, P. (1952), On the granulites of Lapland. *Am. Jour. Sci., Bowen Volume,* 133–171.

FOLINSBEE, R. E. (1940), Gem cordierite from the Great Slave Lake area, N. W. T., Canada (abs.). *Am. Mineral.*, **25,** 216.

———— (1941), The chemical composition of garnet associated with cordierite. *Am. Mineral.*, **26,** 50–53.

FYFE, W. S., F. J. TURNER, AND J. VERHOOGEN (1958), Metamorphic reactions and metamorphic facies. *Geol. Soc. Am. Mem.*, **73.**

HEALD, M. T. (1950), Structure and petrology of the Lovewell Mountain quadrangle, New Hampshire. *Geol. Soc. Am. Bull.*, **61,** 43–89.

HIETANEN, A. (1943), Über das Grundgebirge des Kalantigebietes im südwestlichen Finnland. *Comm. géol. Finlande Bull.*, **130.**

———— (1947), Archean geology of the Turku district in southwestern Finland. *Geol. Soc. Am. Bull.*, **58,** 1019–1084.

HOLMQUIST, P. J. (1921), Typen und Nomenklatur der Adergesteine. *Geol. Fören. Förh.*, **43,** 612–631.

KORZHINSKII, D. S. (1959), *Physiochemical Basis of the Analysis of the Paragenesis of Minerals.* Consultants Bureau, Inc., New York.

KRANCK, E. H. (1937), Beiträge zur Kenntnis der Svecofenniden in Finnland. *Comm. Géol. Finlande Bull.*, **119,** 69–91.

MAGNUSSON, N. H. (1950), The origin of the Sörmland gneisses. *Intel. Geol. Cong., 18th, Great Britain 1948, Rept., pt.* **3,** 14–19.

MIYASHIRO, A. (1957), Cordierite-indialite relations. *Am. Jour. Sci.*, **255,** 43–62.

ORVILLE, P. M. (1958), Feldspar investigations. *Carnegie Inst. Wash., Year Book,* **57,** 206–209.

PARRAS, K. (1946), On the coarse-grained garnet-cordierite gneisses of south and southwest Finland. *Comm. géol. Finlande Bull.*, **138,** 1–7.

———— (1958), On the charnockites in the light of a highly metamorphic rock complex in southwestern Finland. *Comm. géol. Finlande Bull.*, **181.**

RODGERS, J. R. M. GATES, AND J. L. ROSENFELD (1959), Explanatory text for preliminary geological map of Connecticut, 1956. *Conn. Geol. Nat. Hist. Survey Bull.*, **84.**

SCHREYER, W. (1958), Die Quarz-Feldspat-Gefuge der migmatischen Gesteine von Vilshofen an der Donau. *Neues Jahrb. Mineral.*, **92,** 147–170.

———— AND H. S. YODER, JR. (1960), Hydrous Mg-cordierite. *Carnegie Inst. Wash., Year Book,* **59,** 91–94.

SHAPIRO, L. AND W. W. BRANNOCK (1956), Rapid analysis of silicate rocks. *U. S. Geol. Survey Bull.*, **1036-C,** 19–56.

THOMPSON, J. B. (1955), The thermodynamic basis for the mineral facies concept. *Am. Jour. Sci.*, **253,** 65–103.

TUTTLE, O. F. AND N. L. BOWEN (1958), Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O. *Geol. Soc. Am. Mem.*, **74.**