# CORDIERITE IN PEGMATITE NEAR MICANITE, COLORADO

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Abstract

The Climax pegmatite of the Micanite district in Colorado contains unusually large masses of cordierite, which is altered in varying degree to pinite, consisting chiefly of muscovite, chlorite, and biotite, and traces of garnet, zoisite, and tourmaline. Data on 50 other occurrences of pegmatitic and vein cordierite are summarized, and the paragenesis of pegmatitic cordierite is discussed.

## Introduction

The Micanite pegmatite district lies across the Park-Fremont County line in south-central Colorado, a few miles northwest of the site of the former village of Micanite (Fig. 1). The deposits were investigated briefly by Sterrett (1923, p. 53), who recognized cordierite in the Climax deposit. The pegmatite was studied by the writer in 1946 and 1949, at which times some fresh and much altered cordierite was obtained. This collection was supplemented by material previously secured by Professor K. K. Landes, Chairman of the Department of Geology, University of Michigan. The cost of several thin sections was met by the Department of Mineralogy of the University of Michigan. Thanks also are due to Mr. Marion V. Denny for the photograph of Fig. 2 and to Professor C. B. Slawson of the Department of Mineralogy for a critical reading of the manuscript.

## General Geology

The Micanite area is underlain by pre-Cambrian rocks that include granitic gneiss, muscovite gneiss, sillimanite gneiss, mica schist, and biotite granite. Intrusive into the granite and the metamorphic layers are numerous masses of granitic pegmatite, which, in general, are very irregular in shape and structure, with numerous and large apophyses. Zonal structure is developed in some, with conspicuous central units of massive white quartz or of coarse microcline crystals together with massive quartz pods. Concentrations of muscovite occur locally, and it was for this mineral that the deposits first were mined about 1904. In 1934 they were reopened by the Colorado Feldspar Company of Canon City, Colorado, and moderate quantities of good quality feldspar and small amounts of grinding quality muscovite were obtained. Within the district ten major quarries and prospects are recorded (Fig. 1).

The chief minerals of the pegmatites are: quartz, pink microcline in crystals as much as 10 feet on edge, white albite, muscovite in books 2 feet or less in length, biotite, garnet, apatite, magnetite, beryl, sillimanite,

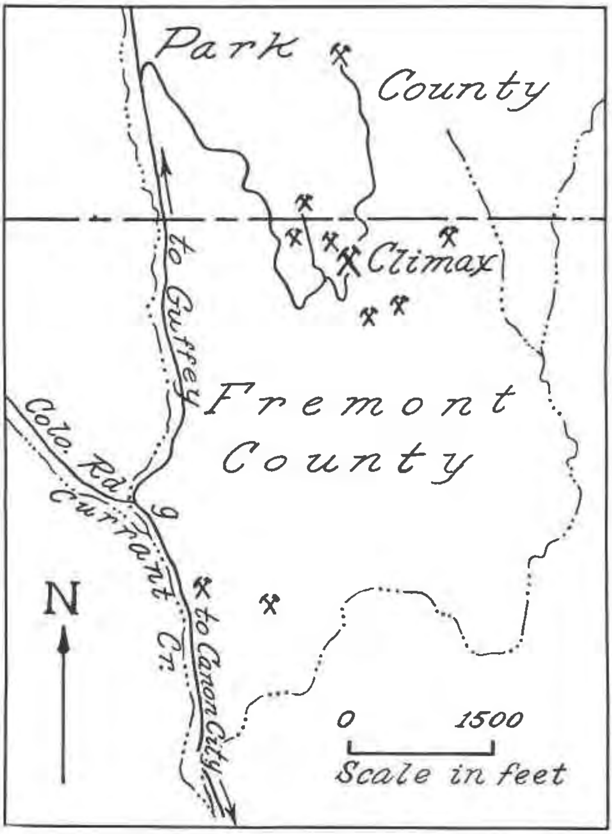


FIG. 1. Index map of part of Park and Fremont Counties, Colorado, showing location of the Micanite pegmatite district and the Climax deposit.

cordierite, pinite, hematite (as inclusions in muscovite), bismutite, and an unidentified iron-manganese phosphate.

## Climax Pegmatite

The Climax pegmatite is a dike of irregular shape with several large offshoots, which lies in sec. 5, T. 16 S., R. 72 W. on the west side of Micanite Ridge. The body dips moderately to the southeast and trends northeast across the foliation of biotite gneiss, which strikes northwest and dips 40–70° SE. One large apophyse trends north from the northwestern end of the dike, and another extends eastward from the eastern margin. The southwestern end of the dike "horsetails" into several small stringers. Other minor lenses of pegmatite continue the trend of the zone to the southwest. Pegmatite is exposed over a length of 460 feet and a width of 300 feet. The workings consist of eight irregular cuts and pits and a caved adit southwest of and below the cuts, which is reported to be 50 feet long.

The central part of the dike is a large body of massive white quartz whose margins contain veins and radial clusters of muscovite and a few pale green apatite crystals, several inches long. Scattered crystals of microcline as large as $3\times4$ feet also appear locally along the margin of the core. The quartz is chiefly milky with small patches of clear material. Much of the light brown mica shows "A"-structure and contains scattered to abundant hematite inclusions. Most of the books occur in tabular, moderately-dipping, fracture-controlled replacement masses, one foot or less thick, in which the blades stand normal to the fracture surface. Individual books $1\times1\frac{1}{2}$ feet were observed. The chief concentrations of muscovite appear to have been found along the hanging-wall margin of the core. The outer parts of the dike consist of graphically intergrown quartz and dark red microcline cut by large thin blades of muscovite-biotite intergrowth. Specimens of an altered iron-manganese phosphate were found on the dump.

## Cordierite

Masses of altered cordierite as much as three feet across are exposed in the wall of the irregular underhand stope from the largest open cut in the southeast part of the dike. They occur in intermediate zone pegmatite along the hanging-wall side of the core and are associated with mica clusters.

The optical properties of the cordierite are:

$$\text{Optically } (-),\ 2V=50°,\ r<v, \text{ distinct}$$
$$\alpha=1.552$$
$$\beta=1.560$$
$$\gamma=1.566$$

According to the graphs prepared by Folinsbee (1941) these data indicate a cordierite with 60% $Fe_2Al_4Si_5O_{18}$ and 1.5% alkalies.

Most of the somewhat rounded altered cordierite blocks consist of a coarse- to fine-grained mixture of green micaceous minerals commonly referred to as pinite. Relicts of gray to dark violet, glassy cordierite also can be recognized and crystals of red-brown garnet, $\frac{3}{4}$ inch in diameter are not uncommon. The aggregate is transected by numerous, generally parallel fractures to which most of the micaceous flakes are normal and which represent the *c* {001} parting planes that develop in cordierite with the onset of alteration (Fig. 2). Directly on the fracture surfaces are thin coatings of micaceous flakes lying parallel with the cracks. Irregularly veins of coarse, comb-structure muscovite, $\frac{3}{4}$ inch wide, cut the pinite at various angles.

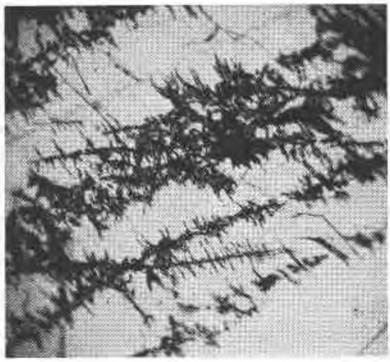

FIG. 2. Specimen of pinite after cordierite, showing development of micaceous blades normal to the {001} parting of the cordierite. Length of specimen is seven inches. Climax pegmatite, Colo.

FIG. 3. Cordierite (light-colored) veined and replaced by pinite. Note parallel stringers along {001} parting. Magnification 20×. Climax pegmatite, Colo.

Microscopically, several stages of alteration can be recognized. The large crystals of cordierite are first traversed by thin, hair-like veinlets of fine-grained muscovite, which send off regular, parallel branches along the *c* {001} parting direction (Fig. 3). In the same stage small radiating clusters of colorless to pale green muscovite flakes develop in widely scattered parts of the cordierite. In the second stage (Fig. 4), subangular pieces of cordierite appear as a replacement breccia, veined and corroded by the micaceous minerals, muscovite, biotite, and chlorite, many flakes of which are stained by limonite. Muscovite is the most abundant of the three, with pale green chlorite next, and a rare flake of biotite, which shows a pleochroism from dark olive green to pale buff. The cordierite relicts are crowded with minute dusty inclusions whose development appears to indicate incipient alteration. In the final stage (Fig. 5) the material consists entirely of a green, shreddy to felted aggregate of fine-grained, plumose muscovite and chlorite with scattered groups of larger muscovite and biotite plates. Here and there occur groups of small, corroded zoisite anhedrons which recall the occurrence of clinozoisite in the pinite of Ebersdorf, Austria (Hlawatsch, 1911). In the final stage tourmaline, pleochroic from pale rose to deep blue, appears in small euhedral crystals (Fig. 6).

FIG. 4. Angular relicts of cordierite (light-colored) cut by ramifying veinlets of pinite and limonite. Magnification 20×. Climax pegmatite, Colo.

FIG. 5. Pinite, chiefly muscovite and chlorite with minor biotite, pseudomorphous after cordierite, in plumose and dendritic arrangement. Crossed nicols, magnification 20×, Climax pegmatite, Colo.

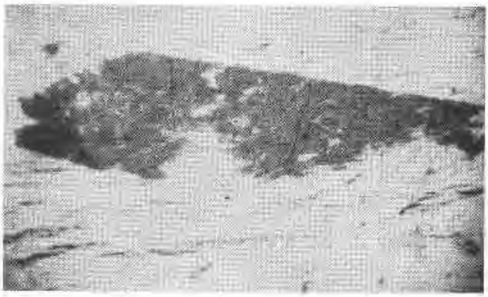

FIG. 6. Tourmaline in pinite after cordierite. Magnification 20×, Climax pegmatite, Colo.

## OTHER CORDIERITE PEGMATITES

*North America*

Cordierite has been found in several other North American pegmatites. Fettke (1914) records it from pegmatites related to the Thomaston granite in southeastern New York. Among the 25 minerals reported from these pegmatites are the aluminous ones, chrysoberyl, dumortierite, kyanite, and cordierite partly altered to pinite. The country rock is the micaceous Manhattan schist. Cordierite from the Haddam, Connecticut, locality has been described by Shepard (1841) and Hovey (1888). The pegmatite, which occurs in biotite gneiss containing cordierite and sillimanite, consists of quartz, microcline, albite, schorl, garnet, zircon, columbite, bismutite, chrysoberyl, and dark blue to purple cordierite, in part pinite. Crystals of gem quality cordierite 5 inches across have been obtained. Cordierite-pinite also occurs in the Collins Hill pegmatite at Middletown, Connecticut (Rice and Foye, 1927) and in the J. Neal pegmatite near Unity, New Hampshire (Shepard, 1841).

Other cordierite-bearing pegmatites from Connecticut have been described by Foye (1922), who records pinite from the Strickland pegmatite at Collins Hill, Portland and cordierite itself in the Bolton schist a few centimeters from the pegmatite contact. The Tims Hill deposit, which contains oligoclase, biotite, tourmaline, allanite, gahnite, and cordierite (altered in part to "fahlunite"), is at the contact of the Haddam gneiss and the Middletown series.

An occurrence at Guilford, Connecticut, usually referred to as a gneiss, consists of blocky masses of purple cordierite, as much as $2\frac{1}{2}$ inches on edge, in a fine-grained, light colored quartz-feldspar-biotite rock.

A dark colored pegmatite in serpentinized peridotite at Winchester, California (Murdoch, 1936), contains oligoclase-andesine, orthoclase, quartz, schorl, biotite, andalusite partly replaced by sillimanite, and bright blue cordierite grains. Pegmatitic lenses in garnet-sillimanite gneiss that occur north of Great Slave Lake, Northwest Territory, Canada (Folinsbee, 1940) contain $4\times2\times2$-inch pieces of gem cordierite, pleochroic from blue to yellow. Ball (1923) notes pegmatites on Upernivik and Langö Islands, latitude 72°47′, Greenland, in which quartz, potash feldspar, garnet, biotite, pyrite, yellow kyanite, and gray-violet cordierite in pieces as large as four centimeters, are the constituents.

*Europe*

Several cordierite pegmatites are known in Finland. The Nyäng pegmatite in gabbro-amphibolite on Kimito, which has been studied by Eskola (1914, p. 38) and Pehrman (1945) contains the usual granitic pegmatite suite plus spinel, sillimanite, and cordierite, largely pinite (gigantolite). According to Eskola (1914), cordierite also is found in pegmatites associated with a microcline granite at Puurolampi near Orijärvi and intrusive into leptite, granite, amphibolite, and gabbro. The cordierite crystals, altered to pinite, display the faces, (010), (110), (130), and (001). A pegmatite at Degerö near Helsingfors consists of microcline, quartz, oligoclase-andesine, biotite, and cordierite in four-centimeter crystals, partly replaced by pinite (Pehrman, 1932). The presence of previously reported cordierite relicts in gigantolite pseudomorphs of the Tammela pegmatites is denied by Mäkinen (1913), who claims the original mineral was tourmaline. Among the 24 minerals in these bodies are andalusite, chrysoberyl, and gigantolite (cordierite?).

Pehrman (1936) has also discovered cordierite pegmatite in plagioclase-biotite gneiss near Åbo. The minerals are microcline, oligoclase, quartz, biotite, apatite, pyrite, zircon, and cordierite, as much as 3.5 cm. across, bordered by sillimanite needles.

Andersen (1931) notes two Norwegian examples of cordierite pegmatites in his group of pegmatites "endemic in metamorphic rocks." One, on the island of Söndeledfjord, contains oligoclase, quartz, biotite, apatite, hematite, anthophyllite, and cordierite and occurs as lenses in anthophyllite-cordierite-plagioclase gneiss. Another, on a small island west of the island of Hannöen, is in quartz-biotite-garnet schist and consists of quartz, plagioclase, garnet, biotite, apatite, and cordierite.

Kuznetzov (1923, 1930) has described a pegmatite near Lake Uvildy in the southern part of the Kyshtym district, Ural Mountains, U.S.S.R., that contains the accessory minerals, black, blue, and pink tourmaline, garnet, beryl, blue dumortierite, and cordierite. The country rocks are mafic and ultramafic in composition. The cordierite pegmatite of Masslyanka from this area has been classed as migmatic by Fersman (1925). Pegmatites in the Altaï Range near the Caucasian Sea contain cordierite and andalusite with quartz, microcline, muscovite, tourmaline, monazite, rutile, pyrite, molybdenite, powellite, beryl, euxenite, and sericite (Kryzanovskii and Labuntzov, 1926).

In Czechoslovakia cordierite has been recorded from a number of pegmatites. At Velká Skála near Pisek it occurs with albite, apatite, and beryl and is partly replaced by pinite (gigantolite) (Ježek and Krejčí, 1919). Similarly altered, it is found in pegmatite at Wasserhäuseln, Petschau in Bohemia (Gareiss, 1901). Pegmatite at Dolni Bory, Moravia, has the unusual accessory assemblage of tourmaline, chlorapatite, monazite, pyrophyllite, diaspore, andalusite, and cordierite. Both tourmaline and cordierite are partly changed to pinite (Sekanina, 1928, and Jaroš, 1936). Zoubek (1927) has noted a pegmatite in cordierite gneiss at Pelhrimova, with accessory garnet, dumortierite, and cordierite.

In Austria cordierite-bearing pegmatite occurs at Ebersdorf near Pöchlarn in biotite gneiss. The pegmatite minerals are orthoclase, quartz, oligoclase-andesine, muscovite, biotite, schorl, pyrite, dumortierite, andalusite, sillimanite, and cordierite (Hlawatsch, 1911). Pinite, which partly replaces cordierite, contains clinozoisite. Quartzose pegmatitic lenses at two localities in the Selrain Alps, at Montavon and in the Pitzthal, contain plagioclase, muscovite, blue tourmaline, ilmenite, andalusite, and cordierite. Pinite after cordierite contains minor quantities of quartz, chlorite, limonite, epidote, garnet, and kyanite (Gemböck, 1898). The surrounding rock is a biotite schist. A well-zoned pegmatite at Vilshofen on the Danube in Bavaria, Germany, has a core of massive quartz, throughout which are scattered hundreds of pinite "crystals", 10×5 centimeters in size. Although no cordierite relicts were detected (Müllbauer, 1930), recognition of the faces (001), (110), (010), (130), and (100) shows that cordierite was the original mineral. The wall rock is biotite gneiss. A well defined group of aluminous, quartz-rich pegmatites has been recognized in Bavaria by Scholz (1925). One variety, represented by the occurrences at Taferlhöhe by Oberfrauenau, Bärenloch on the Arber, Ansdorf by Hohenwarth, Lengau and Herzogau by Waldmünchen, Düllenberg by Waldassen, and Wintersberg and Katherinenberg in the Fichtelgebirge, contains gigantic individuals of andalusite and much cordierite-pinite as well as biotite, tourmaline, ilmenite, and "uranium mica". Other varieties have sillimanite, kyanite, staurolite, dumortierite, and lazulite.

From Ariège in the Pyrenees, Lacroix (1892) has described a pegmatite with accessory garnet, tourmaline, corundum, and andalusite. An associated quartz vein, also in mica schist, contains tourmaline, andalusite, and large crystals of cordierite-pinite.

*Africa*

Lacroix (1939) examined at Ankaditany in South Madagascar a pegmatite injected into a quartz-free, biotite-sillimanite gneiss containing local garnet and cordierite. The pegmatite consists of microcline, quartz, almandite, and cordierite in about equal amounts, although in some parts cordierite predominates and biotite is subordinate.

*Asia*

Near Pipra, in Rewa, India, in a pyroxene granulite consisting of enstatite, diopside, hornblende, biotite, quartz, and plagioclase, Dunn (1929) discovered coarse "segregations" of enstatite-cordierite rock, with minor garnet, sillimanite, quartz, magnetite, and biotite. Brown and Judd (1896) have described a cataclastic, granitic pegmatite from Burma with accessory sillimanite and cordierite.

Shibata (1936) has investigated several cordierite pegmatites in Japan. About two kilometers north of Sasago on the Chûô Railroad is exposed a body of pegmatite containing a fine-grained plagioclase border zone, a wall zone marked by coarse-grained platy biotite, and a core of graphic granite surrounded by a core-margin unit containing andalusite and a graphic intergrowth of quartz and cordierite. This intergrowth is considered to have formed before the crystallization of the graphic granite of the core. Minute dumbell-shaped zircon crystals are included in the cordierite, which is in part altered to pinite. The country rock is a hornfels.

At Higashidani on the west side of Mount Torinomune a pegmatite in amphibolite and cordierite-anthophyllite-biotite schist has an outer zone of oligoclase-andesine, quartz, microcline, and biotite, and a central zone of microcline perthite, quartz, graphic granite, biotite, and cordierite (1×5 cm.). A third pegmatite at Mujinazawa is pipe-like in shape and has been injected into quartz diorite. The outer zone contains plagioclase, potash feldspar, and platy biotite. In the graphic granite core are rosettes of andalusite, schorl, and vugs containing kaolinite, quartz crystals, garnet, pyrite, and sericite. Around the core a graphic granite zone contains biotite and graphic quartz-cordierite rock with included zircon crystals.

Other Japanese occurrences of cordierite in veins or pegmatites are at Hitachi, where the mineral is found in a quartz vein in a copper ore (Kôzu and Watanabe, cited by Shibata, 1936, p. 225); at Naegi in a vein with topaz (same reference); and at Yagen-Yama in Mino Province, where it appears in the margins of banded "granite strings" (pegmatites?) associated with protolithionite, corundum, andalusite, and hercynite (Shibata, 1939).

*Australasia*

Simpson (1934) has recorded cordierite, partly altered to gigantolite and associated with spessartite in a pegmatite at Melville, Western Australia. Granite pegmatites, cordierite pegmatites, and andalusite pegmatites in peridotite are described by de Jong (1923) from the Kaiboba region on Ceram in the Dutch East Indies.

## DISCUSSION

Of the approximately fifty occurrences of pegmatitic or vein cordierite listed in the above summary the type of country rock is not known for 18, but for the rest the wall rock shows considerable variation. Types of biotite gneiss and schist are the most common (10 examples), but hornblende gneiss and amphibolite and their unmetamorphosed igneous equivalents also are represented (6 examples). At only four occurrences is cordierite recorded as being present in the wall rock (cordierite-bearing biotite gneiss and cordierite-anthophyllite rock). Other country rock types include granite, quartz diorite, leptite, granulite, and hornfels.

At a little more than half of the occurrences other aluminous minerals appear with cordierite: andalusite (20 examples), sillimanite (6), dumortierite (4), kyanite, chrysoberyl, and spinel (3 each), corundum (2), and topaz, pyrophyllite and diaspore (one each). Mineral distribution in several deposits shows that pegmatitic cordierite is not one of the earliest minerals to form. It appears to favor cores and core-margin zones, both of which are regarded as having developed at relatively late pegmatitic stages (Heinrich, 1948). Pegmatitic characteristics of the cordierite include coarse grain size, well shaped crystals, and graphic intergrowths with quartz.

The distribution of the occurrences reveals several possible aluminous pegmatite provinces that are characterized by accessory cordierite: (1) southern New England and adjoining New York, (2) southwest Finland, (3) Czechoslovakia and Austria, (4) Bavaria, and (5) Japan. About a dozen other localities are scattered throughout the world.

Theories seeking to explain the origin of pegmatitic cordierite may be listed as follows:

1. *Endogenic origin*
   (a) By inclusion and some recrystallization of material from adjacent, cordierite-bearing wall rocks. Such cordierite is xenocrystic.
   (b) By the incorporation of aluminous country rock at depth by granitic pegmatite magma. Such cordierite is of pyrogenic formation in a contaminated magma.
   (c) By the interaction of quartz-diorite pegmatite magma with amphibolite (Shibata 1936).
2. *Metamorphic origin.* By metamorphic differentiation, i.e., migration, concentration, and recrystallization of mineral substance originally disseminated in wall rock.
3. *Magmatic origin.* By direct crystallization from a pegmatitic magma characterized by a high primary content of aluminum. Such cordierite is of pyrogenic origin from an uncontaminated magma.

The first hypothesis, that of inclusion of wall rock material, has little to recommend it. Apparently cordierite is not a common constituent of the wall rocks of cordierite pegmatites. Moreover the mineral apparently prefers to form in the interior rather than the exterior parts of pegmatites. The mingling of pegmatitic magma with aluminous rock at depth has been a convenient means of explaining an excess of aluminum and can neither be proved or disproved in most cases. The regional distribution of accessory cordierite in some pegmatites may be a point against this hypothesis. One might also expect to find some definite evidence of contamination, possibly relicts of reworked inclusions or a considerable variation in the chemistry of certain pegmatites in a district. Fersman (1931) includes cordierite pegmatites in his Group IV, contact pegmatites, which he regards as contaminated pegmatites. Shibata (1936) ascribes the cordierite in pegmatite north of Sasago to this origin but later states that the mineral at Higashidani was formed by the interaction of quartz diorite pegmatite and amphibolite. The cordierite at Mujinazawa also is explained by this latter mechanism, even though no amphibolite exposures are recorded there. Such an interaction of basic country rock and intermediate magma is not likely to produce a pegmatite of granitic composition with a slight excess of aluminum and magnesium.

An origin by metamorphic differentiation is implied by Andersen (1931), who includes cordierite pegmatites in his group of pegmatites "endemic in metamorphic rocks". A similar origin is suggested by Dunn (1929) in his use of "segregation" for the occurrence at Pipra, Rewa, India. Metamorphic differentiation as outlined in the literature has always been but a vaguely defined term. The process, as sketched, appears to be analogous to a high intensity type of lateral secretion, and is believed to include selective subtraction of certain constituents from a large volume of rock, their migration to certain favored loci, and recrystallization as considerably larger mineral grains. Evidence for operation of these mechanisms is lacking in the case of cordierite pegmatites.

Cordierite is listed as an accessory pegmatite mineral by Ossan (1923) without mention of the possible mode of its formation. Ford (1932, p. 583) states, "Cordierite may be the direct product of igneous action, being stable over a considerable range of temperature and formed apparently without necessarily the aid of mineralizers." Johannsen (1932, Vol. II, pp. 166–167) writes, "Among the granites it (cordierite) is confined almost exclusively to the two-mica varieties. In some cases it is certainly primary; in others it is clearly metamorphic". Factors favoring the theory of pyrogenic formation of cordierite from an uncontaminated magma are: the occurrence of many cordierite pegmatites in provinces, the position of the mineral within pegmatites, its typical pegmatitic characteristics, and the absence of evidence of assimilation in most cordierite pegmatites.

## Conclusions

(1) Cordierite occurs in granitic pegmatites of two types: those containing other aluminous minerals, chiefly andalusite and sillimanite, and those in which cordierite is the only aluminous accessory.

(2) There appears to be a tendency for cordierite pegmatites to occur in provinces.

(3) The country rock around cordierite pegmatites usually does not contain cordierite, although lack of detailed data on country rock mineralogy may affect this conclusion. Wall rocks vary from acid to basic and are both igneous and metamorphic.

(4) The theory of crystallization from an uncontaminated pegmatite magma has favorable supporting arguments, but crystallization from a magma contaminated through assimilation of aluminous rock at depth cannot be dismissed in all cases. Cordierite that occurs near pegmatite margins may represent xenocrystic material.

(5) Cordierite that crystallized in the magmatic pegmatite stage is not in equilibrium during the hydrothermal stage and is altered to pinite, which consists chiefly of muscovite, chlorite, and biotite in varying pro-

portions. This change requires chiefly the introduction of potassium and hydroxyl by pegmatitic solutions.

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