THE GEOLOGICAL SURVEY OF WYOMING

HORACE D. THOMAS, STATE GEOLOGIST

BULLETIN NO. 41

# CORDIERITE DEPOSITS OF THE LARAMIE RANGE, ALBANY COUNTY, WYOMING

BY

**W. H. Newhouse and Arthur F. Hagner**

UNIVERSITY OF WYOMING

Laramie, Wyoming

September, 1949

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# CORDIERITE DEPOSITS OF THE LARAMIE RANGE, ALBANY COUNTY, WYOMING[1]

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W. H. Newhouse and Arthur F. Hagner

## ABSTRACT

The area of pre-Cambrian rocks described lies between a large anorthosite mass to the north and a smaller one to the south. Metanorite and syenite are succeeded southward by a series of gneisses which range in mineral composition from diorite through granodiorite to quartz monzonite. Quartz monzonite and granite are present as dikes and masses.

The gneisses formed by metasomatic replacement of sheared metaorite, and the cordierite deposits developed in the metanorite as an accompanying phase of the metasomatism. The deposits are lenticular in plan and formed by replacement along curved, closely spaced parallel fractures or foliation. Individual cordierite bodies range in size from a few inches long and wide to 240 feet by 30 feet. The cordierite in these bodies ranges from about 50 to over 80 percent, and most of the metanorite contains cordierite in varying amount. It is estimated that the combined deposits which are 100 feet or more long contain a total of over 500,000 short tons of cordierite.

## INTRODUCTION

The cordierite deposits are in the northwestern part of the Sherman quadrangle (Darton, et al, 1910) in T. 17 N., R. 71 and 72 W., in the Laramie Range, Albany County, Wyo. (fig. 1). They are about 15 to 20 miles northeast of Laramie; a gravel road from Laramie extends to within several miles of the deposits. A ranch road connects the main gravel road with the area.

In the map area is a series of pre-Cambrian gneisses that formed by replacement of sheared metanorite (pl. 1). Cordierite deposits were developed principally in the metanorite as an accompanying phase of the metasomatism. These deposits were found in 1946 during geological mapping by the U. S. Geological Survey in cooperation with the Geological Survey of Wyoming as part of program of Interior Department for development of the Missouri River Basin. Most of the deposits are in an area of low relief, but several are on a ridge about 300 feet above the surrounding country.

The writers wish to acknowledge the field assistance given by Messrs. Gabriel Dengo and George De Vore, who mapped the individual cordierite bodies on aerial photographs, and Messrs. Frank W. Osterwald and John P. Albanese who mapped one of the largest deposits with plane table and alidade. Mrs. Phyllis Hull separated some of the cordierite for chemical analysis, and Mrs. Ursula Chaisson determined 2V and checked $\beta$ on the separated material. Dr. M. L. Keith of the Geophysical Laboratory read the manuscript and made a number of critical suggestions, and Dr. H. G. Fisk of the University of Wyoming supplied some information on the uses of cordierite.

[1]Published by permission of the Director, U. S. Geological Survey.

## GENERAL GEOLOGY

The area of pre-Cambrian rocks described lies between a large anorthosite mass to the north and a smaller one to the south. The rocks in the map area have been divided into units on the basis of lithology (pl. 1). In each map unit the principal rock type is indicated, although minor amounts of other rocks may be present locally. From west to east these units trend southeast through east to northeast. Intense widespread shearing of norite formed "openings" for invasion of granitic material which, in varying degrees, formed a series of gneisses from the replaced host rock. The gneissic structure was inherited mainly from closely spaced fractures and foliation in the metanorite.

The map units include anorthosite, noritic anorthosite, metanorite, and syenite in the northern part. These units are succeeded southward by the following gneiss zones: syenite-diorite gneiss, porphyroblastic granodiorite gneiss, and quartz monzonite gneiss. Massive quartz monzonite is present

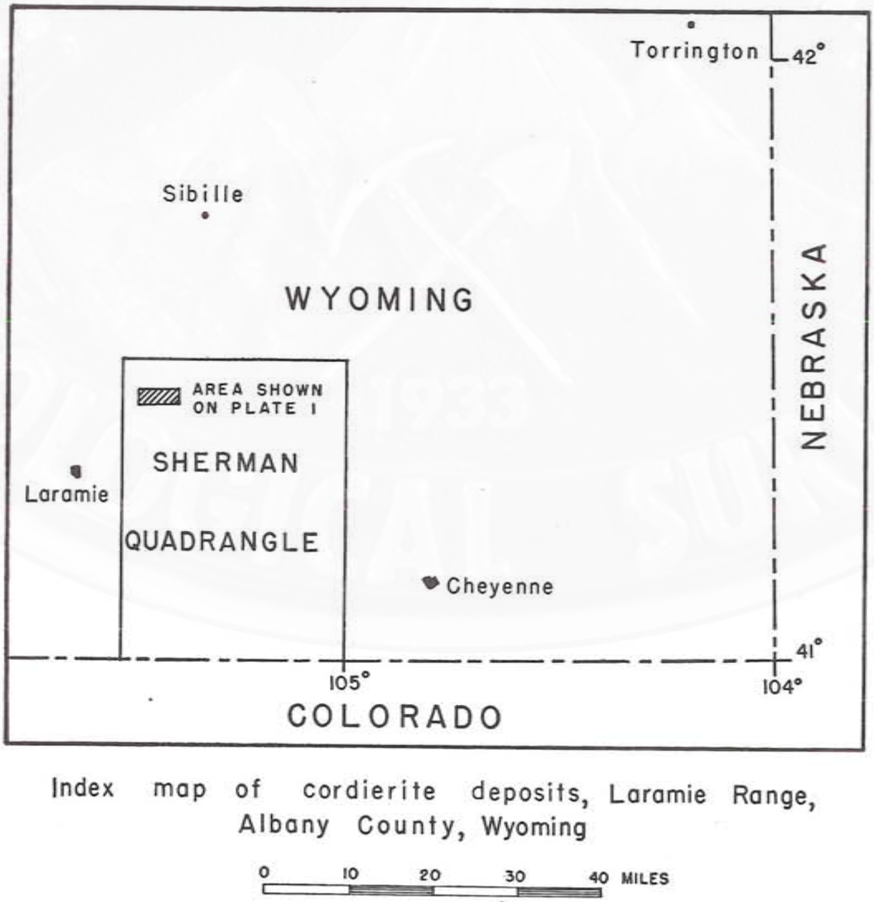



FIG. 1.

in the eastern and western parts of the area. A small mass of pyroxene-hornblende-plagioclase rock occurs in the south-central part of the metanorite. South of the southern projection of metanorite is a unit of mixed rocks which contains interlayered metanorite and gneisses of variable mineral percentages; locally garnet, cordierite, microcline, and quartz are abundant.

Deposits containing a high percentage of cordierite occur in the metanorite, syenite, and syenite-diorite gneiss.

The rocks of the area belong, for the most part, to the granulite facies. The metanorite and diorite gneiss contain rocks of the charnockite series, and in places the diorite gneiss is similar to the arendalite described by Bugge (1943). The cordierite-garnet gneisses in the mixed-rock zone are similar to some of the kinzigites in Fennoscandia described by Hietanen (1947) and others.

*Anorthosite and noritic anorthosite.*—Anorthosite and noritic anorthosite, the oldest rocks in the map area, extend 26 miles north and about 4 miles south of the gneisses. Anorthosite consists of gray and white andesine and labradorite with minor amounts of hypersthene. Noritic anorthosite contains from 10 to 20 percent dark minerals, mostly hypersthene. In both types the feldspar crystals are generally ½ to 1 inch long and 1/16 to ½ inch across; the larger dimensions are more characteristic of the noritic anorthosite. Crystals several inches across occur in a few places. The anorthositic rocks exhibit a foliation or parallelism of platy crystals; the 010 faces are subparallel to parallel. Layering is common, the layers containing different percentages of ferromagnesian minerals, or displaying different grain size. The layering, and the foliation due to platy plagioclase crystals, are parellel as observed in the outcrops. Layers range in thickness from a few inches to thousands of feet. In places anorthosite grades along the strike into noritic varieties.

Many fragments of anorthosite from a few inches to several hundred feet across are included in the later cordierite-bearing metanorite and in the gneisses. Only the larger inclusions are shown on the map.

*Metanorite, cordierite-bearing.*—The cordierite-bearing metanorite* is a gray, fine- to medium-grained rock that consists principally of cordierite with considerable amounts of microcline, andesine, hypersthene, biotite, and quartz. Quartz is erratic in distribution and all the minerals are present in widely varying amounts. Minor constituents are magnetite-ilmenite, apatite, and locally green spinel and garnet.

In the northernmost part of the area the rock retains some of the original structure of the norite but is sheared and has minor small local folds. Layering and schistosity are apparent chiefly on weathered surfaces where the rock contains cordierite. Southward, the metanorite grades into a rock with more marked foliation.

A small body of pyroxene-hornblende-plagioclase rock with minor amounts of magnetite and ilmenite occurs in the southern part of the metanorite (see pl. 1). It is believed to have formed by replacement of meta-

*Many other occurrences of cordierite-bearing rocks have been reported in the literature. Prider (1940, 1945) reviews some of these and others are described by Bugge (1943) and Hietanen (1947).

norite along a fold or series of curved fractures, where the dip and strike change direction.

The norite which existed in the southern part of the area is now almost completely replaced by diorite, granodiorite, and quartz monzonite gneisses. A few large fragments remain but, for the most part, metanorite inclusions in the gneisses are small and do not contain cordierite or hypersthene. They are typically lenses or wisps most of which average 2 to 8 inches in greatest dimension and ½ to 1 inch in thickness. They are generally oriented parallel to the gneissic structure but a few diverge by 5° to 20°. Rarely the orientation of the fragments diverges at greater angles from the gneissic structure.

Most of the metanorite inclusions are foliated. This foliation is due chiefly to a parallelism of biotite flakes and, more rarely, to a layering of light-colored and dark minerals. The degree of foliation varies considerably and depends largely upon the number of alined biotite crystals. When layering is present the rock is generally schistose.

Massive inclusions look like the unsheared metanorite. In places they contain introduced material from the same source as that which produced the gneiss in which they occur. This gneissic material may be concentrated along the borders, in the center, or throughout the inclusion. When almost completely replaced the fragments lose their form. The small inclusions, although finer-grained, approach the mineralogical composition of the enclosing gneiss. In the first stages of replacement of metanorite inclusions by porphyroblastic granodiorite gneiss, porphyroblasts of microcline form in the fragments; hornblende may also develop as smaller crystals. In more advanced stages of replacement the inclusions contain considerable material similar to the groundmass of the gneiss. Analogous replacement phenomena were observed in metanorite fragments within diorite gneiss and quartz monzonite gneiss, but the plagioclase metacrysts in these rocks are smaller than the microcline within fragments in the porphyroblastic granodiorite gneiss.

*Mixed-rock zone.*—The mixed-rock unit is near the center of the area just south of the large projection of metanorite. The unit is made up of interlayered metanorite and gneisses of varying mineral composition. Locally cordierite, garnet, microcline, and quartz are abundant. This zone of mixed rocks ranges in width from about 100 feet to 900 feet. Fractures, schistosity, and layers, and a few small drag folds are characteristic of the metanorite lenses in this unit. The gneisses are fine- to medium-grained and include diorites, granodiorites, and granites; the granites predominate.

*Syenite and syenite-diorite gneiss.*—Syenite is present as a well-defined layer about 1¼ miles long and 1/3 mile wide in the northwestern part of the area. About 1/5 mile south of the eastern end of this layer, in sec. 24, is a smaller syenite mass. In the NW¼ sec. 19 and the northern part of sec. 24 are two masses of syenite-diorite gneiss; a few smaller ones are present which are too small to map on the scale used. A mile and a half northeast of the map area a large syenite mass is associated with metanorite.

Syenite in the northwestern part of the map area is gray, coarse-grained and consists principally of large potash feldspar crystals which average ½ to

1 inch across. Oligoclase-andesine and hypersthene are important constituents with minor amounts of hornblende, magnetite-ilmenite, and apatite. The syenite-diorite gneiss mass in secs. 19 and 24 is gneissic, somewhat finer-grained than the syenite, and contains plagioclase, microcline, biotite, and pyroxene as important constituents. This rock has extensively replaced metanorite and contains numerous inclusions of metanorite and cordierite.

*Diorite gneiss**.—The diorite gneiss is gray, medium- to coarse-grained, and consists principally of andesine and biotite with local microcline and hornblende. The central part of the rock has in places sufficient quartz to make it a quartz diorite gneiss; in the northwestern part it contains hypersthene. Andesine porphyroblasts average 3/16 by 1/16 inch across, and the groundmass minerals average 1/16 inch across. The rock is moderately porphyroblastic, gneissic, and has an alinement of porphyroblasts and groundmass minerals. It is somewhat variable in appearance and mineral composition along the strike.

Metanorite inclusions in the diorite gneiss average 1 to 4 inches long and ¾ inch across. A few are larger, some as much as 200 feet long and 50 feet across. The smaller ones are very abundant, constituting about 15 percent of the rock and in places averaging several dozen per cubic foot. In places they exhibit slight divergencies of foliation and elongation from the strike and dip of the gneiss. The large inclusions are found near the central part of the area. They are foliate to massive and in places have well-developed layering and schistosity. Most of the inclusions contain cordierite-garnet gneiss similar to that in the mixed-rock unit. The amount of this gneiss varies considerably from place to place. The massive rock is believed to be unsheared metanorite. Foliated and layered rock appears to represent metanorite which has been sheared and replaced by diorite gneiss and by cordierite-garnet gneiss.

The diorite gneiss is generally fissile in areas of low relief. Topographic relief in the area underlain by the diorite gneiss is low to moderate, depending on the amount of fissility and the relative percentage of quartz and biotite in the gneiss. The rock weathers to an arkosic soil. Some granite dikes transect the gneiss in various directions.

In places tongues of porphyroblastic granodiorite gneiss are found in the diorite gneiss, and locally diorite gneiss occurs as lenses within porphyroblastic granodiorite gneiss.

*Porphyroblastic granodiorite gneiss.*—The porphyroblastic granodiorite gneiss is pink and white, coarse-grained, and consists principally of oligoclase, microcline, quartz, biotite, and hornblende in varying percentages. The porphyroblasts are pink or white microcline which average ¼ to ¾ inch across; groundmass minerals are ⅛ inch or less across. For the most part the rock has well-developed porphyroblastic and gneissic texture, with a marked alinement of porphyroblasts and groundmass. In sec. 29, south of the map area, the porphyroblasts are lenticular and the rock is medium-grained and somewhat granulated and sheared. The name granodiorite is applied to this

*As used in this paper, if less than 13 percent of the feldspar is K-feldspar, the rock is diorite.
If from 13 percent to 33 1/3 percent of the feldspar is K-feldspar, the rock is granodiorite.
If from 33 percent to 67 percent of the feldspar is K-feldspar, the rock is quartz monzonite.
If more than 67 percent of the feldspar is K-feldspar, the rock is granite.

map unit. On the basis of thin section analysis made on 52 slides, most of the specimens fall into this classification. About 40 percent of the specimens, however, have the mineral composition of quartz monzonite. That is, although this gneiss is coarsely porphyroblastic and forms one lithologic unit, the composition ranges from granodiorite to quartz monzonite.

In general the percentage of inclusions of metanorite is less than in the diorite gneiss. Inclusions are massive to foliate and range from 2 to 6 inches long by ½ inch across. In places they are alined in a direction slightly divergent from the strike and dip of the gneiss. In the southwestern part of the area some inclusions are several feet across, but only a few large ones, measured in tens of feet, occur in the granodiorite gneiss.

Porphyroblastic granodiorite gneiss is not as fissile as the diorite gneiss. The rock forms areas of moderate topographic relief, measured generally in tens of feet; locally the relief is greater. The soil developed from the gneiss is arkosic. Contacts of porphyroblastic granodiorite gneiss with diorite gneiss are generally sharp.

*Quartz monzonite gneiss.*—The quartz monzonite gneiss is pink and white, medium-to coarse-grained, and consists prinicpally of microcline, oligoclase or andesine, and quartz. The map unit also contains granite dikes, massive monzonite, and small lenses of diorite and granodiorite gneiss. Metanorite inclusions are less abundant than in the granodiorite or diorite gneisses. Only a small part of the quartz monzonite gneiss area is shown in the southeastern corner of the map. The name quartz monzonite applies to most of the rocks in this zone, but of 25 thin section analyses, 5 had the mineral composition of a granodiorite and the rest were quartz monzonite. This map unit is the southeasternmost gneiss in the area; to the south, this rock is in contact with the southern anorthosite mass.

*Quartz monzonite and granite.*—In the western part of the area the rock is red, coarse-grained, and consists principally of potash feldspar, plagioclase, and quartz with about 10 percent of biotite and hornblende. It is equigranular to porphyritic, the latter type in places showing a parallelism of microcline phenocrysts, and of groundmass minerals. The rock is more uniform in appearance than the gneisses. Inclusions of metanorite are not as common as in the gneisses. They are generally massive, 4 to 8 inches long by 2 to 4 inches across, and constitute less than 1 percent of the rock.

About 3 miles east of the map area the predominant rock is similar to that described above. In general, however, the percentage of biotite and hornblende increases eastward to approximately 40 percent. The rock weathers to an arkosic soil which supports pine growth.

In the northeastern part of the map area the rocks in this unit are chiefly pink or gray, fine-to medium-grained, and massive; locally they are foliated.

South of the map area in the quartz monzonite gneiss, pink quartz monzonite and granite dikes are relatively numerous. They range from fine-grained to pegmatitic, with attitudes ranging from vertical to horizontal, but are generally nearly normal to the banded structure of the gneisses. Some dikes are short and discontinuous. Some sill-like masses are steeply dipping and parallel, or nearly so, to the gneissic structure.

## CORDIERITE DEPOSITS

*Location.*—Cordierite deposits are scattered over several square miles in the region (pl. 2). The deposits occur on low ridges in an area about 5 miles long and ¼ to 1 mile wide. The principal ones are in secs. 13, 14, and 24, T. 17 N., R. 72 W., and secs. 17, 18, 19, and 20, T. 17 N., R. 71 W. The bodies are lenticular or tabular masses in metanorite, and range in size from a few inches long and wide to 240 feet long and 30 feet wide.

The deposits are 15 to 20 miles northeast of Laramie and can be reached by a gravel county road and ranch roads. The roads are in good condition except after prolonged rain or snow. Because of the low relief and lack of trees or shrubs, it is possible to drive directly to almost all the deposits.

The larger cordierite bodies are indicated on plate 2; numerous very small bodies exist which are too small to show on the scale used.

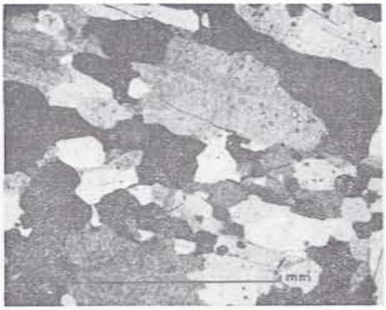
*Mineralogical and chemical composition.*—On weathered surfaces the cordierite rock is dark brown and foliated like the adjoining metanorite (fig. 2). Freshly fractured surfaces are blue or bluish gray and massive with little or no foliation. Associated minerals are chiefly andesine, microcline, hypersthene, and biotite, with minor green spinel, magnetite-ilmenite, apatite, and zircon. Locally, especially in the mixed-rock unit, quartz and garnet are common. The percentage of these minerals varies greatly in the different cordierite deposits and in individual outcrops. Anthophyllite, which is commonly associated with cordierite, was not found in the Laramie Range material. The identification of cordierite is based on physical and optical data, chemical analyses, and x-ray diffraction patterns.

In thin section cordierite is anhedral to subhedral, colorless, and ranges in grain size from a fraction of a millimeter to one mm across. In thick slides the cordierite exhibits striking pleochroism. Inclusions are minute, dustlike particles which give the mineral a cloudy appearance in thin section (fig. 3). Most of the cordierite exhibits well-developed polysynthetic twinning (fig. 4), but some is untwinned. Rarely cordierite is partly altered to a colorless mica.

Cordierite for chemical analysis was selected by picking fragments under a binocular microscope. The analysis is compared with cordierite, from various localities, selected to show the range in composition of the mineral (table 1). The analyses are taken from the list compiled by Folinsbee (1941)*. Laramie Range cordierite is somewhat similar in chemical composition to material from Great Slave Lake, Brocken, and Ilmajoki, Japan; alkalies and lime, however, are high. Folinsbee plotted the optic angle against percentages of alkalies and of lime, and drew curves illustrating that a relationship exists. If the optical properties of the Laramie Range cordierite are plotted against the chemical analysis, the results agree in a general way with Folinsbee's curves.

*Folinsbee's paper contains the principal references on the mineralogy of cordierite.

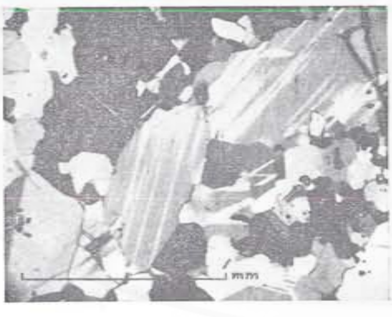
2.



3.

FIG. 2. Cordierite-bearing metanorite showing layering.

FIG. 3. Cordierite with characteristic dustlike inclusions.



4.

5.

FIG. 4. Twinned cordierite showing characteristic irregular width of twin lamellae many of which do not extend all the way across individual grains.

FIG. 5. Cordierite rock containing patches (black) of unreplaced metanorite.

*Occurrence of cordierite.*—Cordierite is found principally in metanorite and in metanorite inclusions within syenite and syenite-diorite gneiss. It is widely present in varying percentage in the main body of metanorite; almost all exposures of this rock contain cordierite (fig. 5). In places cordierite forms 50 to more than 80 percent of the metanorite, and these areas are indicated on the map as cordierite deposits if 20 feet or more in length. Most of these deposits lie in the central part of the metanorite, but a few are in the mixed-rock unit. The deposits are somewhat more resistant to erosion than the enclosing rocks and are exposed chiefly as boulders on minor ridges in an area of low relief (fig. 6). Locally syenite has replaced much of the metanorite but has left, in a number of exposures, unreplaced cordierite bodies as inclusions. Similar unreplaced inclusions are present within diorite gneiss, principally in the mixed-rock unit.

*Structural features of cordierite bodies.*—The interpretation of structural features of the cordierite bodies is difficult because of poor exposures in the metanorite area. Where outcrops occur, the mineral layering, with few exceptions, strikes east or northeast and dips 70° N.-70° S. Individual cordierite bodies are commonly curved (pl. 2), but the curvature of 10° to 15° is too small to show on plate 1. A few bodies show greater curvature.

*Form and size of cordierite bodies.*—Outcrops of cordierite bodies are layered, in general elongated parallel to the foliation of the enclosing rock,

TABLE 1. Chemical analyses and optical properties of cordierite.

| Author Locality | Pehrman[1] Attu | Folinsbee[2] Great Slave Lake N.W.T., Canada | Thiele[3] Brocken | Pehrman[4] Ilmajoki | Newhouse and Hagner[5] Laramie Range, Wyoming | Shibata[6] Sasago, Japan |
|---|---|---|---|---|---|---|
| $SiO_2$ | 50.15 | 48.19 | 48.88 | 50.09 | 49.50 | 43.27 |
| $TiO_2$ | 0.38 | 0.01 | —— | 0.00 | 0.06 | —— |
| $Al_2O_3$ | 33.07 | 33.45 | 33.07 | 31.78 | 32.45 | 30.25 |
| FeO | 2.22 | 8.40 | 8.05 | 8.71 | 8.90 | 15.31 |
| $Fe_2O_3$ | 1.52 | 0.55 | 0.53 | 0.78 | 0.40 | 1.09 |
| MgO | 11.01 | 7.95 | 7.04 | 6.69 | 6.73 | 1.48 |
| MnO | 0.12 | 0.18 | 0.06 | 0.00 | 0.11 | 1.20 |
| $Na_2O$ | 0.14 | 0.22 | 0.09 | 0.00 | 0.46 | 0.90 |
| $K_2O$ | 0.08 | 0.02 | —— | 0.07 | 0.39 | 3.53 |
| CaO | 0.29 | 0.17 | 0.04 | 0.00 | 0.57 | 0.10 |
| $H_2O-$ | 0.09 | 0.01 | 0.20 | —— | none | —— |
| $H_2O+$ | 1.37 | 0.67 | 2.21 | 1.43 | 0.62 | 2.89 |
| Total | 100.44 | 99.82 | 100.17 | 99.55 | 100.19 | 100.00 |
| Density | 2.588 | 2.631 | 2.647 | 2.650 | 2.622 | 2.75 |
| $\alpha$ | 1.527 | 1.544 | 1.549 | 1.543 | 1.543 | 1.588 |
| $\beta$ | 1.532 | 1.550 | (1.555) | 1.548 | 1.550 | 1.568 |
| $\tau$ | 1.538 | 1.556 | 1.560 | 1.553 | 1.557 | 1.573 |
| 2V | 92° | 85°-95° | 74°36′ | 91°29′ | 81°* | 68°5′ |
| Optic sign | + | ± | — | + | ± | — |

[1]Analyst, Pehrman
[2]Analyst, Folinsbee
[3]Analyst, Thiele
[4]Analyst, Pehrman
[5]Analyst, Bruun
[6]Analyst, Tanaka
*Only one 2V determination made.

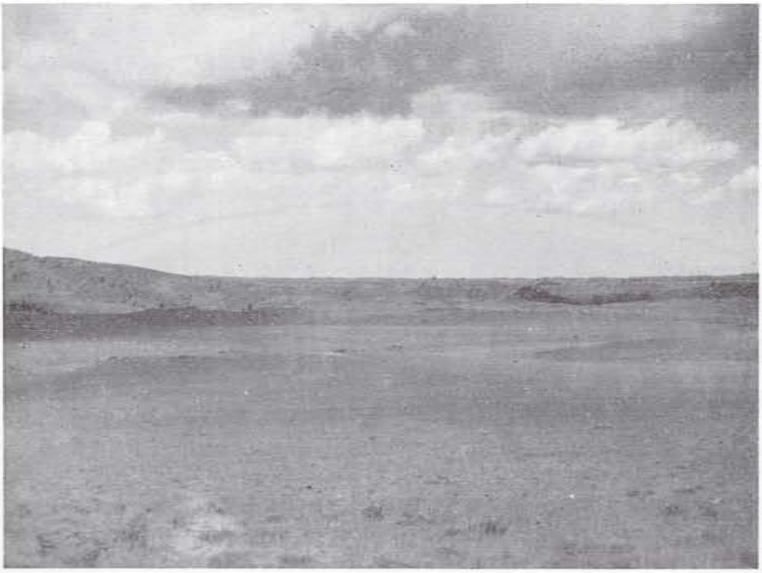


FIG. 6. View northeast across metanorite area. Cordierite deposits form low hills; higher hills in background are anorthosite.

and are lenticular in plan. Layers of cordierite-bearing rock in syenite and in the mixed-rock zone have the same shape, suggesting a common form of cordierite bodies regardless of size. In places, two or three lenses are alined. A few outcrops expose short tabular masses which appear to be almost as wide as they are long.

Twenty-seven exposures of rock containing 50 to 80 percent of cordierite are 100 feet long, 23 are more than 60 feet but less than 100 feet long, and 78 are 20 to 60 feet long. A number of smaller cordierite bodies are not plotted on the map but their positions are indicated by the dips and strikes in the metanorite (pl. 1), all of which were taken on cordierite exposures.

The depths to which the cordierite deposits extend are not known. Although most of the exposures are on small hills, boulders lie on the slopes so it is impossible to determine accurately the vertical extent of individual bodies. In a few of the larger exposures, however, the difference between the highest and lowest points where cordierite was found is measured in tens of feet. It is probable that individual bodies have an average extent in depth of at least half the length of each exposure.

One of the larger cordierite-bearing bodies was mapped with plane table and alidade on the scale of 1 inch to 50 feet by Messrs. Frank W. Osterwald and John P. Albanese (pl. 2). Some of the other deposits in the area contain better-quality cordierite but this was mapped because of size, and good exposure. The deposit is in the center of sec. 20, T. 17 N., R. 71

W. and is on a ridge more than 300 feet above the surrounding terrain. Associated with this cordierite body are quartz monzonite and granite, diorite gneiss, and rocks of the mixed-rock unit.

The cordierite body (pl. 2) is crescent-shaped, the convex side facing south. The easternmost end is covered with aluvium. The rocks in the immediate vicinity are vertical or dip steeply southeast. Strike of foliation is in general east, but ranges from N. 85° E. in the eastern end to N. 85° W. at the western end. The strike is not everywhere parallel to trend of the outcrop. The cordierite body is localized near the center of a fold with near vertical pitch. The quantity of cordierite in the body decreases toward the southeast. The quality of cordierite also decreases southward in the mixed-rock zone as the percentage of granite gneiss increases.

*Quality of cordierite exposures.*—The percentage of cordierite in each body was estimated in the field from grab samples and by considering each exposure as a unit. Many exposures contain between 60 and 80 percent cordierite, only a few contain above 80 percent, and several dozen have less than 60 percent. The richest cordierite-bearing rock is located in the SW¼ sec. 18, but other high-grade exposures are scattered throughout the area.

Two specimens of cordierite-bearing rock were analyzed by Miss Yoshiko Ito of the University of Wyoming Natural Resources Research Institute. Typical high-grade cordierite-bearing rock was selected, but no attempt was made to separate the mineral from the rock. The analyses are listed in table 2.

TABLE 2. Chemical analyses of cordierite-bearing rock.
Laramie Range, Wyoming

| | Spec. 62* | Spec. 75* |
|---|---|---|
| $SiO_2$ | 50.10 | 51.66 |
| $Al_2O_3$ | 29.70 | 28.24 |
| $FeO$ | 10.90 | 7.94 |
| $MgO$ | 6.82 | 5.90 |
| $CaO$ | 1.77 | 2.48 |
| | 99.29 | 96.22 |

(Iron calculated as $FeO$ but determined as $Fe_2O_3$)

*Genesis of cordierite.*—Replacement of metanorite by diorite gneiss, on a volume-for-volume basis, indicates that elements such as Fe, Mg, Ti, Ca, and P were in part driven out by incoming Si, Al, Na, and K. The chemical analyses of metanorite and gneiss will be presented in a later paper. The elements that were driven out contributed in part to the formation of cordierite. It is possible that some of these elements contributed also to the development of titaniferous magnetite at some distance above or below the present erosion surface. Closely spaced fractures, planes of shearing, and the planes of foliation furnished the "openings" along which migrating material replaced the metanorite. Migration took place principally in vertical planes, and to a lesser extent laterally (Newhouse, et al, 1949.). The elements are believed to have moved largely by diffusion through $H_2O$ films in steeply

*See pl. 1 for locations.

dipping shear fractures or along the surfaces of these fractures and the foliation, and to a lesser degree by surface diffusion along grain boundaries. It is considered less likely that the elements were carried by moving solutions.

Movement of material was somewhat analogous to that of a "basic front" as discussed by Sederholm, Backlund, Wegmann, and Reynolds*. The migrating material, however, is not conceived of as an advance wave giving rise to a border or fringe of relatively more basic rock by lateral diffusion. Rather, the process is considered to have been a movement of material, controlled in large part by structural features. Cordierite was localized in places of lowest pressures normal to the fractures and foliation, i.e., along "openings." The curvature which characterizes the larger cordierite bodies and many of the small ones is best explained as due to curving fractures, or locally, to two intersecting shear planes along which cordierite extensively replaced the host rock. The formation of cordierite was a minor phase of the metasomatism which produced the various gneisses in the area.

The mixed rock zone displays an abundance of closely spaced, subparallel fractures throughout most of the area. These fractures are parallel, or nearly so, to the axial planes of small folds. Thin gneissic layers, as much as several millimeters thick, occur along these fractures. Some schistosity is developed along and parallel to the fracture planes. The new minerals of adjacent fractures in places merge to form thicker gneiss layers. These layers are believed to represent preliminary stages of replacement of the metanorite.

Schistose metanorite forms the limbs of small drag folds. Thin layers of gneiss developed along the planes of schistosity that outline the limbs of the folds. Only a small proportion of the gneiss is believed to have formed along this type of structure. Most of the replacement appears to have taken place along fracture planes.

Such fracture planes with the accompanying gneiss layers are rarely observed in the metanorite area. It is therefore possible that this area was not completely replaced because it was insufficiently fractured. The writers, however, favor the following alternative explanation. The small metanorite fragments in the gneisses throughout the area do not contain cordierite. It is likely that the cordierite which formed in the main metanorite mass healed and strengthened the rock so later stresses were relieved by fractures elsewhere in the metanorite.

*Reserves.*—It is estimated that the combined deposits that are 100 feet long or more contain a total of more than 500,000 short tons of cordierite. This estimate is based on the assumption that the deposits extend to a depth of one-half their length. For more accurate data on tonnage and detailed geologic features, it will be necessary to dig pits and trenches across the outcrops of cordierite-bearing rock and to diamond drill the deposits.

## USES OF CORDIERITE

There is a considerable demand for heat-shock resistant material, and for insulating material that is capable of withstanding high temperatures and

*Reynolds (1946, 1947) reviews the work of earlier investigators and describes several illustrative areas.

possesses a very low factor of thermal expansion and good dielectric and mechanical properties. Cordierite which meets these requirements has been developed in the laboratory, but it might be more economical if a suitable natural cordierite could be used. Natural cordierite apparently has not been used because large deposits of pure material, or of cordierite that could be economically separated from impurities, are unknown.

Mr. B. W. Brown (1948) of the University of Wyoming Natural Resources Research Institute prepared a number of cordierite test bars from the Laramie Range material. He concludes, ". . . from these preliminary investigations that Wyoming cordierite is suited to the manufacture of low thermal-expansion bodies when strength, dielectric properties, and color are not critical factors. The thermal-expansion characteristics of the natural cordierite body compare favorably with synthetic cordierite bodies. High iron content, narrow firing range, and lack of transverse strength are factors limiting the use of Wyoming cordierite. However, in bodies where color is of minor importance and high thermal-shock resistance of paramount importance, the natural cordierite seems to warrant further investigation."

The following summary of the uses of synthetic cordierite is taken from an article by Hausner (1946).

1. Thermocouple insulators.
2. Industrial burner tips that must withstand high temperature.
3. Oil burner ignition insulators.
4. Chemical stoneware containers that must withstand quick heating and cooling cycles.
5. Automotive parts, such as rheostat blocks and dimmer winding cores.
6. Electrical resistor bobbins, spools, and protective tubes for special applications.
7. Electrical appliance parts, such as heating elements, spacers, bushings, and hooks.
8. Low-inductance coil forms.
9. High-frequency parts that are exposed to great temperature changes, are needed by the radio industry.

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