PETROGRAPHY OF PRE-BELTIAN
CHERRY CREEK MARBLES,
SOUTHWESTERN MONTANA

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PETROGRAPHY OF PRE-BELTIAN CHERRY CREEK MARBLES SOUTHWESTERN MONTANA

by

Alfred A. Levinson

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology, University of Michigan, 1949.

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ABSTRACT

A petrographic study of 42 specimens of Cherry Creek marbles and associated calcium-magnesium-rich metamorphic rocks from the pre-Beltian of southwestern Montana by means of staining, crushed fragments and thin section methods, reveals a considerable variation in the calcite-dolomite relations as well as the presence of several groups of silicate minerals. One suite consisting chiefly of tremolite, diopside, and phlogopite was formed by the contact action of mafic sills.' Another which includes chiefly tremolite, diopside, graphite, sphene, scapolite, and phlogopite originated through the contact metamorphic action of Laramide pegmatites. Hydrothermal minerals in the marbles are serpentine, talc, and phlogopite. Supergene constituents are manganese oxides, secondary calcite, and possibly some SiO_2 as chalcedony.

INTRODUCTION

Problem

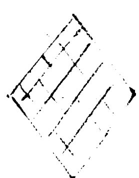
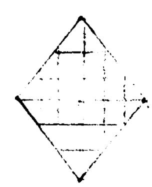
This thesis describes the variation in petrography of the pre-Beltian Cherry Creek marbles and some associated hybrid carbonate rocks of southwestern Montana and makes some suggestions regarding the origins of the various mineral assemblages. The investigation was completed during the school year, 1948-1949, and submitted in partial fulfillment for the requirements of the degree of Master of Science in Geology at the University of Michigan.

Location of Areas

All hand specimens studied were collected by Dr. E. Wm. Heinrich during the field seasons of 1947 and 1948 from outcrops of the Cherry Creek series. Many were obtained from Carter Creek, and Axes Canyon, 10 to 12 miles southeast of Dillon, Montana, in Madison and Beaverhead Counties. Both of these streams drain westward across the foothills in the southern end of the Ruby Range. Some samples were collected in the Tobacco Root Mountains about 25 miles northeast of the first location. Other specimens were obtained from the type section of the Cherry Creek rocks in the foothills of the Gravelly Range about 12 miles south of Ennis, Montana. One specimen was obtained from Ross Creek in Gallatin County, north of Bozeman.

Technique

The thin sections were first examined to identify the minerals present and to determine their relative abundance. No attempt was made to distinguish calcite from dolomite in thin section, for twinning was not always visible. Where it was visible, it was usually impossible to distinguish the carbonate as crystal outlines were usually lacking. The following table gives the more important microscopic characteristics of calcite and dolomite:

	Calcite	Dolomite
Indicies	n_e=1.486	n_e=1.500
	n_ω=1.658	n_ω=1.680
Appearance	clear	turbid
Form	rarely in rhombs	commonly in rhombs
Texture	commonly interlocking	rarely interlocking
Twinning		

Textures were also carefully studied with an attempt to correlate the various marble horizons.

In those specimens containing over seventy-five percent carbonate, calcite was distinguished from dolomite by means of two staining tests. Hand specimens, with freshly sawed surfaces, were first immersed in Lemberg solution for about one minute. This procedure stains calcite a strong violet and leaves dolomite white. Lemberg solution is prepared by boiling for 20 minutes a mixture of 6 grams of logwood extract, 4 grams of $AlCl_3$, and 60cc. of water. Water is added to replace that lost by evaporation. The product is cooled and filtered for use.

All results were checked by means of another chemical test. A copper nitrate solution was prepared by boiling crystals of the compound in water for a few minutes. If a hand specimen containing calcite is immersed in this solution, an effervescence can be noted, and a blue-green compound is formed. For best results, the solution was kept close to the boiling point. No effect is recognizable with the immersion of dolomite. For these coarse-grained carbonate rocks the blue calcite stain produced by immersion in copper nitrate solution gave less uniform results than the Lemberg solution. This observation is in agreement with that of Keith (1946).

Crushed fragment determinations were made on 10 specimens by means of the immersion method. Indicies of refraction of the unknown mineral were determined whenever no other quicker diagnostic property was available.

Acknowledgements

The writer wishes to express his appreciation to Dr. E. Wm Heinrich, of the Department of Mineralogy, University of Michigan, who suggested the problem, and provided thin section and hand specimens, and whose help and guidance made this report possible. The writer also wishes to express his thanks to Dr. Robert M. Garrells, of Northwestern University, who helped in obtaining thin sections; to Dr. Walter F. Hunt and Dr. Kenneth K. Landes, for their various constructive criticisms; and to Mr. M. V. Denny, who helped with the photomicrographs.

Special thanks are due Mr. J. Arnold Kohn who contributed help, criticism, and read the manuscript, and to Messrs. James E. Bever and Daniel A. Jobin who helped with many suggestions throughout the process of investigation.

GENERAL GEOLOGY

The Cherry Creek series is one of four distinct pre-Cambrian units in southwestern Montana. From oldest to youngest these are: (1) the Pony series, composed mainly of gneisses and schists of igneous origin, with some admixture of meta-sedimentary material, (2) the Cherry Creek series, about 30,000 feet thick and containing, in the Ruby Mountains, seven main marble horizons in addition to gneisses, quartzites, mica schists, and quartz-feldspar gneisses, nearly all of sedimentary origin, (3) the Blacktail granite gneiss, which occurs as a large batholith of granitic rock intruded into the two older pre-Beltian series, accompanied by numerous sills of pegmatite and granite, all now metamorphosed, (4) the Belt series, consisting of 5000 feet of fine-grained shale underlain by greenish-gray arkose and arkosic conglomerate.

Below, in summary form, is the sequence of geologic events which have been worked out:[1]

1. Formation of the Pony series (Archeozoic)
2. Deposition of the Cherry Creek sediments (Lower Proterozoic)
3. Intrusion of mafic and ultra-mafic sills into the Pony and Cherry Creek series
4. Regional metamorphism
5. Intrusion of the Blacktail granites, pegmatites, and aplites (Middle Proterozoic)

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1 - Dr. E. Wm. Heinrich, per. comm.

6. Continued regional metamorphism
7. Unconformity
8. Belt series deposited
9. Paleozoic and Mesozoic Sequences deposited
10. Laramide revolution
11. Boulder batholith intruded with accompanying pegmatites
12. Intrusion of Tertiary (?) ultra-mafic bodies

In the late Tertiary there was faulting and subsequent vigorous erosion. This has exposed the pre-Beltian metasediments along the flanks of many mountain ranges in southwestern Montana.

The Cherry Creek marbles, therefore, were first subjected to contact metamorphism by the intrusion of basic sills (now hornblende gneisses and amphibolites), which process acounts for some of the contact minerals, and were then subjected to regional metamorphism along with the other pre-Beltian rocks, at the close of Cherry Creek time. In Laramide time, pegmatites intruded into marbles also produced various contact minerals. In several places marbles have been baked for short distances along contacts of Tertiary (?) diabase dikes.

PETROGRAPHY

General Statement

The marbles of the Cherry Creek series form very conspicuous layers and are especially important because they can readily be used to map the metamorphic structure of the pre-Cambrian complex. They vary considerably in texture and mineral composition. Most are somewhat dolomitic, and many are true dolomites. Some are massive, thick-layered, and relatively pure, whereas others are thin-layered, and some show alternations of thin dark bands with thicker, lighter-colored layers. Some of the thin, dark, and more resistant layers show the effects of strong deformation, being strongly contorted and crumpled.

Many of the marbles contain accessory minerals, principally fosterite, diopside, sphene, phlogopite, serpentine and graphite. Some types have been strongly serpentinized, with the production of a striking banding or nodular structure that consists of alternating golden-yellow serpentine layers or pods and gray carbonate layers. In others the carbonate has been replaced in wholesale fashion and the entire rock is yellow-brown due to serpentine clusters. Colored chert (black, red, buff, and yellow) occurs locally in abundance. In a few places entire layers or large lenses of marble have been replaced almost entirely by white, fine-grained quartz. The resulting rock resembles a very pure quartzite. This is especially true near deposits of talc. Other secondary minerals in marbles are talc, tremolite, actinolite and manganese oxides. Talc occurs in large lenses (several hundred feet), as small disseminated pods and thin veinlets. Manganese oxides likewise are disseminated widely as layers, lenses, small pods, and coatings and stains around individual minerals. Tremolite and actinolite occur as pyrometasomatic minerals along the contacts with hornblende rich layers. These two minerals, together with clusters of phlogopite, disseminated graphite, and large irregular replacement masses of fine-grained, brown, cherty silica, also occur in marble along the margins of pegmatite intrusions.

The marbles studied may be divided into several types on the basis of their general mineral content and field occurrence:

A. Relatively pure marbles of regional metamorphic origin

M-21, M-22, M-23, M-24a, M-25, M-27

1-10, 1-22, 19-8, 19-13, 19-9, 19-29b, 22-4a

B. Impure marbles of regional metamorphic origin:

0-2, 18-8, 18-16, 32-2

C. Lime-silicate rocks formed by contact metamorphic action of mafic sills (now hornblende gneisses and amphibolites):

a. Thin Sections:

M-26, 10-2, 19-29c, 19-33

b. Crushed fragment analysis:

M-82, 1-12, 1-22, 6-8, 8-22, 10-13c

D. Lime-silicate rocks produced by contact metamorphic action of Laramide pegamtites:

M-3, M-22, 0-1, 16-3, 18-4, 16-1 (crushed fragment)

E. Baked rocks produced by contact metamorphic action of Tertiary diabase:

1-40

F. Magnesium-silicate rocks produced by hydrothermal alteration:

a. Serpentine: M-24, 1-3b, 1-27, 1-36

b. Talc: M-18, M-19, M-20

c. Silica: 32-2, 19-29a, M-83 (crushed fragment)

G. Marbles modified by supergene alteration:

19-8, 19-13, 1-40

A. Relatively pure marbles of regional metamorphic origin

Of the relatively pure marbles examined dolomite is twice as abundant as calcite. Of the 13 in this group, eight are nearly pure dolomite and four are almost entirely calcite. No hand specimen is available to test the thirteenth. In only one specimen did calcite and dolomite occur together (specimen 19-9). However, in this case, the calcite appears interstitial between grains of dolomite and is most probably of later origin.

By means of a micrometer ocular, the grain sizes of the carbonate were measured in all thin sections of this group. Below is a brief summary of the findings:

1. Calcite marbles

M-22 The average grain is about 1.2mm in diameter. Grains as small as .45mm were observed as well as exceptionally large ones measuring 1.8mm.

M-25 Generally very small ranging from .0075mm to .45mm--average about .15mm (Plate 1)

19-8 Grains fall into three distinct groups:

a. Elongate - 1.2mm by .75mm

b. Equi-dimensional - .75mm

c. Carbonate in manganese oxide zone - smallest = .0075mm average = .3mm may be secondary

22-4a Generally equi-dimensional with average diameter of .6mm - smallest = .22mm and largest = 1.2mm

2 Dolomite marbles.

M-23 Mostly 1.2mm in diameter or larger. A few small crystals of .45mm were measured (Plate 2).

M-24a Generally large -- 1.0mm to 1.2mm.

In the manganese oxide vein, much smaller (.3mm) grains were observed.

M-27 One-half had diameters of 1.0mm and the other half had diameters of .6mm (Plate 3).

1-10 Average fairly consistent -- .6mm in diameter

1-22 Grains fall into two groups:

a. Well elongated, in which the dolomite is about twice as long as it is wide 1.4mm by .7mm

b. Slightly elongated -- .8mm by .6mm

19-13 Very coarse grained -- the average diameter is about
1.9mm and some as large as 2.4mm were observed

19-9 Dolomite grains vary from .9mm to 1.2mm --
Calcite, which is interstitial, averages .75mm

19-29b Grains fall into three groups:

a. Well elongated -- 1.5 by .6mm

b. Slightly elongated -- .6mm by .8mm

c. Those crystals in altered diopside zone -- about .4mm in diameter

From the above figures it is fairly obvious that few if any definite trends may be observed. In general, it may be said that the dolomitetends to form larger crystals than the calcite. This is borne out by the fact that the smallest grains are in a calcite marble (M-25), whereas the largest are in dolomite marbles (19-13). However, in those marbles, either calcite or dolomite, in which there has been introduction of material such as manganese oxides or diopside in the form of veins, the carbonate in and near the contact is definitely smaller (19-29b, 19-8, M-24a).

In studying the marbles of this group, one of the most striking things observed is the accessory mineral relationship. The first thing noticed is that in three of the four calcite marbles, sphene was found. It was not observed in any of the dolomite marbles. To a lesser extent graphite also shows this same tendency. The latter was observed in three of the calcite marbles and in only two dolomite marbles (M-24a, and 19-29b). Feldspar (acid plagioclase, microcline, and orthoclase) also was found only in the calcite marbles. Quartz, talc, and phlogopite are equally abundant in both types. The dolomite marbles, with the exception of 19-29b which contained diopside, were lacking in mafic minerals. Mafics were present in three of the four calcite marbles. There was no consistency in the type of the mafic in the calcite marbles. One contained diopside, another actinolite, and the last tremolite. In general, the calcite marbles contained many more contact minerals than the dolomite marbles. Many of the latter contained little more than dolomite, quartz, and phlogopite.

It has generally been stated[2] that the interlocking texture so often observed in calcite marbles is rarely found in dolomite marbles. This is not in accordance with the findings of this thesis. Four of the dolomitic marbles (one-half the total), M-23, M-24a, M-27, and 19-9, showed interlocking of the carbonate grains. This texture was exceptionally well developed in M-23 and M-27 (Plates 2 and 3). Three of the four calcite marbles showed interlocking texture and the fourth was sutured, (Plate 4). A mosaic texture, however, was observed in three specimens confined to the dolomite marble group, (Plate 5). On the basis

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2 Dr. E. Wm. Heinrich, per. comm.

of these findings, it may be said that an interlocking texture is possible in all marbles of the Cherry Creek series, but is especially characteristic of the calcite marbles. In rocks of this series, therefore, the interlocking grain character cannot be used as a microscopic criterion for distinguishing calcite from dolomite.

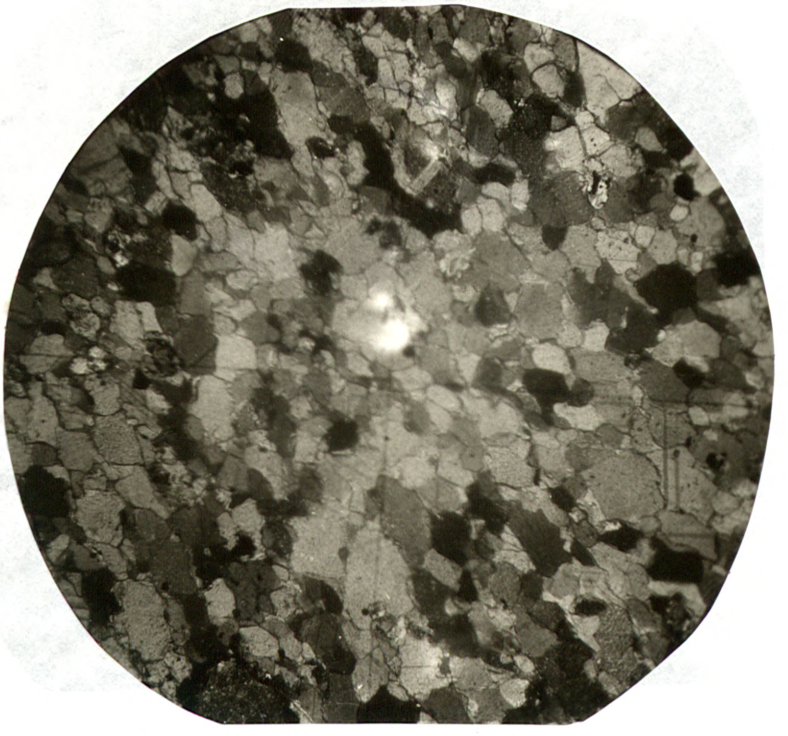
An elongate texture was observed only in a few scattered examples. Therefore, not enough evidence is available to reach any definite conclusions. However, from the scanty material at hand, it does not seem confined to either of the groups.

B. Impure marbles of regional metamorphic origin

Quartz and diopside are present in the four marbles of this group. Calcite, sphene, and graphite are present in three. The relationship is fairly obvious. All but 0-2 are probably silicified calcite marbles which had some argillaceous and organic impurities before they were metamorphosed. These impurities would provide the elements necessary for the sphene and graphite. The titanium in the sphene might have come from rutile which is very common in argillaceous rocks as so-called clay slate needles. Graphite may be formed from residual organic (carbonaceous) material during regional metamorphism.

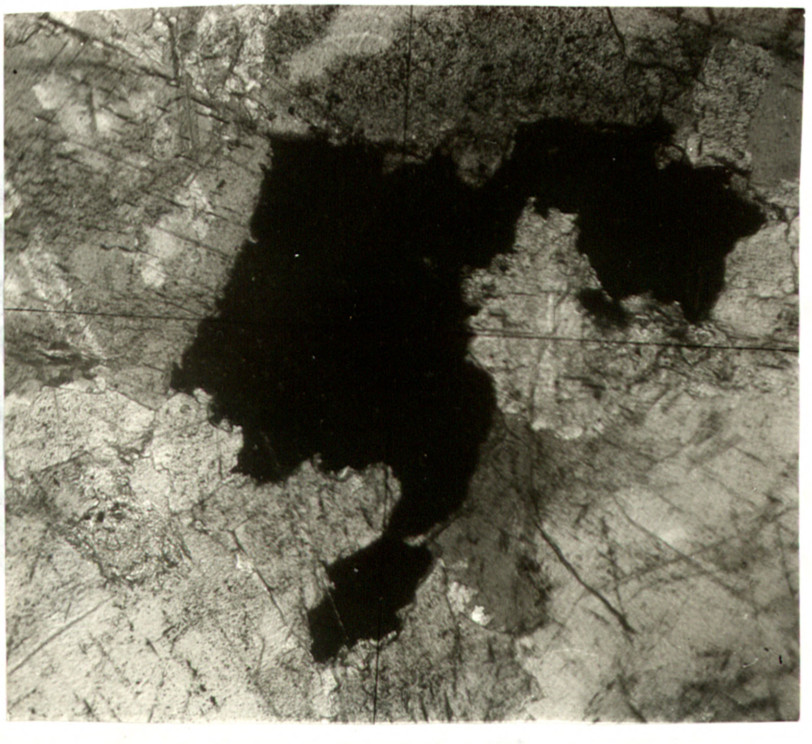
The association of calcite and diopside at first may appear unnatural. However, when one considers the process of de-dolomitization,

Plate 1



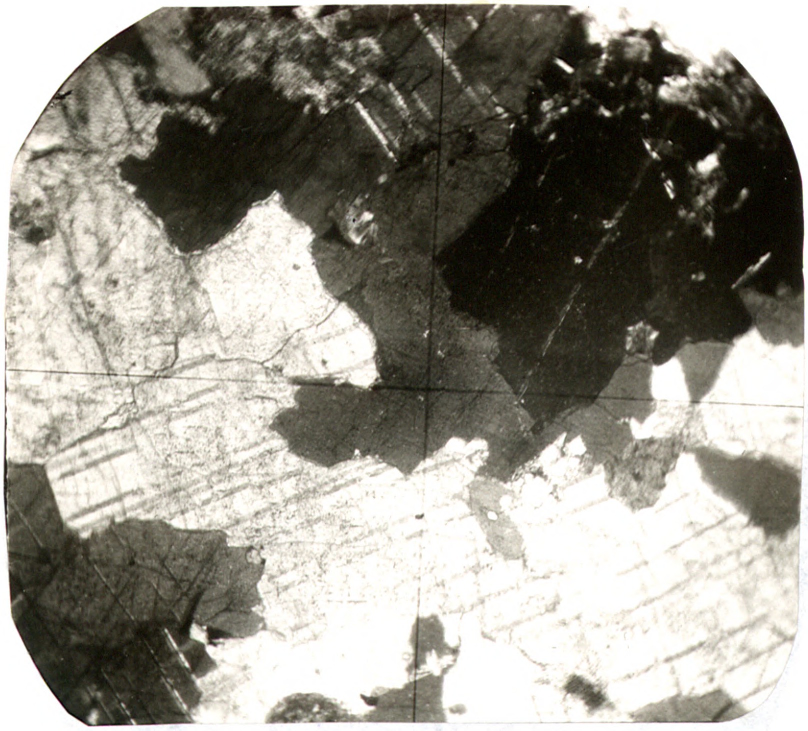
M-25 Calcite marble showing extremely small crystals (90 X)

Plate 2



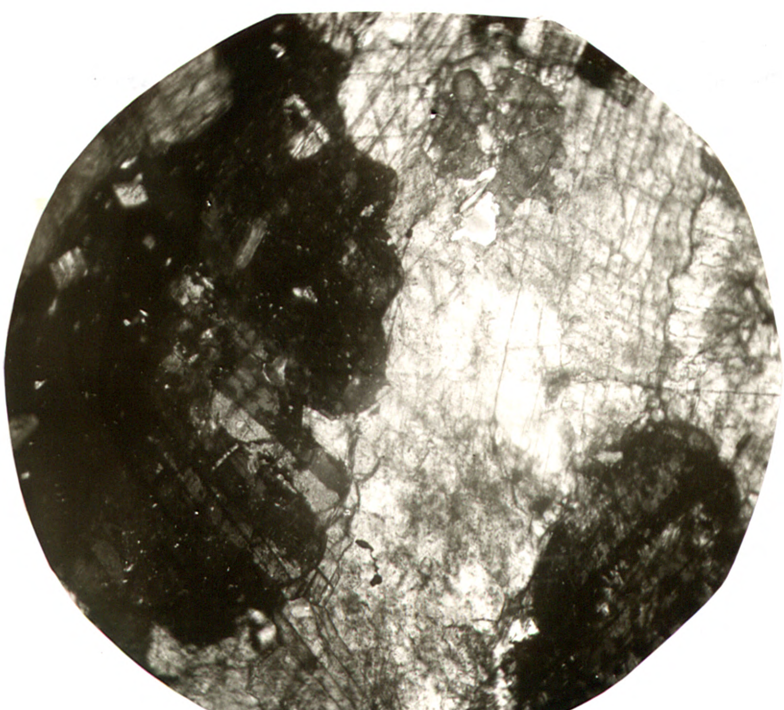
M-23 Dolomite marble showing the interlocking character of a dolomite grain (black area - in extinction - 90 X)

Plate 3



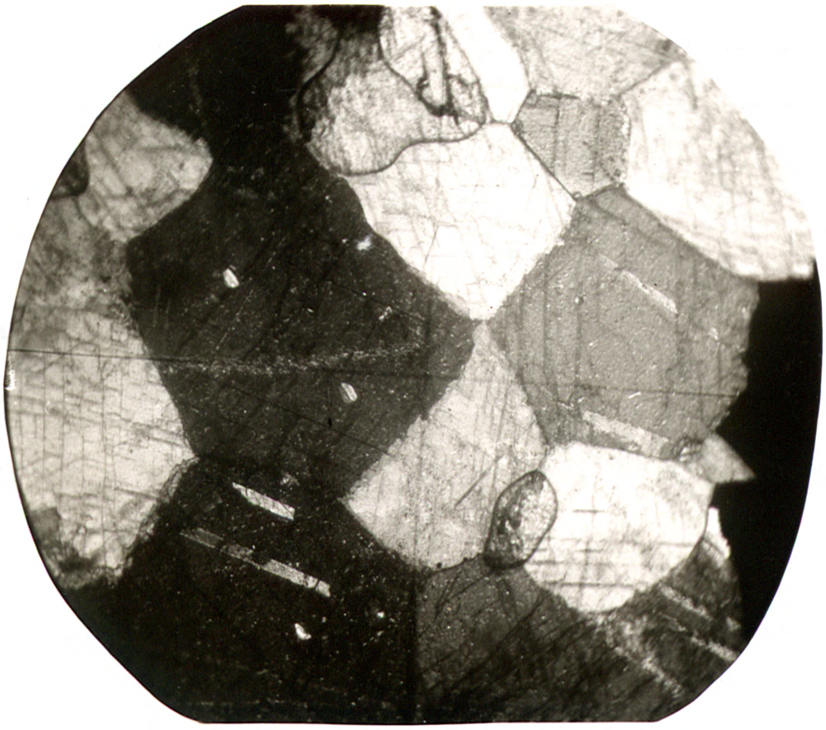
M-27 Dolomite marble showing interlocking texture (90 X)

Plate 4



M-24a Calcite marble showing sutured texture (90 X)

Plate 5



1-10 Dolomite marble showing mosaic texture (90 X) the combination may be expected. In this process, the calcium-magnesium carbonate is decomposed to liberate magnesium and calcite. If there is any silica available, magnesium or magnesium-line silicates, such as diopside, phlogopite, etc., would be likely to form. Such is probably thecase here.

Specimen 0-2, a gneiss, has probably been derived from a calcareous shale or argillaceous limestone. It is banded and contains sphene, graphite, garnet and abundant zoisite. The elements aluminum for zoisite, titanium for sphene and carbon for the graphite would most likely be found in one of the above rock types.

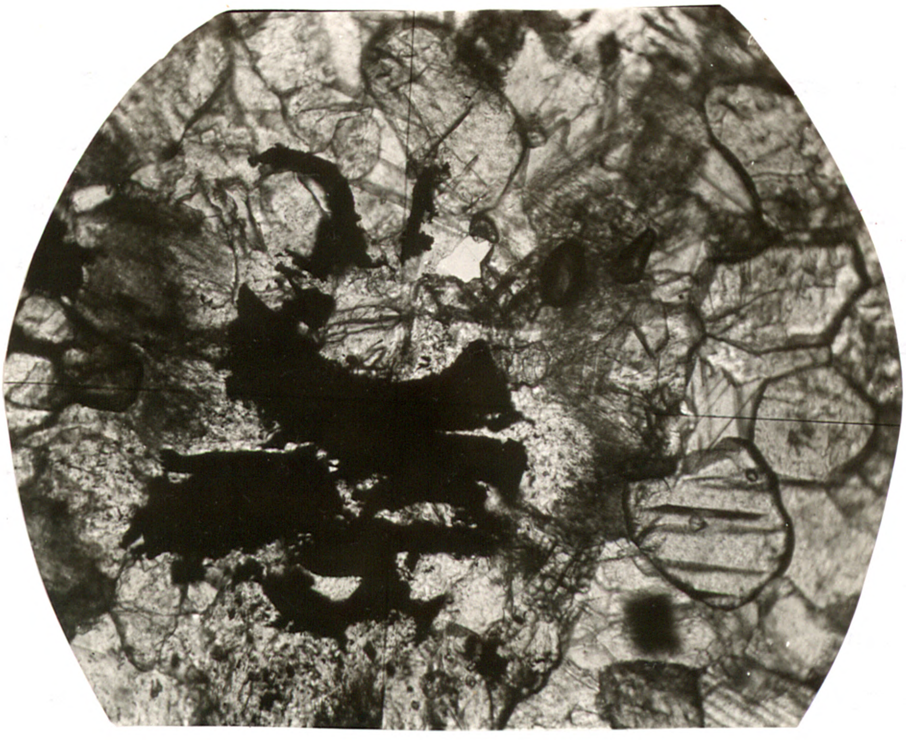
C. Lime-silicate rocks formed by contact metamorphic action of mafic sills (now hornblende gneisses and amphibolites)

By means of crushed fragments identification methods all specimens in this group are shown to be tremolite, with the exception of 8-22 which is actinolite. All thin sections of rocks from this group also contained tremolite with the exception of 19-29c. Likewise, with the exception of but one thin section (19-33), all showed diopside. Phlogopite and either calcite or dolomite, are common in all sections. It may be concluded, therefore, that phlogopite, tremolite, and diopside are the typical contact metamorphic minerals formed from the calcite - dolomite marbles by mafic sills in this area.

D. Lime-silicate rocks produced by contact metamorphic action of Laramide pegmatites.

These rocks generally have two mafic minerals, amphibole (tremolite, actinolite, or actinolitic-hornblende) and pyroxene, always diopside. Only

Plate 6



18-4 Graphite (90 X)

Plate 7

M-22 Graphite (90 X)

M-3, and M-22 have but one mafic mineral. The pegmatite magma undoubtedly carried a considerable amount of chlorine, hydroxyl, and small amounts of boron, which elements aided in the formation of the minerals scapolite, phlogopite, and tourmaline, respectively. Some of the marbles were obviously impure originally. M-22 and O-1 probably originally contained some rutile, which is the source of the titanium now represented by sphene. The sphene occurs mostly as characteristic wedge-shaped crystals. Some are slightly rounded.

Graphite is present in about one-half the sections. It is recognized by: (1) the characteristic shape as exemplified in Plates 6 and 7, (2) grinding striations parallel to the direction of grinding, (3) crinkly edges, and (4) grinding dust on the edge of the slide. The graphite is especially interesting in this area, because it occurs in several different ways. One type is found as scattered crystals in the metamorphic rock. It also occurs as somewhat irregular veins near a series of Laramide pegmatites (Crystal Springs mine). Some graphite veins occur along fault planes. By far the chief host rock for the veins is gneiss with minor occurrences as veinlets, pods, stringers, and disseminations. It is closely associated with the Laramide pegmatites, and is clearly late in origin, having been formed by fluids moving along fractures in the rocks. Some of the disseminated graphite in pegmatites probably formed at the same time as the other magmatic minerals.

The most probable sources of the carbon are either (1) primary C or CO_2 in pegmatite magmas, or (2) carbonate in the marbles decomposed to CO_2, then to CO, by the contact action of the pegmatites. The second possibility does not seem likely, for if the carbonate had been dissociated by pegmatites to yield graphite, magnesium-rich silicates may reasonably be expected to be much more abundant since the graphite is so abundant. Neither the field evidence nor the thin sections show any large amounts of diopside or phlogopite.

The first possibility seems much more probable. It is not uncommon to find graphite as a magmatic accessory mineral. The graphite may either have existed as dissolved carbon or as dissolved CO_2. Winchell (1911) believes it existed as CO_2 which was subsequently deoxidized.

E. Rocks produced by contact metamorphic action of Tertiary diabase.

Specimen 1-40 abounds with an indeterminate dark brown isotropic material that almost completely obscures the very fine-grained calcite. In the hand specimen, yellow circular to elongate areas of serpentine are visible, but only traces of serpentine were observed in the thin section. This specimen was obtained from directly along the contact of a marble layer and Tertiary diabase, and illustrates very well the baking action of the mafic intrusion.

F. Magnesium-silicate rocks produced by hydrothermal alteration.

The hydrothermal solutions altering the marbles undoubtedly contained large amounts of one mineralizer, namely hydroxyl. This ion is now copiously represented in the minerals serpentine, talc, and phlogopite. De-dolomitization near the contact of the hydrothermal solutions probably took place. This would account for the diopside and actinolite in the silicified members of this group (32-2, and 19-29a). Associated with the formation of talc is silicification and locally, at the Keystone Talc mine, the production of unusually coarse diopside, in blades several inches long. The talc deposits have been described by Perry (1948) and Heinrich (1949). It is found throughout the area but is only being produced commercially 11 miles southeast of Dillon, 20 miles south of Ennis, and 11 miles south-southwest of Dillon. In the latter area, "the ore body consists of a 10-to 50-foot band of impure marble which has been altered in part to talc and graphite. The graphite occurs as flakes as much as 3/8 inch wide arranged parallel to the foliation of the grayish green talc. The talc rock is somewhat variable in composition. Some of it is nearly pure talc; other parts contain graphite as well; still other phases consist of calcite, garnet, actinolite, quartz, graphite, and minor talc which grades locally into a talc — free rock of quartz, garnet, and graphite."[3]

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3 Heinrich, E. Wm., (1949) Pegmatite Mineral Deposits in Montana: Mont. Bur. Mines and Geol., Mem. 28.

Under the microscope talc is commonly observed replacing tremolite. In a few cases the change is almost complete.

G. Marbles modified by supergene alteration

Those marbles which have been affected by supergene action contain a great deal of manganese oxides. Locally closely associated with such rocks are very large (4 to 6 inches) cleavages of calcite representing recrystallized material. The manganese in this region is of supergene origin. In the vicinity of Cherry Creek, south of Ennis, there are irregular lense-like bodies of manganese oxides, chiefly psilomelane and to a lesser extent, wad and manganite. Locally the marbles are brownish-red and pink because of the small amounts of iron and manganese oxides distributed through them. Low grade manganese and iron ores have been mined in this area. They are believed to have formed in the Tertiary by the weathering of the discolored beds. In this way the iron and manganese were dissolved in part and then redeposited in more concentrated form in other places. Pardee (1918) reports that one Cherry Creek marble contains 0.47 % manganese, and 1.28 % iron.

The ore bodies are irregular, but most of them approach flat lense-like or pipe-like forms. The largest is 50 feet long and 9 feet wide. Only about half the width is high grade ore. The general features of these deposits show clearly that they are deposited in solution cavities. Some have also been deposited in surrounding marbles. This has been caused by surface waters circulating through joints and other openings in the marbles. Under these conditions, Pardee believes that the only source of the manganese are the marbles themselves.

MINERAL OCCURRENCE AND FREQUENCY IN THIN SECTIONS

	18-4	18-8	18-16	M-3	M-23	M-25	M-26	0-1	0-2	32-2	M-24	M-24a	M-27	1-3b	1-10	1-22	1-27	1-36	1-40	10-2	M-22	16-3	19-8	19-9	19-13	19-29a	19-29b	19-29c	19-33	M-18	M-19	M-20	M-21	M-32	22-4a
CARBONATE								VA												R		A											VA		
CALCITE	A	VA	A			VA				VA	VA			VA			VA		VA		VA		VA	R		A		VA				R			VA
DOLOMITE					VA		VA					VA	VA		VA	VA		A						VA	VA		VA		VA			VA		A	
SERPENTINE					VR		VR				A			A	VR		R	A	VR				VR		VR			VR			R		VR		
TREMOLITE				VR			R		R									R		VA		A	VR				R		VR						
ACTINOLITE						VR																				A									
ACTINOLITIC HORNBLENDE								R																											
DIOPSIDE	A	A	A				R	R	R	VA								R		A	R	R				R	R	R							
MICA																																VR			
MUSCOVITE				VR																															
PHLOGOPITE		A	R		VR		VR					VR	VR	R	VR		VR	VR		VR		A	VR	VR	VR	VR	R	R	VR	VR	VR				VR
MANGANESE OXIDE																	R		A				A		A			R	R					R	R
QUARTZ	R	R	VR	R		VR		R	R	A		VR	VR			VR		VR			R	VR	VR	VR	VR	A				VR				VA	
CHALCEDONY																VR						VR										VR			
GARNET									R				VR																						
GRAPHITE	R		R	VR		VR		VR	VR	R							VR				VR											VR	VR		VR
MAGNETITE							VR		VR			VR	VR	VR									VR	VR	VR					VR	VR		VR		
ILMENITE					VR																														
PYRITE									VR																										
PYRRHOTITE	VR																				VR														
HEMATITE				VR		VR		VR	VR																										
LIMONITE		VR	R					VR	VR				VR									R					VR					VR	VR		VR
SPHENE	R	R	R			VR		VR	R	R											VR		VR		VR	R					VR				
TALC	VR				VR	VR	VR				VR		VR	VR				VR				VR	VR	VR	VR			VR		VA	VA	VR			
CHLORITE				A	VR	VR			VR				VR										VR	VR						R	R	VR			
ZOISITE								VR	A																										
CLINOZOISITE				VA																															
ACID PLAGIOCLASE						VR		VR	VR												VR														
MICROCLINE	A		A			VR															VR														
ORTHOCLASE			A			VR		R																											
KAOLINITE						VR																													
BIOTITE									R																					VR	VR				
SCAPOLITE								R	A												R														
ZIRCON																														VR		VR			
FOSTERITE																																			
TOURMALINE								VR																											
APATITE						VR			VR											VR					VR					VR					

VA - Very Abundant (comprising over 50% of the thin section), A - Abundant (15% to 50%), R - Rare (5% to 15%),

VR - Very Rare (less than 5%)

CONCLUSIONS

A study of the petrography of the Cherry Creek marbles of southwestern Montana indicates that they have passed through the following stages of development:

1. Deposition of limey material as relatively pure $CaCO_3$. In a few cases impurities such as SiO_2 (quartz), K_2O (in sericite?), TiO_2 (as rutile), and C (carbonaceous matter) were present. However, rocks containing large amounts of such extraneous materials are rare and there seems to have been a rather sharp separation of the deposition of limey material (now marbles), from that of clayey matter (now schists), and from that of detreital quartz (now quartzite). Mixed rocks are not common.
2. Differential modification of these rocks by solutions containing magnesium to produce dolomite. Possibly some chert was formed at this time.
3. Intrusion of mafic sills and contact metamorphism with the formation of tremolite, diopside, and phlogopite.
4. Strong regional metamorphism and consequent formation of marbles.
5. Local hydrothermal alteration along contacts and layering to produce serpentine marbles and deposits of talc, with which are associated upon silicification, the production of diopside and actinolite, and the formation of large masses of fine-grained white quartz.

6. Stages 1 to 5 were completed in pre-Beltian time.
7. During Laramide time pegmatites intruded into the marbles forming the contact minerals tremolite, diopside, sphene, scapolite, and phlogopite. Locally graphite deposits were formed during this stage.
8. In Tertiary time diabase dikes were locally intruded
9. During recent or possibly Pleistocene time supergene solutions dissolved small amounts of manganese oxides and re-deposited them in favorable localities to form small deposits of psilomelane, wad and manganite.

APPENDIX

The description of the specimens, except crushed fragment, are grouped geographically into areas. The southernmost area is listed first.

1. Southern end of Ruby Mountains:

a.Ruby Crest

18-4

18-8

18-16

b.Axes Canyon

M-3

M-23

M-25

M-26

M-83 (crushed fragment analysis)

0-1

0-2

6-8 (crushed fragment analysis)

8-22(crushed fragment analysis)

32-2

c.Carter Creek

M-24

M-24a

M-27

1-3b

1-10

1-12 (crushed fragment analysis)

1-22

1-27

1-36

1-40

10-2

d. North of Carter Creek

M-22

10-13c (crushed fragment analysis)

16-1 (crushed fragment analysis)

16-3

e. Stone Creek

19-8

19-9

19-13

19-29a

19-29b

19-29c

19-33

2. Horse Creek - near Sheridan

M-18

M-19

3. Ennis Area

M-20

M-21

M-32

M-82 (crushed fragment analysis)

4. Ross Creek, Gallatin County - north of Bozeman

22-4a

DESCRIPTIONS OF THIN SECTIONS

18-4

On Ruby Crest -- Westernmost marble

This rock consists of about equal amounts of diopside and carbonate. The carbonate is generally twinned and is present as calcite. Feldspar (microcline) is the next most common constituent. A most excellent typical group of graphite crystals was observed and is shown in Plate 6. The staining tests show the calcite to be restricted to veins.

18-8

Ruby Crest -- Central marble -- Headwaters of Timber Gulch -- due east of the head of Axes Canyon

This rock consists mainly of carbonate which is medium-grained. The other main component is diopside. Staining tests show the carbonate to be calcite. Diopside is present in poorly developed bands along with quartz and phlogopite. However, none of these minerals is entirely confined to the bands or veins. Phlogopite, although classified as common, is only about half as common as diopside. From the thin section the quartz appears interstitial. Only faint suggestions of veins or banding are observed. All components are well interlocked.

18-16

On Ruby Crest -- Easternmost marble -- near head of Timber Gulch-- very thin bedded

Carbonate, diopside, and feldspar are all abundant and are present in approximately equal amounts in this rock. The carbonate is generally twinned, and the staining tests show it to be calcite. The hand specimen shows banding and the calcite is present in veins which cut across the rock randomly. The feldspar consists of both orthoclase and microcline. All minerals are well interlocked and medium-grained.

M-3

At Crystal Graphite mine -- Probably part of the Bird's Nest Marble

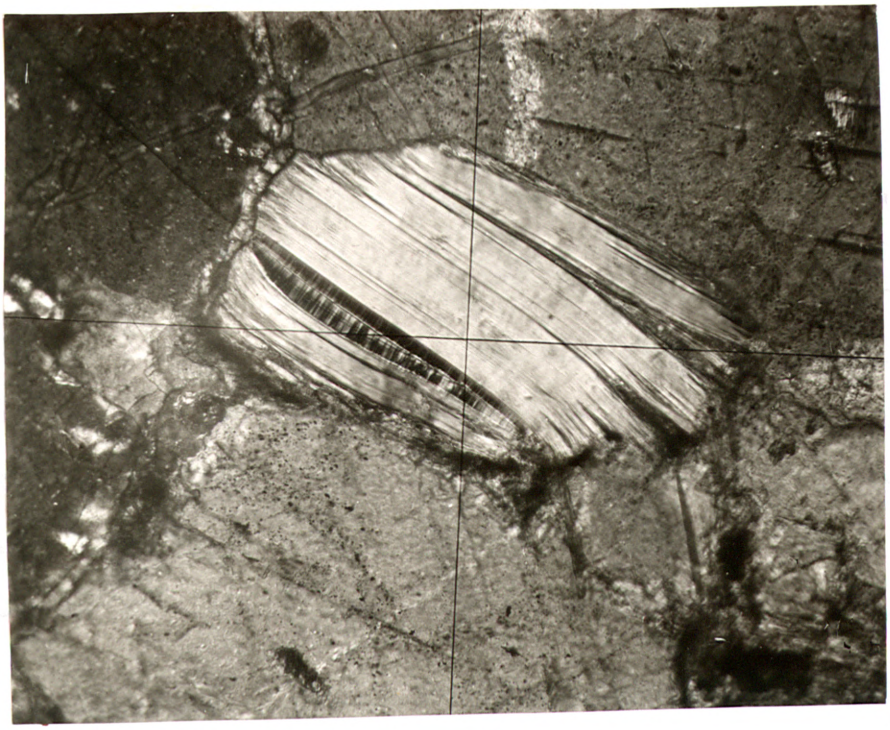
This rock was probably originally a carbonate rock that has been transformed mainly to clinozoisite, the latter being very abundant. The crystals of clinozoisite are tightly interlocking in nature and chlorite is present (about 15%) between some of them. Quartz, muscovite, graphite and tremolite were the other main components observed. This rock represents an extreme example of hydrothermally altered marble associated with the contact action of Laramide pegmatites.

M-23

From Axes Canyon Talc mine -- Portal Marble -- the one in which the Axes Canyon Talc mine is developed

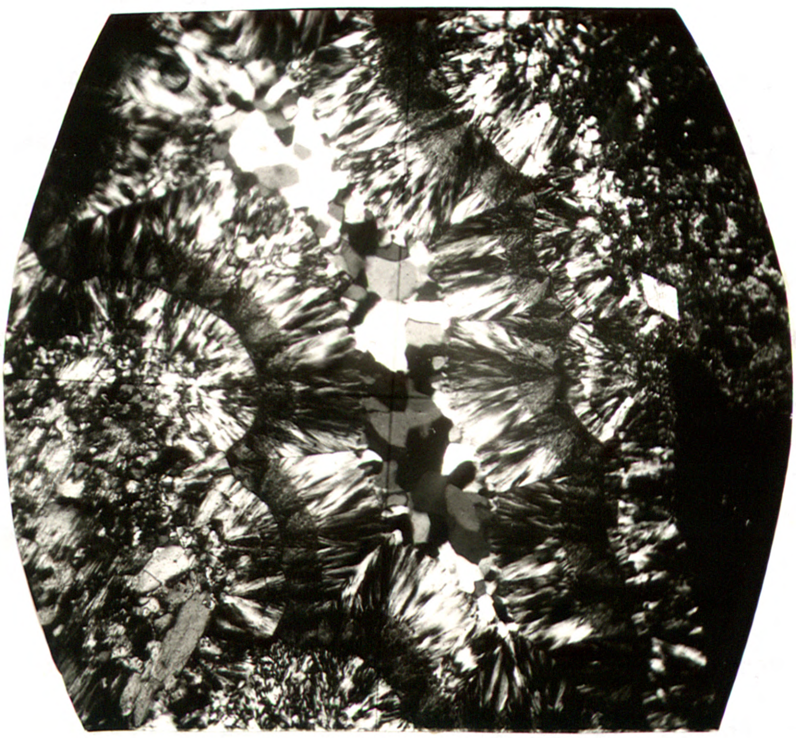
This rock is practically a pure dolomite with many extremely large crystals of carbonate, about half of which are twinned. These crystals are extremely well interlocked. One piece of rutilated chlorite was found.

Plate 8



M-26 Serpentine and Phlogopite (160X)

Plate 9



16-3 Chalcedony (crossed nicols, 90 X)

M-25

Axes Canyon -- second marble band west of graphite mill

The carbonate material of this rock consists of fine-grained to medium-grained crystals slightly interlocking and noticeably free from twinning. It comprises about 85% of the rock, and the staining tests show it to be entirely calcite. The remaining 15% consists mainly of subhedral to euhedral crystals of bladed actinolite and feldspar (acid plagioclase, microcline, and orthoclase), both of which are altered. Chlorite is also found and is more or less concentrated in circular or elongate areas.

M-26

Axes Canyon -- the marble band just west of the graphite mill -- same band as 6-8.

Dolomite is the main component of this rock. It is mostly medium-grained but some is fine-grained, and a few crystals are quite large. All are tightly interlocked and generally untwinned. Small amounts of diopside and tremolite were observed in an altered condition. In one place diopside was observed being replaced by tremolite and talc was in turn replacing the tremolite. A very interesting relationship, in which serpentine was present between flakes of mica, was observed (Plate 8).

O-1

Axes Canyon -- Bird's Nest Marble -- along Laramide pegmatite

This rock is generally medium-grained. The carbonate comprises slightly over half the total, and about one-half of this is twinned.

Quartz, feldspar, scapolite, diopside and actinolitic hornblende make up the greater part of the remainder of the slide and are well interlocked with the carbonate. Some of the actinolitic hornblende seems to have replaced the diopside. A few minute crystals of blue tourmaline (indicolite) were observed.

0-2

Bird's Nest Marble -- away from the contact of the Laramide pegmatite

This rock is a gneiss, probably originally from a calcareous shale. The various bands contain, in general, concentrations of certain minerals. Quartz, for instance, is more or less confined to bands and in one instance one band is composed of quartz and biotite. Zoisite bands contain little or no quartz but have scapolite and garnet. Amphibole and pyroxene are likewise confined to particular bands. Scapolite, which is abundant in this section, is typical of the scapolite found throughout the study. It is colorless, usually in columnar aggregates, and the crystals are usually large. It has a distinct cleavage. The birefringence varies from rather weak to rather strong. The maximum interference color is second order violet. Extinction is parallel in most sections. In these sections one of the most distinguishing features is the low relief.

32-2

Bird's Nest Marble -- away from Pegmatite

This rock is probably a silicified calcite marble. In the thin section quartz is by far the most abundant mineral. Diopside and carbonate are present in about equal amounts. The latter is fine-grained, and all components are tightly interlocked. In the hand specimen there is a suggestion of banding. Some bands reacted more favorably to the staining tests, and these same bands also reacted better to dilute hydrochloric acid indicating that it is predominatly calcite.

M-24

Carter Creek -- first marble band west of Keystone Talc mine -- serpentine marble

This ophicalcite is composed of about 75% fine-grained calcite and about 24% serpentine, which in some places is concentrated in large circular areas. In other places it is in very small circular areas between the interlocking, untwinned carbonate grains. Smaller amounts are present throughout the rock as small fibers. The remainder of the rock consists of talc, some of which is in veins, indicating that it is younger than the main part of the rock. About 20% of the carbonate is stained brown.

M-24a

Same location as M-24

This specimen consists of about 99% carbonate which the staining tests show is dolomite. Phlogopite, the only other mineral of consequence, is interstitial. The carbonate is generally untwinned and medium-grained. The texture is sutured, as shown in Plate 4.

M-27

Carter Creek -- Keystone Talc Marble

About 95% of this slide consists of medium-grained, tightly-interlocked carbonate crystals about three-fourths of which are twinned. Phlogopite and chlorite are the only other constituents of importance. One piece of rutilated chlorite was observed. Some chlorite is present in veins, indicating that it is younger than the carbonate. Small amounts of talc replacing phlogopite were observed. The hand specimen was unaffected by either of the staining tests and is, therefore, dolomitic.

1-3b

Carter Creek — the Carter Creek Marble

This rock is another ophicalcite with almost twice as much very fine-grained and tightly interlocking calcite as serpentine. The latter is generally in medium-sized pockets. Phlogopite, with a peculiar pleochroism, comprises about 5% of the rock. The pleochroism varies from practically colorless perpendicular to the elongation, to a deep dark blue parallel to the elongation. The borders of the crystals are colorless. However, with crossed nicols these borders appear to have an anomolous blue color.

1-10

Carter Creek -- typical Carter Creek Marble

This rock consists of practically 100% carbonate. Few crystals are twinned. The staining tests show it is dolomite. The only other minerals noted were phlogopite, which is very rare, and even smaller amounts of serpentine and talc (?). The outstanding feature of this rock is its mosaic texture, (Plate 5).

1-22

Carter Creek -- Carter Creek Marble

This marble is practically 100% dolomite. It is very coarse-grained, and the twinning, which is observed in about one-half the crystals, is correspondingly coarse. The mosaic texture is extremely well-developed. The other minerals observed were quartz and chalcedony. Both are interstitial and occur together in but one place in the slide.

1-27

Carter Creek -- Carter Creek Marble

This rock consists of very fine-grained calcite with serpentine as the interstitial component. The texture is unique. In the hand specimen, extremely well developed veins of serpentine, up to about 6 inches in thickness, were observed. This feature is not present in the thin sections, however. Some of the serpentine in the hand specimen also occurs in lenses about one inch long and 1/4 inch thick.

1-36

Carter Creek -- Carter Creek Marble

Serpentine and carbonate, most of the latter being dolomite, make up the greater part of the rock. The carbonate is generally untwinned and varies in size from fine-to coarse-grained. Serpentine is generally confined to circular areas of varying sizes. Tremolite is the next most abundant mineral, being about twice as common as diopside. It seems to be surrounded by serpentine in many places. It appears from this relationship that the serpentine is replacing the tremolite. Small amounts of talc also replace tremolite. There seems to be a fair elongation to the carbonate grains.

1-40

Carter Creek — Carter Creek Marble -- along contact of Tertiary diabase and is baked

This rock consists of a great deal of an indeterminate dark compound and extremely fine-grained calcite. The slide appears veined but this observation was not verified in the hand specimen. Small amounts of serpentine were observed. One piece of carbonate with a concretionary structure was observed.

10-2

Carter Creek — the marble directly below Christensen Sillimanite Horizon

Seventy percent of this rock is tremolite and twenty percent consists of diopside. Both represent metamorphism of the carbonate, only five percent of which is left. All crystals are crushed and tightly interlocked.

M-22

Same marble band as O-1 but farther to the northeast - At Bird's Nest Graphite mine along contact of combined aplite - pegmatite carrying graphite.

Medium to very large grains of calcite, all of which are twinned, comprise the greater part of the slide. Scapolite, quartz, diopside and feldspar, all of which comprise about 5% of the total, are interlocked with the carbonate. A few grains of biaxial calcite were observed along with a most excellent crystal of graphite (Plate 7).

16-3

North of Carter Creek -- from the contact of Keystone (Laramide) pegmatite

This rock abounds with chalcedony, some of which is in veins, some in large circular areas, and the rest surrounds the remaining carbonate and other large crystals. It is obvious from inspection of the slide that the chalcedony is of later origin than the main part of the rock. Parts of the rock are extremely altered and limonite is quite abundant. The chalcedony varies from a very fine variety to the coarse variety shown in Plate 9. It shows the radial structure typical of it and the fibers are length fast. Small amounts of talc replacing tremolite were observed.

19-8

Stone Creek at the Forks -- the Easternmost marble.

This specimen consists mostly of medium- to large-grained carbonate crystals. The twinning suggests calcite, and this is substantiated by the staining tests. Manganese oxide, with its characteristic earthy appearance, is quite common. Quartz is probably the most abundant of the remaining minerals and is without question interstitial. A mica is also present and is considered phlogopite on the basis of pleochroism.

19-9

Stone Creek -- little to west of 19-8 -- talc veins in outcrop

This rock is practically pure carbonate, composed of small to mostly medium-grained crystals which are extremely well interlocked. A few are twinned. Phlogopite, present in very small crystals, and magnetite, are the most abundant of the very rare accessory constituents. The staining tests on the hand specimens show in a most beautiful manner the mode of occurrence of interstitial calcite in a mass of dolomite. In a few instances it is possible to trace the calcite from one interstitial emplacement to another by means of a thin stained line. It is obvious from this relationship that the calcite is later in origin than the dolomite.

19-13

Stone Creek -- 3rd Marble on Stone Creek -- black chert very abundant

The carbonate in this marble is dolomite. It is generally grained. The texture is different from anyother observed in the study. It is not mosaic, but then again it is not interlocking and may best be described as a sutured texture (Plate). Quartz, one of the very rare minerals present, is interstitial. Manganese oxide is not uncommon. A composite pseudomorph of talc, serpentine, quartz and sphene, possibly after diopside (?), was observed

19-29a

Stone Creek -- silicified marble

This specimen is probably a silicified carbonate. Carbonate, quartz, and actinolite are the most important mineral constituents. The staining tests show the carbonate to be calcite. The rock is definitely banded. This is not very obvious from the thin section examination but definitely recognized in the hand specimen. The carbonate is interspersed with quartz, but is not common in some quartz veins and is absent in others. Actinolite seems to be more common in the quartz veins than in the calcite. All crystals are medium-grained and well interlocked.

19-29b

Stone Creek -- pure marble

This specimen consists mainly of large-grained carbonate which seems to be dolomite from examination of the twinning. This is substantiated by the staining tests. There is a fair expression of banding in thin section, but this is difficult to observe in hand specimen. The bands seem to contain dolomite crystals of slightly different sizes. One small band of extremely altered diopside was observed. This was surrounded by manganese oxide, which also occurs in other thin veins throughout the slide.

19-29c

Stone Creek -- 4th marble -- impure marble along contact of hornblende sill

This rock consists of bands of fine-grained carbonate (calcite) alternating with bands of earthy manganese oxide. The extreme fineness of the banding can be appreciated only when one examines the stained hand specimen. Small wisps of phlogopite are generally present throughout the rock. Small amounts of diopside are present, in a very altered condition, only in the veins of manganese oxide.

19-33

Stone Creek -- near a contact with hornblende gneiss

This rock consists mainly of carbonate, which is generally fine-grained and untwinned. The staining tests show it to be dolomite. Tremolite, phlogopite, and an earthy material which is manganese oxide were the only other constituents found. The mica seems to follow fractures. The very small and badly altered crystals of tremolite are confined to veins along which the manganese oxide was later introduced.

M-18

Horse Creek — near Sheridan -- southwest end of Tobacco Root Mts.

This talc schist is quite similar to slide M-19 in origin and main mineral composition. However, there is less talc (only 80%) and more chlorite. Instead of serpentine there are small amounts of garnet and phlogopite. Some of the chlorite (pennine) has replaced the garnet.

M-19

Horse Creek — near Sheridan -- S. W. end of Tobacco Root Mts.

This rock is a talc schist originally from a magnesium-rich carbonate. Ninety percent of it consists of fine-grained wispy talc. The remainder is made up of small areas of serpentine and chlorite.

M-20

Ennis Area —from the Froks of Cherry Creek — hydrothermally altered limestone associated with chalcopyrite and talc which are hydrothermal

This rock is a very pure, medium-grained carbonate (95%). All the carbonate is twinned and the crystals are well interlocked. Some grains are surrounded with limonite, which seems to have been a cementing agent at one time. A vein of chalcedony runs through the slide. Chlorite, in small amounts, occurs in nests. Both staining tests show the mass of the carbonate to be dolomite. Calcite is confined to parallel bands which are exceptionally parallel and most probably indicates later deposition in bedding planes due to the action of ground water. In thin section the calcite in the bedding planes appears much smaller and ill-formed compared to the large, well-formed dolomite. The chalcedony is found along with the calcite and represents a later, possibly supergene, origin.

M-21

Black Point Dolomitic Marble -- North of Johnny Gulch -- Ennis Area

This section shows a practically pure, exceedingly fine-grained and tightly-interlocked carbonate rock. It appears to have been dolomitized, as rhombs of what is most probably dolomite are visible with calcite around them. An opaque, disseminated material was visible along cleavages and may be graphite. No hand specimen available to test carbonate by chemical means.

M-32

Ennis area -- Silicified Black Point Dolomite from Johnny Gulch

This slide was extremely thick and difficult to analyze. Quartz, which was very abundant, dolomite, and manganese oxide were recognizable. The rock is probably a silicified dolomite.

22-4a

Ross Creek in Gallatin County, north of Bozeman

This rock consists, for the greater part, of carbonate. The staining bests show it to be calcite. It is generally medium-grained, untwinned, and well interlocked. Manganese oxide was observed in one large mass. Phlogopite (on basis of pleochroism), graphite, and limonite are very rare.

DESCRIPTION OF SAMPLES STUDIED BY CRUSHED FRAGMENTS

16-1 Contact of Keystone pegmatite (3 specimens)
Mainly tremolite (Biaxial negative, large 2V, small extinction angle, bladed structures), some phlogopite (small 2V), minor amounts of diopside (pale green color, 2V about 60, positive sign, extinction angle about 40 degrees).

10-13c Near Keystone pegmatite—contact of mafic sill
Tremolite — same characteristics as 16-1

M-82 Contact of mafic sill
Tremolite

1-12 Carter Creek Marble
Tremolite and minor amounts of magnetite

M-83 Silicified zone in Axes Canyon Talc -- at Quarry
Mainly diopside (indicies greater than 1.65, Biaxial positive, pale green color, not bladed 2V about 60, extinction angle about 40 degrees).
Small amounts of tremolite, and magnetite.

6-8 Contact with mafic sill--on Axes Canyon--First marble west of graphite mill
Entirely Tremolite

8-22 Contact mafic sill--near head of Axes Canyon
Actinolite--pale green color and pleochroism, Biaxial negative, large 2V, extinction angle about 18 degrees

1-22 Carter Creek — contact of mafic sill
Tremolite

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