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# Mottling in the Meagher Limestone

Ronald J. White

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# IN THE MEAGHER LIMESTONE

by
Ronald J. White

A Thesis
Submitted to the Department of Geology
in partial fulfullment of the
Requirements for the degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
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## ABSTRACT

The middle Cambrian Meagher limestone of southwest Montana is characterized by mottled members that are finely crystalline in the tan part and microcrystalline in the dark matrix. As seen in the literature, similar mottled limestones are thought to be an arrested stage in the dolomitization, or alteration of limestones.

Laboratory data has shown that the tan parts of the mottled Meagher are recrystallized limestone that is dolomitic in some places, but not in all cases. Hence, these mottled limestones are not necessarily dolomite in the tan areas, or an arrested stage in the process of dolomitization.

A study of the tan areas shows them to vary from the dark matrix in the following ways: (1) the occurrence of relatively large, well-formed crystals; (2) the inclusion of iron stains; (3) the uniformity with which tan areas spread into the limestone matrix; and (4) the considerable variation in chemical composition between tan areas and the dark matrix.

On the basis of these points, the mottled Meagher limestone is interpreted as having been formed by the migration of extraneous solutions through permeable zones in the calcareous muds during, or prior to lithification.

# MOTTLING IN THE MEAGHER LIMESTONE

R. J. White

## INTRODUCTION

Analysis has shown that the mottled Meagher limestones contain lithologic characteristics that are, to the authors knowledge, undescribed in the literature. This study was undertaken as an undergraduate thesis problem which is required as partial fulfillment of the Bachelor of Science degree in Geological Engineering, at Montana School of Mines. Samples were obtained from several localities throughout southwest Montana, and the experimental work was conducted through the facilities of the school laboratories.

The purpose of this study is twofold: (1) to establish the true identity of the tan parts of the mottled Meagher limestones and, (2) to uncover any pertinent data relating to the origin of these mottled limestones. The true lithologic characteristics of the Meagher limestones are explained herein, but the ideas relating to the origin that are contained in the report are purely hypothetical.

This problem is closely associated with an unpublished paper by A. M. Hanson on the Cambrian system of Montana. Much of the general information on the Meagher formation has been obtained from Dr. Hanson, in addition to his untiring suggestions and criticisms of the problem itself. The author wishes to further acknowledge the work of Dr. E. S. Perry and Forbes Robertson, also of the Geology depart-

ment, for their helpful criticism of the manuscript. Special thanks are due Mr. C. J. Bartzen, of the Montana Bureau of Mines and Geology, for making the chemical analyses of the samples.

## REVIEW OF THE LITERATURE ON MOTTLED LIMESTONES

Considerable work has been done on the problem of mottled limestones and their bearing on dolomitization. Francis M. Van Tuyl has contributed immensely to the dolomite problem, while W. A. Tarr, R. C. Wallace, E. Steidmann, and R. H. Griffin have also volunteered considerable information, especially with reference to the mottled limestones. (See Bibliography)

Supplementing the work of Van Tuyl, Wallace studied the mottled Ordovician limestones of Manitoba with the view of determining their origin. He established the relationship of mottling to fucoid-like algal markings, concluded that the magnesia was indigenous, and theorized (1) that "the relationship has resulted from a process of local replacement produced by the magnesia contained in algae which were embedded in the limestone at the time it was deposited". On the other hand, Van Tuyl (1) maintains that the dolomite was formed by the selective alteration of fucoid-like markings upon the addition of magnesia-bearing solutions. In support of his opinion, Van Tuyl mentions the association of unaltered markings with dolomitic areas; imperfect dolomitization; and the gradation of mottled beds into dolomite, both latterally and vertically.

In an earlier study of the Tribes Hill formation, Van Tuyl (2) attributed the mottled parts to the presence of coarse-grained dolomite. The dolomitization was thought to have proceeded along stratification lines and along lines which appeared to be worm castings. He concluded that "the mottled limestone represented an incomplete stage in the process of dolomitization and that the alteration had taken place at the time of, or shortly after, deposition".

Perhaps the most recent study of mottled limestones was made by Griffin (3) in the Platteville limestone around Minneapolis and St. Paul. After detailed study he concluded that the mottled part was dolomite, and that the dolomitization had taken place after lithification but before jointing. He regarded the dolomite as being "effected by introduced magnesian solutions migrating laterally and vertically through permeable zones in the limestone".

At the present time, mottled limestones are thought to contain dolomite in the tan or mottled parts, while the remainder is generally conceded to be limestone. Dolomites are believed to have been formed by the alteration of limestone, and mottled limestones are thought to be a result of incipient dolomitization, or a gradational or transition phase in the formation of dolomite that has been arrested by unknown factors. It is generally believed that dolomitization resulted from the migration of extraneous magesium-bearing solutions. The time of dolomitization is thought to be during, or shortly after, lithification, but prior to the emergence of the limestone from the seas.

## THE MEAGHER FORMATION

### DEFINITION

The Meagher formation, of Middle Cambrian age, is underlain by the Wolsey shale and overlain by the Park shale. The Meagher was first described as the "Mottled Limestones" by Peale (4) in 1890. Subsequent work by W. H. Weed (5) in 1899, assigned the Meagher as a member of the Barker formation which included all Cambrian rocks. In 1900, Weed (6) further clarified the situation by elevating the members of the Barker to formational rank. Thus the Meagher formation was first defined by Weed and the type section originally studied lies in the Little Belt Mountains.

### DESCRIPTION

#### Lithology

Recent work by A. M. Hanson (7), has shown that the dominantly calcareous Meagher formation grades from limestones in the more easterly exposures to dolomites in the West (see figure 1.). The transition zone is characterized by interbedded limestones and dolomites.

The limestones are more commonly thin to medium-bedded, but some massive outcrops occur in a few localities. Grain size in the limestone is characteristically fine and may be termed aphanitic. Oolitic members are common towards the center of the formation with the individual oolites ranging as high as two mm in diameter. However, most mottled sections are finely crystalline in the tan portions and aphanitic or microcrystalline in the darker parts. The

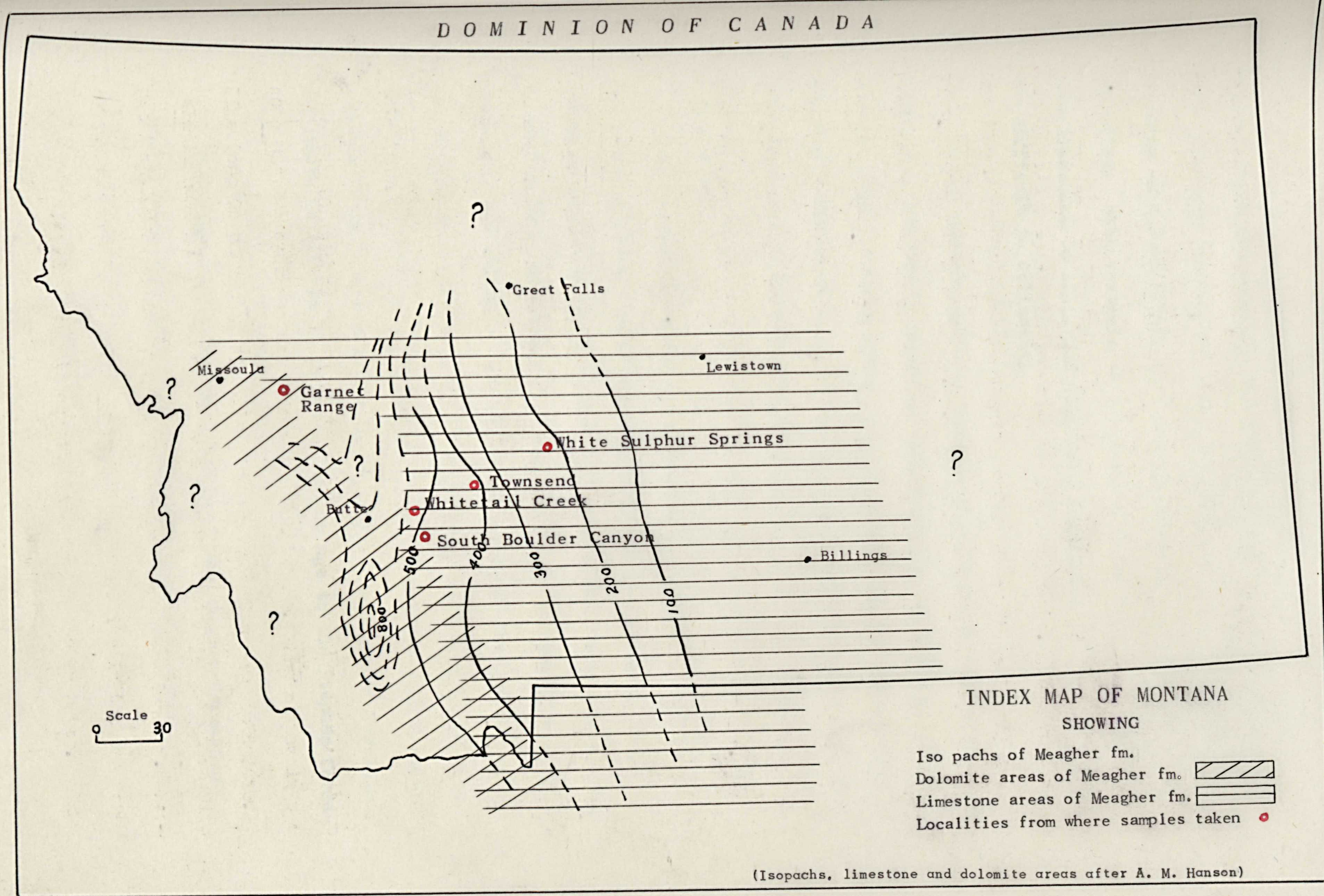

DOMINION OF CANADA
Great Falls
Lewistown
Missoula
Garnet Range
White Sulphur Springs
Townsend
Whitetail Creek
Butte
South Boulder Canyon
Billings
?
500
400
300
200
100
800
Scale
0
30
INDEX MAP OF MONTANA
SHOWING
Iso pachs of Meagher fm.
Dolomite areas of Meagher fm.
Limestone areas of Meagher fm.
Localities from where samples taken
(Isopachs, limestone and dolomite areas after A. M. Hanson)

Figure 1

mottled parts are commonly tan to light gray in color, whereas the pure limestone ranges from black to light gray. Although some shale partings have been found, they are uncommon throughout most of the formation. Both contacts of the Meagher formation are gradational from limestone to shale and the exact boundaries for the most part are difficult to delineate.

In the western section, where the formation is almost all dolomite, the Meagher is generally medium-bedded to massive. Mottling is also found in these areas, but the grain size is larger than in limestone counterparts to the east. The color ranges through different shades of brownish-gray.

Distribution

The Meagher formation is wide-spread throughout central and southwest Montana. In northwestern and western Wyoming, it is known as the Death Canyon member (8) of the Gros Ventre formation. According to A. M. Hanson (7), the Damnation, Dearborn, Pagoda, Pentagon, and Steamboat formations of northwest Montana are roughly equivalent to the Meagher in that area. From a point west of Anaconda, northwest to the Garnet range, the Silver Hill formation appears to correlate with the lower part of the Meagher formation. Far north in Alberta it is equivalent in age to the Stephen formation.

The dolomitic sedimentary facies of the Meagher formation forms a known belt roughly 50 miles in width and extending from the Montana - Idaho - Wyoming border northward through Melrose, Anaconda, and Missoula (see figure 1). The limestone sedimentary facies extends as far east as Cooke City, White Sulphur Springs, and Neihart.

The Silver Hill Formation

Starting from a point southwest of Anaconda, the Silver Hill formation extends northwest through Phillipsburg to the Garnet Range east of Missoula. A sample from this formation was used in this study because it was thought to be a westerly extension of Meagher formation. According to Hanson (7), incomplete fossil evidence places the Silver Hill equivalent to the Wolsey, which underlies the Meagher in other localities. Since the Wolsey - Meagher contact is gradational, it is not impossible that either the fossils or the environmental conditions may have crossed the time boundary. Lithologic study and comparison with other Meagher samples would make the Silver Hill equivalent to the Meagher. Therefore, on the basis of lithology, the Silver Hill is here considered to be part of the Meagher formation.

## FOSSILS

Fossils are relatively scarce in the Meagher formation and are mostly confined to zones in the upper and lower parts of the formation. According to Deiss (4) some of the more important fossils include Agnostus interstrictus; Bathyuriscus haydeni and powersi; Ehmania weedi, walcotti, and gallatinensis; and Kootenia serrata.

## ORIGIN

The Meagher formation was formed under essentially stable environmental conditions that characterized the seaways of the Cordilleran region during Middle Cambrian time. Although it contains some fine clastics which are indicative of minor disturbances, the greatest part of the formation originated from very fine limy particles formed by either bacterial action or chemical precipitation,or both. It appears that the depth of deposition differed considerably throughout the time interval. Pisolitic and oolitic members certainly indicate shallow deposition where the tiny calcareous particles underwent considerable movement, probably as the result of wave action.

## ECONOMIC ASPECTS

### Metallic Deposits

Since it is a limestone formation, the Meagher has in many places been the host rock for mineralizing solutions. The Hecla district, west of Melrose, is a situation where sulfides of copper, lead, zinc, and silver have been deposited in the Meagher. South of Whitehall, the Mayflower Mine has also produced considerable wealth of gold and associated metals from the ore shoots in the Meagher limestone. In the Rochester district, Sahinen (27) has described ore shoots containing gold, silver, and lead that replace limestones of Cambrian age, and possibly of the Meagher formation.

### Building Stone

In the vicinity of Townsend, a limestone commercially designated as the "Black and Gold marble" has been quarried from the Meagher and shipped East for use as building stone. An example of mottled limestone from this area can be seen in Plate 1.

EXPLANATION OF

PLATE 1

Photograph of polished section

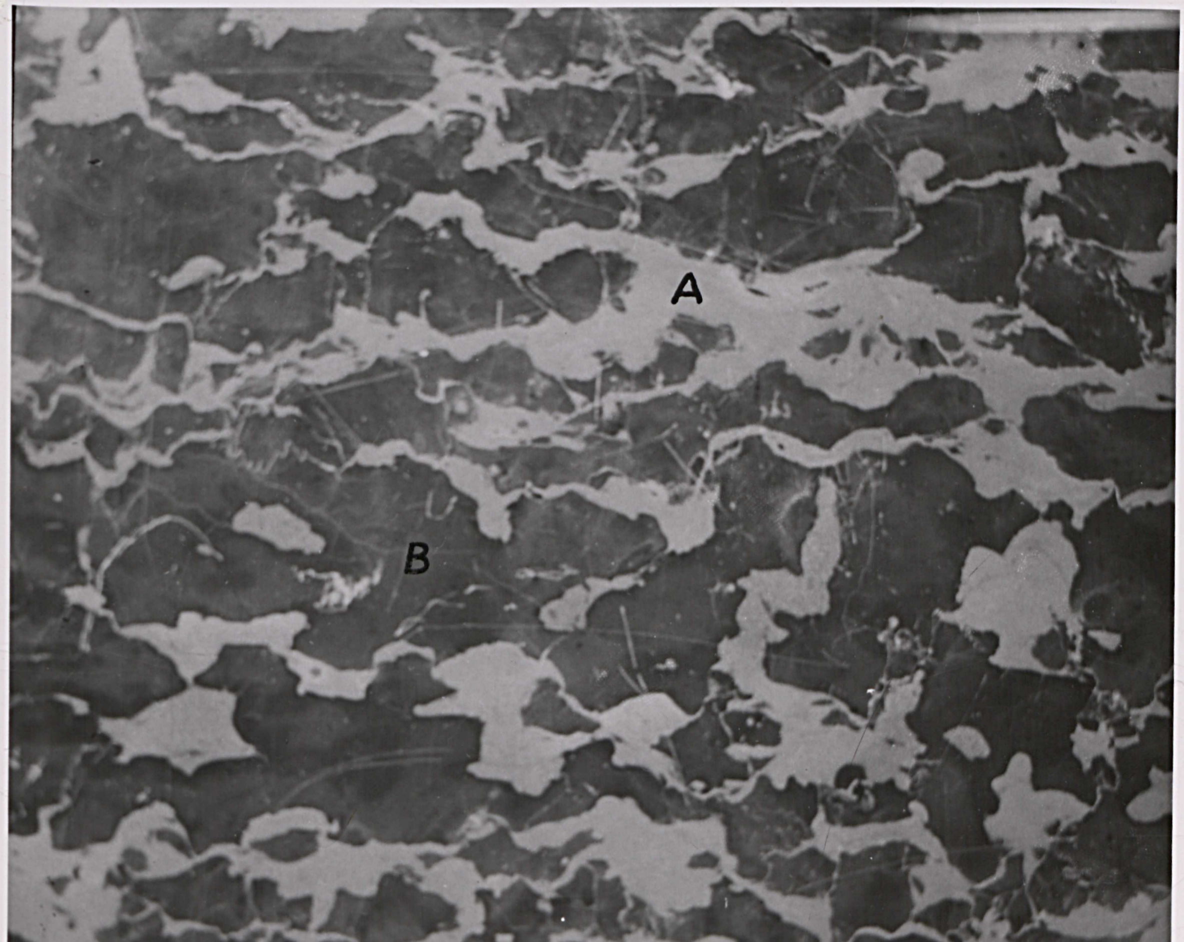
Sample from Townsend

Indicated scale is equivalent to one inch

A - Dolomite, B - Limestone

Note tendency of dolomite to follow stratification lines, and black patches in the limestone.

PLATE 1




Polished Section of Meagher limestone from Townsend X 1.3

Flux

At the East Helena plant of the American Smelting and Refining Company, limestone from the Meagher formation is being used as a flux in the lead smelting operations. Material for this process is obtained from a quarry in the vicinity of East Helena.

## MOTTLING OF THE LIMESTONE

### LITHOLOGY

Color

The mottled limestone members of the Meagher formation display a striking variation in color, both in vertical and lateral extent. In view of this fact, any correlation on the basis of color is virtually impossible. There is, however, a considerable color difference in the dark gray limestone as well as in the mottled portions.

Color in the gray limestone ranges from a very light gray as found in some samples from White Sulphur Springs and Whitetail Deer Creek, to black, as displayed in rocks from Townsend (see plate 1) and the Silver Hill formation. The black color probably results from finely dispersed carbonaceous material. The importance of iron in relation to color is not manifest in the gray limestone. However, with the exception of the Silver Hill sample, the lighter colored limestone appears to carry the greatest amount of iron. See Table 1). It is notable that the insoluble content is much greater in the light gray rock.

The mottled portion of the limestone shows by far the greatest range in color. Almost all shades of tan or buff are represented, and in some samples the color becomes bright brownish red. Iron is of lesser importance in this part than in the gray limestone as previously mentioned. Although the iron is undoubtedly responsible for much of the color, the relative amount present is not responsible for the variation in intensity of color. Coloration in the mottled part appears to be related to two factors; namely, the grain size and possibly the insoluble content. In the samples analyzed, the mottling assumed the brightest hues where the grain size was smallest (see plate 1. nos. C and D). Furthermore, these bright colorations in the mottling are also associated with abnormally high insoluble residues. As shown by chemically analysis, (See Table 1) the insoluble residue in the bright mottlings is almost four times as great as that found in the tan or buff mottling.

Grain Size and Crystallization

One of the most striking features of this problem is the difference in grain size between the mottled or tan part and the matrix-forming limestone. As will be discussed in a later part, this difference in grain size is believed to have a considerable bearing on the origin of the mottling. The primary limestone is made of aphanitic anhedral grains, and even under high magnification the calcareous particles are almost indistinguishable. On the other hand, the mottling is characterized by relatively large euhedral and subhedral rhombs of calcite or dolomite. (See Plate 2). Some of these rhombs have been magnified to a size greater than one-quarter inch, while the corresponding limestone particles are barely visible. See plate 2, nos. A, B, and F). A study of the contacts (plate 2) shows that the growth of the rhombs was not confined to any single direction,

EXPLANATION OF PLATE 2

Micro-photographs of mottled contacts in the Meagher Limestone

Mottled limestones at A, primary limestones at B

A. Sample from South Boulder Canyon, magnified approx. 70 times

Dark blotches in the mottled areas is iron staining

Note euhedral rhombs of calcite

B. Sample from South Boulder Canyon, magnified approx. 55 times

Iron occurs around the grain boundaries of euhedral rhombs and as interstitial blotches.

C. Sample from White Sulfur Springs, magnified approx. 55 times

Color contact as indicated, heavy iron stains in the dark areas.

Grain size contact gradational from left to right, aphanitic primary limestone farther to right and not shown.

D. Sample from Whitetail Creek, magnified approx. 55 times

Iron stains associated with Dolomite (A)

Fossil fragments in both limestone and dolomite areas

E. Sample from Townsend, magnified approx. 70 times

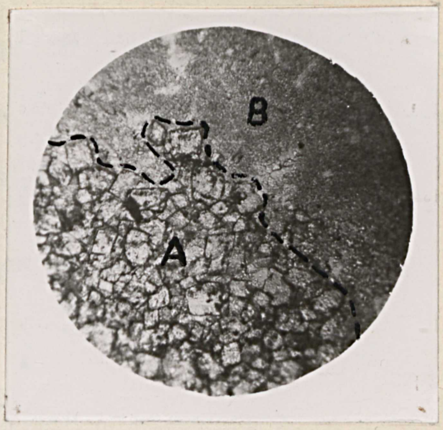
F. Sample from Silver Hill Formation, Garnet Range,

magnified approx. 55 times

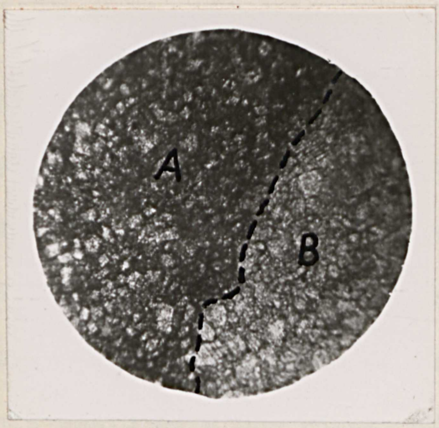
Euhedral rhombs of dolomite almost entirely masked by iron stains. (A)

PLATE 2

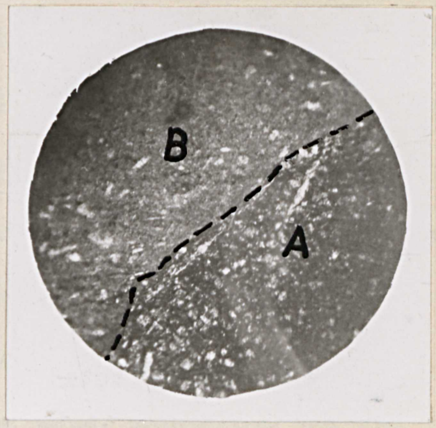

A



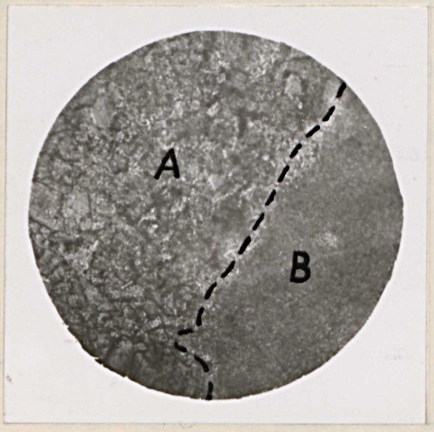

B



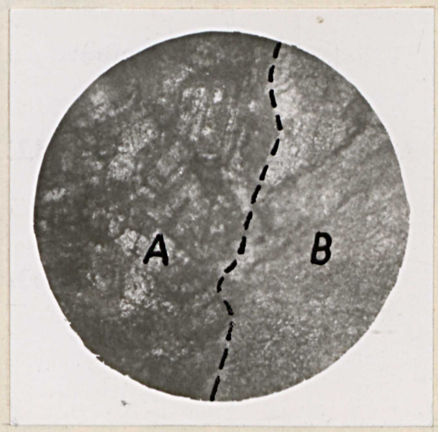

C




D




E




F

Micro-photographs of thin sections of Meagher limestone but rather that they expanded with equal facility in all directions.

The crystalline structure assumes paramount importance in the mottled part where it is a definite indication of the conditions under which the mottling was formed. The situation will be further explored in a later discussion on the origin.

## ANALYTICAL DATA

### Chemical Analysis

Samples from five localities (see figure 1) were submitted to be analyized for magnesium oxide, calcium oxide, total iron, and the insoluble residue. Each one of these samples was broken and crushed, and the tan or mottled part was separated from the primary limestone. This separation was effected by hand, and the two components were analyized separately. In this manner, a true picture of the chemical make-up of each part of the rock was obtained. Hand separation, although necessarily tedious, was very effective and the only chance for error was inclusion of primary limestone in the mottled samples. This would have the effect of lowering the total magnesium content in the mottling. It is highly improbable that this possible error has varied the true value by more than one per cent.

In addition to establishing the limestone and dolomite relationship, the chemical analysis has proved useful in relating color to chemical content in addition to revealing facts pertaining to the origin of the rock.

### Thin and polished sections

Both thin and polished sections were made of each sample from the localities as shown in figure 1.

CHEMICAL ANALYSIS OF MOTTLED MEAGHER LIMESTONES

| Locality | Tan Areas | | | | | Grey Matrix | | | |
|---|---|---|---|---|---|---|---|---|---|
| | CaO | MgO | Total Iron | Introduced Iron | Insol | CaO | MgO | Total Iron | Insol |
| White Sulfur Springs | 42.6 | 0.2 | 0.9 | 0.7 | 16.2 | 52.2 | 0.4 | 0.2 | 4.2 |
| South Boulder Creek | 50.4 | 0.2 | 1.6 | 1.5 | 4.3 | 54.1 | 0 | 0.1 | 1.2 |
| Whitetail Creek | 34.8 | 8.6 | 1.8 | 1.4 | 14.9 | 46.6 | 1.8 | 0.4 | 8.4 |
| Townsend | 35.8 | 10.8 | 1.8 | 1.7 | 3.4 | 52.9 | 0.9 | 0.1 | 1.1 |
| Silver Hill fm., (Garnet Range) | 41.4 | 7.5 | 0.7 | 0.5 | 3.5 | 52.7 | 1.2 | 0.2 | 1.6 |

TABLE 1

Thin sections were made by cutting strips with a diamond saw to a thickness of approximately two to three mm. One side of this strip was polished, and the section was cemented to a glass slide with Lakeside cement. Using coarse carborundum, the section was ground to a thickness of less than one mm. The sample was then ground further to a thickness of approximately .03mm, using fine carborundum. Finally, a cover glass was cemented to the completed section with Lakeside. Since these sections were to be used for studying contacts rather than petrographic work, an exact thickness was not obtained and some sections were thicker than indicated above.

Polished sections were made of each sample in order to obtain a true picture of the mottled structure, as well as any indications relating to its origin. Samples that had been oriented in the field were cut both normal and parallel to the plane of bedding. The diamond saw was again used for the initial cutting and was followed by polishing with carborundum that ranged from 100 to 1000 mesh.

Photographs

For the purpose of illustrating the discussion, both regular and micro-photographs were taken of several samples. Some of these photos were considerably enlarged for further clarification. Photos on the accompanying plates were made from thin and polished sections.

Staining Methods

One method of differentiating limestone from dolomite is the application of staining techniques. The many staining methods have been reviewed in considerable detail by Rodgers (10) and their individual applications evaluated. All of these methods, with the exception of the copper nitrate stain, were rejected by the author because of the interference by iron, instability of the stain, lack of permanency, and the difficulty of application. After experimenting with each method, Mr. Rodgers concluded that the copper nitrate stain was the most reliable.

The method, as suggested by Rodgers, consists of immersing a polished section of the unknown in a molar solution of copper nitrate for a period ranging from 2½ to 6 hours, depending upon the amount of calcite present. The writer found that 4½ to 5 hours gave quite satisfactory results. During this immersion, the limestone areas are stained light green in color, whereas the dolomite areas remain unchanged. Upon removal from the solution, the specimen is immediately placed in a strong solution of ammonium hydroxide for a short period of time, (a few seconds is sufficient). Excess precipitate may then be removed by washing and gentle buffing.

In addition to the unknown samples, several known pieces of dolomite and limestone were stained by this method. The results were positive. Areas of limestone and dolomite as indicated by the stain checked perfectly with those shown by chemical analysis. The known samples were chosen so that a considerable variation in grain size could be tested. This was to supplement Rodgers' (10) experiment, since he made no direct observations on the relation of grain size to the staining method. Both dolomite and limestone samples had a range in grain size from aphanitic to one mm or more. As was to be expected, the dolomite did not stain, but the staining on the coarse oolitic limestone sample was slightly less intense than on the aphanitic samples.

However, this slight variation might be dependent on other factors. Consequently, on the basis of this procedure, it may be concluded that grain size (within the limits as indicated above) should not cause any important variation in this staining technique.

Effervescence Tests

As in the staining experiments, both known and unknown samples were subjected to effervescence tests with dilute hydrochloric acid. In this method limestone will effervesce quite freely whereas the dolomite is not supposed to react unless finely ground. The results were very inconsistent and must be assumed negative. A known dolomite, such as the Bighorn of Wyoming, did not effervesce. On the other hand, tan or mottled parts of the Meagher limestone, which proved to be dolomitic by stains and chemical analysis, effervesced almost as freely as the limestone. However, the dolomite portions of the limestone contained approximately 10% magnesium oxide, while the almost pure Bighorn dolomite contains almost 20%. Effervesence in the dolomite areas might be caused by interstitial calcite, or separate grains. This experiment would seem to conflict with the results of the staining tests, and the amount of magnesium present seems to be an important criterion.

## ORIGIN OF MOTTLING IN THE MEAGHER LIMESTONE

General Statement

Previous discussion has indicated that the areal extent of the mottled Meagher limestone is quite large. As a result, a truly authoritative discussion of its origin requires much more field and laboratory study than is possible under the existing circumstances.

EXPLANATION OF PLATE 3

Photographs of polished sections from South Boulder Canyon

A. Magnified approximately three times

Indicated scale is equivalent to one inch

A - is primary matrix, B - is first stage limestone mottling,

C - is second stage of limestone mottling

Calcite veinlets in primary limestone

B. Magnified approximately three times

Indicated scale is equivalent to one inch

A - primary matrix, B - tan mottling

Calcite veinlets in primary limestone

C. Magnified approximately three times

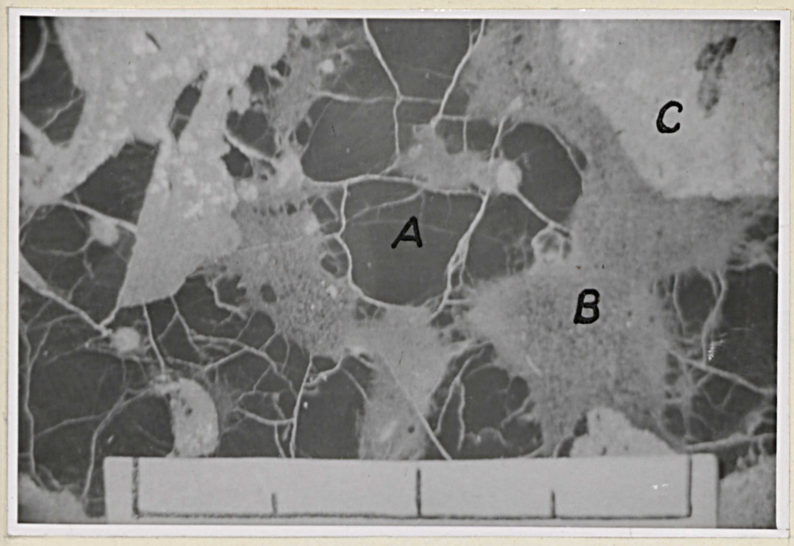
Indicated scale is equivalent to one inch

A - primary matrix, B - tan mottling

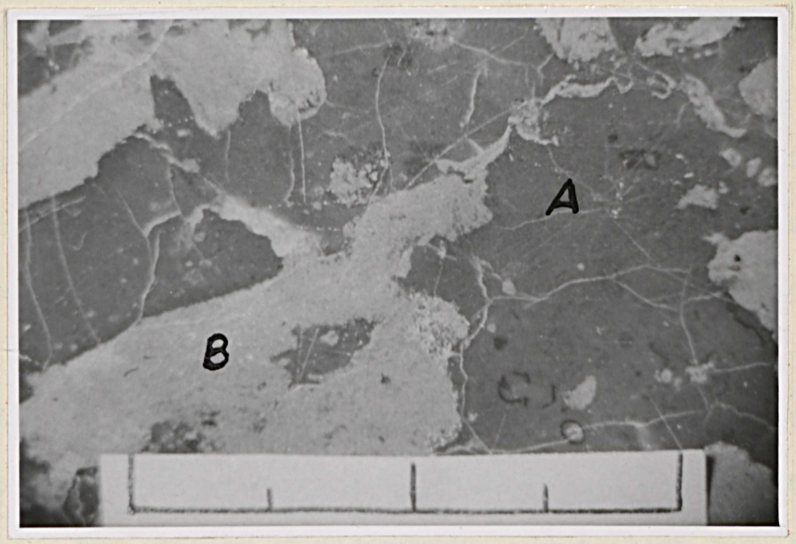
Calcite veinlets cut primary limestone but not tan mottling

PLATE 3

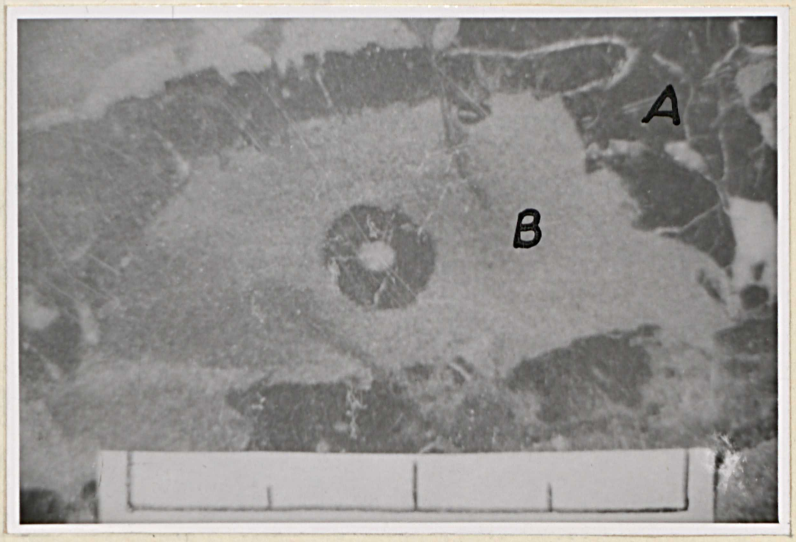
A




B




C




Photographs of polished sections of Meagher limestone from South Boulder Creek

There are, however, several interesting facts that can be seen from the limited material that is available. Furthermore, the knowledge resulting from this study might be put to considerable advantage in a detailed field study of the Meagher formation. In reviewing the origin, a discussion of the environment of original limestone deposition will be followed by the problem of mottling.

Origin of Primary Limestone

The original or primary limestones of the mottled members were formed by the lithification of calcareous muds. Pettijohn (11, p.307) classifies them as calcilutites, and maintains that their origin is of several modes. In addition to the inorganic carbonates and the organic secretions, these fine limestones may be attributed to the destruction of calcareous fossils. Evidences of fossil fragments can be seen in some mottled limestones of the Meagher formation (see plate 2, D).

Calcite veinlets occurring in this limestone (see plate 3) should be regarded as secondary even though they are thought to have been formed during the process of diagenesis. In a later section, the mottling will be regarded as secondary, and since the veinlets are post-mottling, they should also be classed as secondary. These veinlets seldom cut the mottled portion; for this reason they might be thought of as pre-mottling, and that the subsequent mottling solutions had completely obliterated them. Closer examination, however, indicates the veinlets had formed after the mottling as can be seen by the following reasons:

1. As shown in the next section, the mottling is believed to have formed prior to lithification, and the cracks must

have formed subsequent to induration and are, therefore, post-mottling.

2. Cracks formed prior to mottling would have formed chanelways for the migrating solutions.

3. Fractures themselves were probably formed by slumping and differential compaction. The fine limestone was probably more susceptible to fracture than the coarsely crystalline mottling which probably received additional cementing material from the migrating solutions.

Origin of The Mottling

In referring to the time of alteration, mottling in the Meagher limestone is regarded by the author to be a secondary feature. Although the mottling is thought to have taken place before lithification of the limy muds, the fact remains that the mottling has resulted from the entrance of extraneous solutions carrying magnesium and/or iron. It is for this reason that it is thought to be secondary and had taken place after deposition but before lithification. This theory on the secondary origin on the mottling is supported by the following evidence:

1. Large variation in crystal size indicates widely different environments of formation between the tan and primary calcareous portions.

2. Uniform growth of crystals, especially around the contacts, shows that crystals grew with equal facility in all directions and the muds would have to be in at least a plastic state to allow this.

3. Mottled areas tend to spread out somewhat uniformly rather

than remain confined to strictly narrow channels.

4. Association of mottling to original line of weakness, such as bedding (see plate 1) rather than to secondary veinlets.

In regarding the manner of alteration, we find that the way in which dolomite replaces calcite, like the replacement theory of ore genesis, is not completely understood. Mottled limestones appear to be the only solution to the problem at the present time. Hence, extensive studies in separate localities, though not entirely conclusive have brought to light interesting facts on the problem. This investigation of the Meagher has corroborated many known facts and has revealed several new ideas.

As indicated by other work and further supported by this study, there would seem to be little doubt that the mottling has been formed by the migration of extraneous solutions. There are many facts that support the validity of this statement;

1. The occurrence of considerably more iron in the mottled portions than in the primary limestone. The iron is easily visible in thin section as stains which surround the boundaries of the euhedral rhombs.
2. Introduction of magnesium and other material in the mottled parts is thought to be a result of migrating solution.
3. Recrystallization in limestone mottling and dolomitization in other mottled areas must have been attended by the introduction of extraneous solutions.
4. The occurrence of euhedral crystals in mottled areas adjacent to aphanitic anhedral limestone grains.

Assuming that the migrating solutions were responsible for the mottling, the next important point is the source of these solutions. Mottled limestones in the Meagher occupy a relatively large region. Dolomitization or limestone recrystallization by percolating ground water is not an unknown phenomenon. However, the assumption that ground water could have effected such a wide-spread change of similar manner is a little beyond the realms of possibilities. The only other alternative is the introduction of sea water into the calcareous ooze prior to the emergence of the limestones from the sea. This suggestion has been strongly advocated by earlier workers and its validity seems unquestionable. The immediate environment associated with the introduction of these solutions is highly controversial. It has been indicated that special conditions, which are not to be found in the present seas, were responsible for the dolomitization and recrystallization. P. E. Raymond (12) has pointed out the association of dolomitization to subsequent sedimentary breaks. It is not impossible that mottling and dolomitization might be associated with special conditions surrounding the emergence of limestones from the seas.

The limited information that is available seems to indicate the possibility of more than one mottling stage in the Meagher formation. Further field study is necessary to either verify or nullify this point. The introduced iron, as found by subtracting the iron in the primary limestone from that in the mottling, is a clue in favor of the idea as mentioned. A study of figures 1 and 2 shows the high iron content to be found in three closely associated areas; South Boulder Creek, Whitetail Creek, and Townsend. The outermost areas, White Sulphur Springs and the Silver Hill formation, show a much

EXPLANATION OF PLATE 4

Photographs of polished sections from Whitetail Creek

Indicated scales are equivalent to one inch

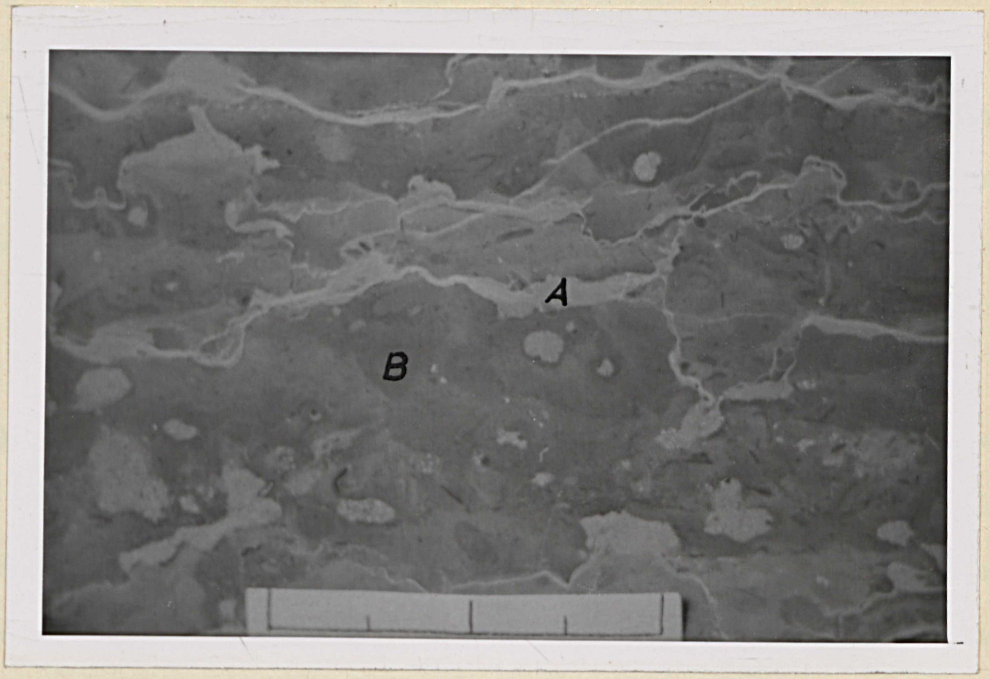
Areas marked A are Dolomite

Areas marked B are limestones

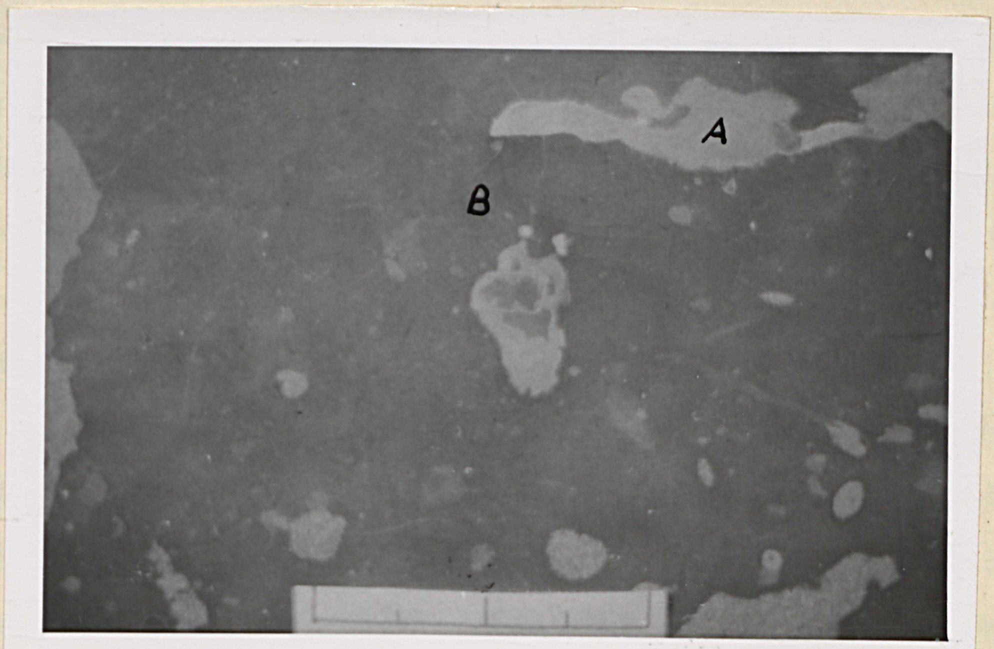
A. Section cut normal to plane of bedding, showing association of dolomite to bedding planes and the black blotches of primary limestone

B. Section cut parallel to the plane of bedding, showing the manner of vertical migration of dolomitizing solutions.

PLATE 4




A




B

Photographs of polished sections of Meagher limestone from Whitetail Creek smaller amount of introduced iron. If sea water were the source of the migrating solutions, one might expect the iron content to be similar over large areas, unless there were more than one occurrence of mottling. If this idea is plausible, it is not entirely supported by a similar comparison of introduced magnesia and insolubles, even though the White Sulphur Springs sample contains very little magnesium or iron. Another point is the occurrence of dolomitized mottling in the westerly exposures, while in the east (White Sulphur Springs) the mottling is only recrystallized limestone. The association of grain size with the multiple mottling theory is notat all indicative. Perhaps the most striking piece of evidence is the presence of two stages of mottling in a sample from South Boulder Canyon (see plate 3, No. A). This condition, however, might be of purely localized nature. Field studies also indicate the non-uniformity of the mottled limestones in vertical extent. The presence of pisolitic and oolitic members interstratified with mottled members indicates the possibility of more than one mottling stage. It does not seem probable that the aphanitic limestones were entirely susceptible to migrating solutions, while coarser oolitic limestones were non-receptive.

There appears to be two ways in which the extraneous solutions permeated through the limy muds. The first is the localization of mottling along natural bedding planes and its vertical migration from these natural channels. Plates 1 and A illustrate this fact quite clearly. This condition is not of local nature but may be seen in several samples from different localities. The other natural localizing medium is a lithologic change found in the primary limestone and consisting of irregular black patches in a background of lighter colored material. Griffin (3) also was cognizant of this variation in the limestone as it occurs in the Platteville formation when he said: "On polished surface, it shows an obscure mottling due to a slight color difference in small, irregularly shaped areas". He did not attach any significance relative to mottling to this irregularity. However, on polished sections studied by the author (see plates 1 and 4), especially of the dark colored limestones, these obscure dark areas seem to have localized the mottling solutions. A close scrutiny of the plates mentioned will in many cases show the mottling to be contained in these dark areas. There does not seem to be any apparent reason for this condition, and the lithologic variation as indicated by the dark color is also unknown.

Much of the mottling is caused by a combination by the two points as mentioned above. Work by other men indicates that the mottling may be associated with any kind of lithologic variation that will facilitate the migration of extraneous solutions. Examples of other variations in lithology are algal remains and worm trails. Although mottling in the Meagher is in many places associated with the points mentioned in the previous paragraph, they are not definite criteria, and other changes in lithology are undoubtedly also responsive to mottling solutions.

## COMPARISON OF MEAGHER WITH OTHER MOTTLED LIMESTONES

In general, mottled limestones of the Meagher formation are somewhat similar to others that have been described in the literature. There are, however, some interesting facts uncovered in this study that are not mentioned in other works.

The determination of whether the mottling is either dolomite or limestone cannot be definitely ascertained in a field study. Because of the low amounts of magnesium oxide present in the dolomite, acid tests fail and laboratory techniques must be applied to obtain the true picture. A study of outcrop material is deceiving, differential weathering brings dolomite into relief in some places, while in other localities, mottling of almost identical lithology is characterized by the differential weathering of recrystallization limestone.

The variation of grain size, as found in the mottled limestones of the Meagher, is a feature that has received limited attention in the literature. Crystals in the mottled portions are commonly 30 to 50 times larger than the primary limy particles of the matrix. Some of these crystals are almost visible with the naked eye. Their occurrence is indicative of a long, slow period of alteration.

All previous papers read by the author attributed mottling to incipient dolomitization. Mottled limestones of the Meagher may be classed as such in some cases, but laboratory evaluation is essential to differentiate this incipient dolomitization from recrystallization of limestones. The introduction of high amounts of iron and the presence of insoluble material is another apparent peculiarity that is limited to the Meagher formation. An analysis of the insoluble has not been made, but it is thought to be composed of materials common to sea water that were not removed in the chemical determination.

Migrating solutions are quite commonly localized by bedding planes as well as lithologic features such as algal remains and worm castings. The association of mottling to black patches, as found in the Meagher, has not been discussed in the literature and might probably be a local condition caused perhaps by variations in permeability.

## CONCLUSIONS

Buff or tan mottling in the Meagher limestone is thought to be recrystallized limestone in some horizons, and selective dolomitization in others. Iron stains, high insoluble residues, and recrystallization in the tan portions are evidence supporting an origin resulting from the migration of extraneous solutions. A study of the relation of mottling to the dark limestone indicates that the alteration took place during, or prior to, lithification. The source of the solutions is problematical and the material deposited by them differed considerably. It is believed there are several separate mottled zones throughout the formation and the environmental conditions surrounding their deposition was not constant.

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