5-20-1941

Basic Information in the Granitic Rocks of the Boulder Batholith

Clifford G. Sherwin

Follow this and additional works at: http://digitalcommons.mtech.edu/bach_theses

Part of the Ceramic Materials Commons, Environmental Engineering Commons, Geology Commons, Geophysics and Seismology Commons, Metallurgy Commons, Other Engineering Commons, and the Other Materials Science and Engineering Commons

Recommended Citation
http://digitalcommons.mtech.edu/bach_theses/144

This Bachelors Thesis is brought to you for free and open access by the Student Scholarship at Digital Commons @ Montana Tech. It has been accepted for inclusion in Bachelors Theses and Reports, 1928 - 1970 by an authorized administrator of Digital Commons @ Montana Tech. For more information, please contact sjuskiewicz@mtech.edu.
BASIC INCLUSIONS IN THE GRANITIC ROCKS
OF THE BOULDER BATHOLITH

By

CLIFFORD G. SHERWIN

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

MONTANA SCHOOL OF MINES
Butte, Montana
May 20, 1941
MONTANA SCHOOL OF MINES LIBRARY.
BASIC INCLUSIONS IN THE GRANITIC ROCKS OF THE BOULDER BATHOLITH

INTRODUCTION

Dark fine grained basic masses of rock are found in nearly every part of the Boulder batholith, these commonly being referred to as "inclusions", "segregations", "autoliths", and various other names. The origin, distribution, and composition of the dark inclusions form the basis for this report.

The fundamental problem has been to determine, if possible, a logical hypothesis as to the mode of origin of the inclusions. To this end, many factors have been taken into consideration such as: the distribution within the batholith, relation of relative abundance and proximity of the batholith contact, and mineral composition of the inclusion and host rock.

The problem of the origin of inclusions in plutonic rocks has commanded considerable attention in the past but little actual work has been done on the problem, especially in the Boulder batholith. As the inclusions are so plentiful and conspicuous in this locality, it is an ideal place to study them. The large amount of mineralization in the batholith has added even more importance to the problem as they may have been a factor in the genesis of the ores. In such an economically important district as that in which lies the Boulder Batholith, the problem warrants even more detailed consideration than it has been afforded in the past.
In the following pages, a general description of the occurrence, distribution, and characteristics of the important described occurrences of inclusions is presented, following which is a detailed description and discussion of inclusions in the Boulder batholith. Particular attention has been paid to the relation of the minerals in the inclusion and the surrounding rock. The next part of the paper consists of an analysis of the facts to formulate a plausible theory of origin of the inclusions. In conclusion, a brief summary of the problem and results of the investigation is advanced.

HISTORY

As early as 1880, geologists were interested in the phenomenon of inclusions in plutonic rocks. The earliest publication known to the author is a paper entitled: "On concretionary patches and fragments of other rocks in granite" which was written by J.A. Phillips in 1880. 1

Weed, in his professional paper on the Butte mining district,2 vaguely mentions the presence of inclusions in the granite, but offered no explanation for their origin. Probably the first comprehensive study and publication is that by N.L. Bowen in 1922 on "The behavior of inclusions in igneous magmas".3 Since that time, most of Bowen's ideas have been only slightly modified. In 1928, Pabst made a detailed study of

inclusions in the Sierras and published his findings. Only short discussions or brief mention had been made of the inclusions in the Boulder batholith until Frank Grout published his "Criteria of origin of inclusions in plutonic rocks" in 1937. He presents an excellent discussion on the inclusions found near Divide, Montana, but little mention is made of inclusions found elsewhere in the batholith. Grout puts forth some very conclusive evidence to prove that the inclusions in this locality are derived from the incorporation and alteration of shale. A more detailed study of inclusions in many other parts of the batholith has been undertaken by the author.

FIELD AND LABORATORY PROCEDURE

Many areas where inclusions are found were investigated and specimens collected from each. The general method used in the field work was to collect representative specimens from any locality in which they were fairly plentiful. Any inclusions that showed unusual or outstanding characteristics were also collected. Only samples of the fresh rock were of value since the much weathered material could not be made into satisfactory thin-sections for microscopic study. An attempt was made in all localities to determine the lateral proximity of the batholith contact. An area on the Big Hole River about two miles west of the pumping station, proved to be the most interesting for study and much information was gained there.

After the specimens were collected in the field, the laboratory work consisted of preparing thin-sections from representative material. Several sections were made by George Rev of New York, which were used for detailed mineralogical studies. The sections made by the author have served mainly as a means of determining the mineral associations from the various localities. Laboratory studies were conducted chiefly with the petrographic microscope, both in the examination of thin-sections and ground material in oil immersion.

NOMENCLATURE

Many descriptive terms in connection with inclusions have been rather loosely used by authors in the past so an attempt has been made by Grout to standardize the nomenclature by defining most of the terms in common usage. The following list is an excerpt from his classification:

1 General terms not implying origin:

- Inclusions, basic inclusions, enclosures, inclusions, knots, clots, dark spots, niggerheads, enclaves.

2 Implying a source outside the intrusive:

- Xenoliths, foreign inclusions, exogenous inclusions, accidental inclusions, enclaves enallogenae.

3 Implying a source in the igneous rock mass itself:

- Indigenous spots, endogenous inclusions, schlieren, cognate inclusions.

A. Segregations, basic segregations, secretions, lateral secretions, concretions, nodules, autoliths.

B. Cognate fragments, endogenous fragments, protoclastic structures.

Implying a mixed origin:

Reaction inclusion, hybrid inclusion, migmatite inclusion.

INCLUSIONS IN GENERAL

OCCURRENCE

Inclusions are common in igneous masses the world over, having been reported in the Kimberlite of South Africa ¹, Germany ², France ³, and other countries. In the United States, the best known occurrences are those in the Sierra Nevada, Boulder batholith of Montana, Alta Stock, Utah, Duluth gabbro mass and in the Vermillion range.

Any generalization on the distribution of inclusions is necessarily ambiguous due to the extreme irregularity of their occurrence. Some writers have contended that they were to be found at or near the contact only, while others have reported the distribution to be fairly uniform throughout the entire extent of the batholith. ⁴ There seems to be no definite pattern for their occurrence as they may occur in groups or "swarms" at one place in the igneous mass, while other parts of the mass may entirely devoid of them.

RELATION TO VARIOUS ROCK TYPES

Intermediate rock types such as quartz diorite and

---

⁴Pabst, op. cit., p. 368
quartz monzonite seem to be the most favorable host rock for inclusions since they are rarely found in more basic types and seldom in the more acidic. This one point is almost unanimously agreed upon by men who have worked on this problem and it may be regarded as quite well established.

GENERAL CHARACTERISTICS

In contrast to xenoliths which are generally angular to sub-angular, inclusions under discussion are for the most part well rounded with few angular corners so the distinction is not hard to make between the two.

The contact between inclusion and host rock may vary from a sharp line to an irregular, diffused appearance and in one single inclusion, the contact may fluctuate between the two extremes.

Irregularity in shape is found to characterize most inclusions, but in general they are elongated in one direction and flattened in the other. It is thought that this is due to plastic deformation caused by the flow of the surrounding rock. This characteristic is noted in practically every occurrence of inclusions.

Due to their greater resistance to weathering, it is common to find the inclusions weathering in marked relief above the enclosing rock. This is shown clearly in Figure 5.

Though complete information is not available on all occurrences, it is not unusual to find inclusions with a
porphyritic texture. This has been observed by Pabst ¹ and Grout ², as well as by the author. With few exceptions, the texture is finely granular, with phenocrysts of feldspar in varying amounts. The color ranges from grey to black, depending on the amount of weathering and the texture of the inclusion.

INCLUSIONS IN THE BOULDER BATHOLITH

SIZE

The inclusions in the Boulder batholith vary greatly in size from one locality to another and within a short distance. The size ranges from almost microscopic proportions, to a yard or more in diameter. Near Divide, large inclusions were found intermingled with smaller ones, but the average size is probably about two feet in diameter. Since they are often lense-shaped, the true diameter may not be seen if only the edge is exposed. As far as the author could determine, there is little connection between the size of inclusions and the distance from the contact.

DISTRIBUTION

Conformable to the results of others working on the problem of inclusions in other localities, it was found that the distribution is more or less general throughout the southern part of the batholith ³ and not restricted in any

---

¹Pabst, Adolf, op. cit., p. 339
²Grout, F.F. op. cit., p. 1564
³No work was done in the northern part of the batholith
sense to the immediate vicinity of the contact.

Near Divide, the number of inclusions was greater in one locality close to the contact, but at Homestake and along Roosevelt Drive which are near the center of the batholith, they were quite abundant. In a quarry at the foot of East Ridge large numbers of inclusions were also found. In general, there are few places in this vicinity of the batholith that inclusions are not found.

SHAPE AND ORIENTATION

The shape varies almost as much as the size, with no two the same. The corners are in all cases rounded and the contact between the inclusion and surrounding rock may be diffused, or as the other extreme, sharp. There is no general rule on this as an inclusion may have an indefinite contact on one side and a very sharp line of differentiation on the other.

As stated before, the inclusions are predominantly disc-shaped, that is, flattened in one direction. Where more than one inclusion occurs, they all seem to be oriented with the flattened axis on one direction. This may be due to flowage or movement of the surrounding rock while in the molten condition.¹ Near Divide, this is particularly striking as the inclusions are very abundant. This is to be expected since there is no doubt considerable flowage at or near the contact.

¹Pabst found this to be true in the Sierras. See op. cit., p.332.
ROCK TYPES AT CONTACT OF BATHOLITH

As can be seen from the map, the batholith is surrounded by volcanics in the north, and by limestone, shale, and lake beds to the south. To the author's knowledge, there are no basic border facies at any place along the southern part of the batholith contact.

At Divide, the sedimentary rock is shale and limestone, with shale predominating; both are altered to a hornfels, with the limestone affected for some distance from the contact and commonly marbleized.

Xenoliths of Chert and altered limestone are common at the contact but none of the shale. This is thought by Grout to be indicative that the shale was incorporated in the magma and remade to form the dark inclusions present.

At Lime Kiln Hill, the only rock present is limestone with no evidence of a basic border facies. The contact is characterized by a large epidote crystals with the impure limestone altered to a greenish calc-hornfels, whereas the pure limestone has been coarsely recrystalized to marble. No shale is noted here and few xenoliths of other material, but the inclusions are nearly as numerous as at Divide. Hornfels has been developed but not to as great an extent as at Divide.

MEGASCOPIC DESCRIPTION

In all cases, the inclusions are much finer grained than the enclosing rock, usually from one fifth to one tenth the grain size of the matrix. In general, the texture is
sugary or finely granular with phenocrysts of feldspar which range up to six mm., but the average size is probably about one mm. The number of phenocrysts vary in different inclusions but where a porphyritic texture is seen, the phenocrysts are quite abundant.

The inclusions have a homogenous appearance and to the unaided eye appear to be made up entirely of dark mafic minerals. The color ranges from black to a medium grey but the color contrast is always sharp between the inclusion and host rock.

Some writers have mentioned salic halos around the inclusions and this may be true to some degree for those found near Divide, but it is not a general characteristic and seems to hold little significance.

MICROSCOPIC DESCRIPTION

Microscopically, the texture of inclusions is typically hypidiomorphic granular and an average estimate of the grain size is from 0.1 to 1.0 mm., the total range being observed in a single specimen. The texture and grain size is consistent to the contact where the only change is in the grain size and the amount of mafic minerals. Under the microscope, the contact is irregular and an interfingering effect is produced between the inclusion and the host rock, large crystals lying across the boundary.

In general, the grain size of the salic minerals is slightly larger than the ferromagnesian minerals but large crystals of biotite and hornblende are seen quite commonly.
Pabst has gone to some length to show that there is a general orientation of the feldspar laths in one direction which is true to some extent for the inclusions in the Boulder batholith. This would indicate that the inclusions were plastic enough at the time of formation to undergo deformation and reorientation of the component minerals.

**MINERALOGY**

With no exceptions, the mineralogy of the inclusions and surrounding rock was found to be identical. As would be expected, there is a concentration of the ferromagnesian minerals such as hornblende and biotite, and a reduction in the amount of potash feldspar and quartz in the dark inclusions; but qualitatively, the mineralogy is the same.

The plagioclase in the host rock is predominantly oligoclase (Ab$_{60}$ An$_{10}$ ÷ Ab$_{70}$ An$_{30}$) and in the inclusions the plagioclase was found to be practically identical in composition. Pronounced zoning was evident in many of the plagioclase phenocrysts and the core was found to be much more calcic than the outer rim. Some difficulty was experienced in determining the precise composition of the core, but the more calcic character was easily recognized.

In order of their abundance, the chief minerals found in the inclusions are: plagioclase (oligoclase, Ab$_{90}$ An$_{10}$), hornblende, biotite, quartz, and potash feldspar. The potash feldspar is microcline microperthite in some specimens. Accessory minerals include chiefly apatite, magnetite, and titanite. Apatite is very common in all of the inclusions
studied and occurs as small prismatic crystals throughout the mass. Titanite is recognizable by its thin, wedge-shaped, highly birefringent crystals. Magnetite is seen as dark, opaque splotches on the lighter background and is commonly scattered as small inclusions in the other minerals.

Hornblende is the usual pleochroic green to brown variety and is often found as small rounded grains contained in the larger plagioclase crystals. In one thinsection, a poikolitic texture was evident with hornblende containing grains of plagioclase, but this was not common in any of the other sections.

Biotite is less common than hornblende but an abundance of small grains is found in all of the inclusions. Much of the biotite has the typical "maple wood" structure which is especially conspicuous in the larger euhedral crystals.

A common textural feature of the inclusions is a sieve or poikolitic texture, with plagioclase crystals enclosing complete crystals or rounded fragments of hornblende and biotite; only rarely is the reversal true, e.g., the case cited above where hornblende contains plagioclase. The inclusions have almost a true diobasic or ophitic texture. Sericitization of the plagioclase is more pronounced in the inclusions than in the host rock but this characteristic is extremely variable. Albite twinning combined with Carlsbad twinning is very common in the plagioclase crystals, nearly every crystal exhibiting some form of twinning. One grain showed wavy extinction which is illustrated in Figure 20.
The order of crystallization is difficult to determine but seems to conform somewhat to the surrounding rock. Plagioclase and quartz are apparently the latest but a small amount of these two minerals undoubtedly crystallized out early. Good euhedral crystals of biotite, hornblende, and plagioclase are all found.

Summarizing the facts concerning the mineralogy of the inclusions and enclosing rock, the following points seem indisputable: (1) the minerals in the inclusion and the host rock are identical; (2) quantitatively, the inclusions contain more mafic minerals than the quartz monzonite host; (3) there is a reduction in the amount of quartz and potash feldspar and an increase in the amount of plagioclase in the inclusions; (4) the plagioclase in the inclusions and host rock is of the same composition; (5) plagioclase in the inclusions is commonly poikilitic, there being no evidence of this in the quartz monzonite surrounding the inclusions; (6) a definite interlocking of the grains exists at the contact with only a change in grain size from inclusion to host rock.
QUANTITATIVE MINERALOGY

<table>
<thead>
<tr>
<th></th>
<th>Butte granite</th>
<th>Inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>22.87%</td>
<td>2 %</td>
</tr>
<tr>
<td>Orthoclase</td>
<td>18.55</td>
<td>—</td>
</tr>
<tr>
<td>Albite (Ab$^{90}$ An$^{10}$)</td>
<td>23.06</td>
<td>60</td>
</tr>
<tr>
<td>Anorthite (Ab$^{10}$ An$^{90}$)</td>
<td>16.68</td>
<td>—</td>
</tr>
<tr>
<td>Biotite</td>
<td>10.92</td>
<td>15</td>
</tr>
<tr>
<td>Hornblende</td>
<td>3.56</td>
<td>20</td>
</tr>
<tr>
<td>Magnetite</td>
<td>1.36</td>
<td>3</td>
</tr>
<tr>
<td>Ilmenite</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Pyrite</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Apatite</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>Etc</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99.15%</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

1 Data of geochemistry, U.S.G.S. Bull. 770 p. 432

2 Estimated from grain counts and from Grout, Op. cit., p. 1561. This conforms closely to Pabst's findings in the inclusions of the Sierra Nevada batholith.
ORIGIN OF INCLUSIONS

There are two main schools of thought on the origin of inclusions such as are found in the Boulder batholith. One, represented by the views of Grout, is that the inclusions are formed by the remaking of shale xenoliths which have been incorporated in the magma. The second hypothesis of origin, as advanced by Pabst, holds that the inclusions are formed due to the segregation of basic minerals from the magma as it was in the process of cooling.

Grout has based most of his evidence on the relationship of the inclusions and sedimentary rocks near Divide, Montana. In this locality, the inclusions are very abundant near the contact of the batholith, the sedimentary rock consisting chiefly of shale and limestone with shale predominating. Both shale and limestone have been extremely altered by contact metamorphism, producing an abundance of hornfels. The limestone is extremely baked and is marbleized and bleached to a white color for some distance from the contact. Numerous xenoliths of altered limestone are found in the igneous rock near the contact but at some distance from the contact, their occurrence is rare. No xenoliths of altered shale are found but the presence of numerous inclusions has indicated to Grout that the shale hornfels was completely remade into an igneous looking rock and is not represented by the inclusion.

The fact that shale xenoliths are absent and limestone xenoliths present has been the basis of his argument that the shale has been remade. Offhand, this explanation appears to
have merit in this locality but from observations made by the 
author, it appears that there are several weak points to the 
hypothesis, namely:

(1) If shale were incorporated by the magma and the 
other sedimentary rocks, such as limestone, relatively un-
affected, unaltered xenoliths of material other than shale 
should be found in almost as equal abundance as inclusions. 
However, this is not the case since in many parts of the 
batholith, inclusions are found in large numbers, but there is 
no evidence of limestone xenoliths. In other words, the 
chances for finding limestone xenoliths should be about the 
same as for finding inclusions in any one locality. This 
condition does not exist.

(2) On the theory that the inclusions are formed by 
the remaking of shale at the contact of the batholith, it 
follows that it is necessary to have shale to produce in-
cclusions. The main argument against this is that at Lime 
Kiln Hill, where no evidence of shale is seen at the contact, 
the only rock present being marbleized limestone. However, 
inclusions are nearly as numerous here as at Divide where 
both shale and limestone are found. This is one of the 
strongest points against the hypothesis of origin from shale. 
Grout's statement that inclusions are found only where shale 
is in contact with the igneous rock must be refuted in the 
light of the above.

(3) If inclusions are remade from shale, we should find 
somewhere only partially remade inclusions, e.g., large ones 
with shale
with shale or hornfels centers. Even at Divide where inclusions are so numerous, no partially remade inclusions were found.

(4) Inclusions are found in many localities in the heart of the batholith, at places many miles from the contact laterally and without much doubt, a mile or so from the contact vertically. At the base of East Ridge, inclusions are very numerous and from thin section study are found to be identical in composition as those at Divide and other localities.

East Ridge is known to be a block that has been uplifted due to a large fault with a throw of perhaps two or three thousand feet. From this fact, it can be reasoned that the upper contact of the batholith was several thousand feet above the present surface. Finding inclusions here seems to definitely prove that the immediate proximity of the batholith contact has little to do with their occurrence.

(5) Having found inclusions so deep in the batholith, it is difficult to picture how a mass of shale could fall into a molten magma, (as it must be to remake shale), be remade into an inclusion, and fall several thousand feet through the magma without becoming completely assimilated. Even at the contact, the average size of inclusions is not more than two or three feet in diameter. It seems that a mass of foreign material of such small proportions would certainly be so assimilated by the time it got to that depth that it would be totally lost.
The upper contact of the batholith is admittedly difficult to establish, but from the above reasoning it seems logical that a minimum value of at least two thousand feet can be established as the distance from the present erosion surface.

Though complete information is not available, inclusions of the nature under discussion have been reported on the 3800 foot level of the Belmont mine. Those found were not the same as the unaltered quartz monzonite which commonly resemble inclusions in the sericitized and hydrothermally altered wall rock in the Butte mines.

One of the main arguments in support of the theory that inclusions were formed by the remaking of shale, is the fine grained texture. Most sedimentary rocks which undergo the changes produced by contact action will be remade to a finer, sugary, hornfels texture. The only igneous rocks resembling this texture are aplites and lamprophyric dike rocks and very few other igneous rocks. ¹ Segregations would tend to be coarse grained as the temperature would be low and promote slow crystallization, rather than a rapid action which would give rise to a finer grained texture. This is the strongest argument for shale origin and against segregation.

Grout points out that porphyritic texture with feldspar phenocrysts may be produced by direct addition or exchange

¹Grout, F.F., op. cit., p. 1570
reaction with the magma upon sedimentary rock. On the other hand, nearly all of the quartz monzonite surrounding inclusions is porphyritic with large feldspar phenocrysts. This is strikingly evident on Roosevelt Drive where many inclusions were found. It seems logical that if the host rock contains such an abundance of feldspar phenocrysts, feldspar would be one of the chief minerals to segregate from the magma if segregation were the process by which they were formed. The question of the feldspar phenocrysts is perplexing since they are contained in the host rock but conceivably could be produced by addition or reaction of the magma on a sedimentary rock. The occurrence of feldspar phenocrysts in the inclusions seems to add little to the solution of the problem at the time of writing.

While little is known about the process of segregation, the possibilities for this mode of origin seem much greater than that of shale remade to form inclusions. Little evidence can be given to support the theory of segregation but much evidence has been given to weaken the theory of origin from shale.

A third mode of origin has been suggested by some writers, which states that the inclusions were formed by the magma stoping off the early basic border facies. This hypothesis is particularly untenable for two reasons: (1) There are few localities on the contact of the batholith where a basic border facies exists. Certainly none is found to any extent at Lime Kiln Hill where inclusions are very plentiful. (2) Most of the inclusions are porphyritic and nowhere was
a porphyritic basic border facies seen. At Divide, there is a basic zone near the contact which resembles the inclusions slightly but there is no evidence of a porphyritic texture. Thus it seems that the argument for a cognate origin from the basic border facies is of little importance in the Boulder batholith, though this mode of origin is accepted in igneous masses elsewhere.
SUMMARY

From the broader field relations and from microscopic studies, the following conclusions have been drawn:

1. The mineralogy of the inclusions and host rock is identical.
2. There is a great increase in the amount of hornblende and biotite and a marked decrease in the amount of potash feldspar and quartz in the inclusions.
3. The texture of inclusions is always finer grained than the surrounding quartz monzonite.
4. The distribution of inclusions is general and not restricted to the vicinity of the batholith contact.
5. The distance from the contact that inclusions are found ranges several miles laterally and at least two thousand feet vertically.
6. Inclusions are not confined to localities where shale is in contact with the batholith, but are found also at limestone and other contacts.
7. No xenoliths of sedimentary rock are found associated with inclusions at any distance from the contact.
8. Inclusions are almost always porphyritic, the basic border zone is never porphyritic.
9. In only a few limited localities is a basic border zone found.
10. Some orientation of the minerals in the inclusions has taken place, indication that they were able to undergo plastic deformation at the time of formation.

In view of the above conclusions, the process of segregation seems to be the best explanation for the origin of inclusions in the Boulder batholith.
It is possible that the inclusions which Grout studied at Divide are formed by a different mechanism, that is, incorporation and remaking of shale by the magma. However, it is highly improbable that there is more than one mode of origin as the thin sections show little variation in the properties of inclusions that are found in widely different localities, and compare exactly with those found at Divide.

The only significance that can be attached to inclusions at this time is that their presence does not necessarily indicate that the batholith contact is within a relatively short distance. So little is known of the vertical extent of the batholith that it is impossible to predict any maximum depth at which they are found. In this paper it has only been possible to establish a minimum depth.
BIBLIOGRAPHY


12) Balk, Robert, Structural behavior of igneous rocks, Mem. 5, G.S.A.

Fig. 1
Large boulder near contact at Lime Kiln Hill showing inclusions. Note size of pick for scale.

Fig. 2
Closeup view of area near pick in Figure 1. Host rock is quartz monzonite.
Fig. 3
Inclusion at Lime Kiln Hill illustrating the irregular shapes that may occur.

Fig. 4
Inclusion in quartz monzonite near Roosevelt Drive.
Inclusions in large boulder about 100 yards from contact at Lime Kiln Hill. Differential weathering of inclusions and host rock result in the inclusions weathering into relief.

Closeup of inclusion near the center of Figure 1. Note that near the lower part of the inclusion, the host apparently cuts the inclusion.
Fig. 7

Inclusion in building stone taken from quarry at the base of East Ridge.

Fig. 8

Specimen from Lime Kiln Hill illustrating differential weathering of inclusion and quartz monzonite. X 1/3
Fig. 9
Swarm of inclusions in quartz monzonite at Divide.

Fig. 10
Weathered inclusions in quartz monzonite. Same locality as above.
Fig. 11
Aplitic dike about 6 in. wide cutting through inclusions near Divide.

Fig. 12
Aplitic dike about 2 in. wide cutting through swarm of inclusions. Same locality as above.
Fig. 13
Contact of batholith and sediments in old railroad cut near Divide.

Fig. 14
Contact of batholith with limestone. Note the abundance of inclusions at the contact. Same locality as above.
Fig. 15

Large inclusion seen in lower right corner of Figure 12. Note the general orientation of the smaller inclusions in the same direction as the large one. Scale is about X 1/20.
Fig. 16
Schlieren structure seen near the contact at Divide. About 50% of the rock is composed of basic inclusions.

Fig. 17
Looking south down the Big Hole River from the old railroad cut where Figures 9 to 17 were taken. The bridge in the background is on the main highway from Divide to Wisdom.
Fig. 18
Inclusion in quartz monzonite from East Ridge quarry.

Fig. 19
Weathered inclusion in quartz monzonite found at Lime Kiln Hill. X 1/4
Fig. 20
Comparison of dark inclusion on the left with ordinary quartz monzonite on the right. X 1/4

Fig. 21
Specimen from East Ridge quarry illustrating the gradational and indistinct contacts that may occur between inclusion and host rock of quartz monzonite. X 1/4
Fig. 22
Limestone xenolith included in a host of quartz monzonite. The dark rim around the limestone is a reaction rim composed of augite. Remainder of limestone inclusion is relatively unaltered. X1/2

Fig. 23
Specimen taken from the contact of an aplite dike with basic border zone. The dark needle like crystals are hornblende. Both pictures on this page are taken near Divide. X 1
Fig. 24
Photomicrograph of inclusion. Dark grey portion in center of field is secondary plagioclase, i.e., later than the adjacent rock minerals. X 25

Fig. 25
Photomicrograph of inclusion showing large dark crystal of biotite, surrounded by lighter plagioclase. X 25

Fig. 26
Photomicrograph of inclusion showing zoning of plagioclase in center of field. The plagioclase is somewhat sericitized.
**Fig. 27**

Photomicrograph of inclusion and host rock. Upper 1/3 of field is quartz monzonite and the lower 2/3 is the dark inclusion. Crossed nicols X 25.

**Fig. 28**

Photomicrograph of inclusion showing zoning of plagioclase. Crossed nicols, X 25.
Fig. 29

Photomicrograph of inclusion. Plagioclase (P), hornblende (H), biotite (B). Small white crystals are apatite. Crossed nicols X 25.

Fig. 30

Photomicrograph of inclusion showing typical diabasic texture. Crossed nicols X 25.

Fig. 31

Photomicrograph of inclusion with plagioclase phenocryst in center of field. Note biotite in center of plagioclase. Crossed nicols X 25.