DRUSY VUGS IN A MONZONITE DIKE, BEARPAW MOUNTAINS, MONTANA[1]

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Contents

Abstract

A monzonite dike in the Beaver Creek Stock, Bearpaw Mountains, Montana, contains some isolated cavities characterized by the following minerals: microperthite, albite, hornblende, zircon, biotite, magnetite, sphene, epidote, actinolite, axinite, chlorite, prehnite, datolite, calcite, analcite, thomsonite, and pyrite.

This unique occurrence contributes significant evidence concerning the crystallization history of the monzonite through its magmatic, pegmatitic, and hydrothermal stages.

Introduction

More than 100 specimens of monzonite containing drusy vugs were collected from a small rock quarry in the Bearpaw Mountains near Havre, Montana (Fig. 1). Several tons of broken rock on the quarry floor gave a fine opportunity to assemble a representative suite of specimens from the thousands available. The original collection was made

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by Pecora in 1937 and was augmented by subsequent collections in 1938–40 made by both authors and a number of their friends, including George Bowery, G. H. Brodie, E. L. Cherbonnier, Jacob Freedman, R. L. Griggs, E. H. Harp, J. B. Lyons, T. C. Marvin, J. I. Snow, and R. H. Worman.
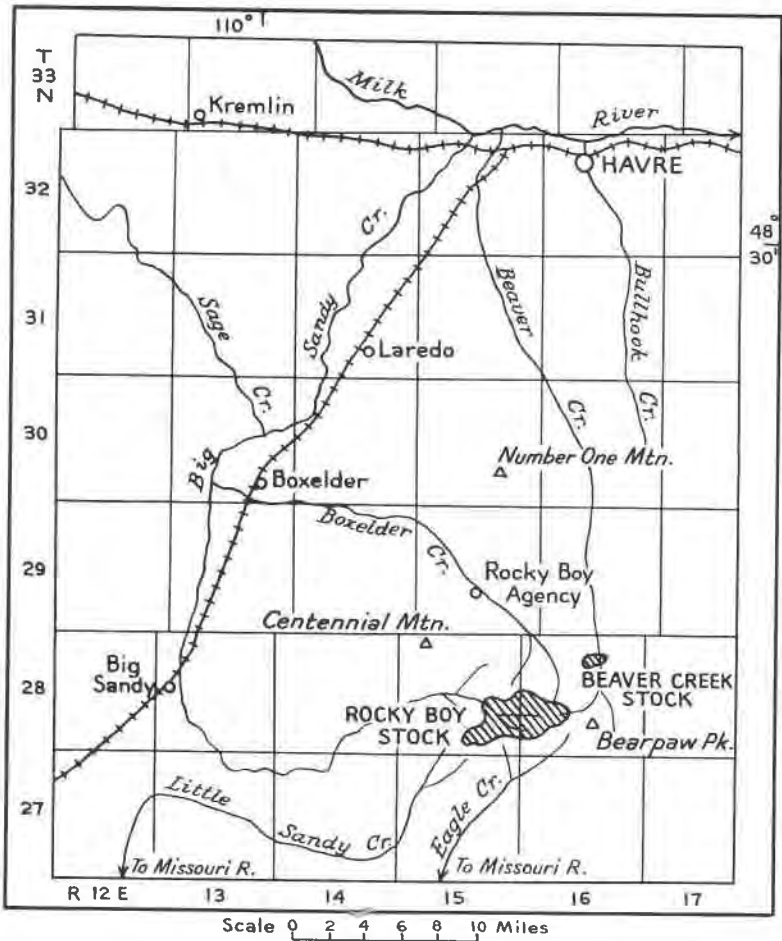

FIG. 1. Index map of a part of north-central Montana showing the location of the Beaver Creek stock.

Three fine crystals of hornblende in the original collection were studied crystallographically by Fisher, who also contributed to the study of several other minerals.

Field work was made possible by a grant from the Holden Fund, and laboratory studies were carried on at Harvard University. The authors are especially grateful to Professor E. S. Larsen. Messrs. E. B. Dane and B. M. Shaub kindly supervised the making of 2 photographs illustrating this report. The manuscript was critically read by Dr. Michael Fleischer.

The minerals that crystallized in these unusual vugs are so small that the binocular microscope and the immersion method have proved invaluable in studying age relations and making identifications.

LOCALITY OF THE QUARRY

The quarry from which the collections were made is situated in the Rocky Boy's Indian Reservation, along the Beaver Creek Road, on the west bank of Beaver Creek, about 22 miles south of Havre, Montana. In 1937 and 1938 this quarry was a source of rock used for small bridges being built along Beaver Creek by a unit of the Civilian Conservation Corps stationed about 15 miles south of Havre.

GEOLOGICAL SETTING

Summary

Monzonite is a common rock in the Bearpaw Mountains. Different varieties of monzonite make up some stocks entirely, as for example that of Number One Mountain (see index map). In the Rocky Boy Stock, masses of monzonite are intrusive into pyroxenite and shonkinite and are intruded by nepheline syenite and pegmatites, as described by Pecora (1942). In the Beaver Creek Stock, monzonite is exposed only as dikes in shonkinite.

Tiny shreds and knots of feldspar are common in the dark-colored monzonite of these stocks but it is only in one dike in the Beaver Creek Stock that well-defined vugs have been found. In many other monzonite dikes there are suggestions of the presence of similar vugs.

The igneous rocks of the Beaver Creek Stock were first described by Weed and Pirsson (1896). The stock is approximately one mile in diameter and is in contact with deformed beds of the Colorado Formation of Upper Cretaceous Age.

The monzonite dike

The monzonite dike in the Beaver Creek Quarry is illustrated in Fig. 2. The uppermost part of the dike is probably its original pinnacle, from which enclosing softer shonkinite has been eroded. The rock of the pinnacle, like that along the sides of the dike, is a dark, chilled monzonite. The lateral contact surfaces show a hexagonal joint pattern. The dike is about 2 feet thick at its pinnacle and about 50 feet below the top it is about 20 feet thick.

Fɪɢ. 2. The monzonite dike, Beaver Creek Quarry; the area containing the drusy vugs is outlined.

The vugs occur in the interior part of the dike some 30 feet below the pinnacle. The rock containing the cavities is fine-grained, grading into a finer-grained texture upward in the dike and a medium-grained texture

Fɪɢ. 3. Photomicrograph of a thin section of monzonite (crossed nicols).

downward. In the upper part of the dike feldspathic shreds are common, and in the lower part neither cavities nor feldspathic shreds are present. The dike contains neither inclusions nor veins.

The principal minerals of the monzonite are augite, hornblende, biotite, plagioclase, and sanidine. Gradations in grain size in different parts of the dike are best characterized by the size of plagioclase laths imbedded in coarse sanidine. The texture of the rock in thin section is illustrated in Fig. 3. A modal analysis of two thin sections of the fine-grained rock is given below.

	Volume %
Augite	23
Hornblende	12
Biotite	7
Sanidine	38
Andesine	19
Accessory	1
	100

Several rock fragments were collected from the blocks that had been blasted from the dike, and a representative sample was analyzed (Table 1).

TABLE 1. CHEMICAL ANALYSIS (BY F. A. GONYER) AND NORM OF MONZONITE FROM THE DIKE IN THE BEAVER CREEK QUARRY, BEARPAW MOUNTAINS, MONTANA

Analysis		Norm	
SiO_2	50.92	ne	7.1
Al_2O_3	16.40	or	27.8
Fe_2O_3	3.10	ab	18.3
FeO	6.06	an	14.2
MgO	4.16	di	15.9
CaO	7.64	ol	7.9
Na_2O	3.69	ap	1.7
K_2O	4.74	il	0.9
TiO_2	0.47	mt	4.4
P_2O_5	0.72		
MnO	0.07	C.I.P.W. position II. 6.2	
BaO	0.29	BOROLANOSE	
H_2O+	0.94		
Total	99.20		

S.G. (of hand specimen) = 2.73.

The groundmass of the monzonite containing the vugs, as shown by thin sections, is much more altered than that of monzonite elsewhere in the dike, principally illustrated by the hornblendization of the pyroxene and the change, locally, of feldspar to zeolites. Microperthite is much more abundant in the monzonite near the vugs than elsewhere.

The Drusy Vugs

General statement

The vugs occur only in one part of the dike, and contain or are filled by an array of minerals representing a long sequence of crystallization. The vugs have an outer light-colored shell and an internal cavity that is lined with minerals attached to the inner wall of the shell.

Form and size

The drusy vugs have a spheroidal or ellipsoidal form and are distinct with respect to host monzonite (see Fig. 4). The maximum diameter
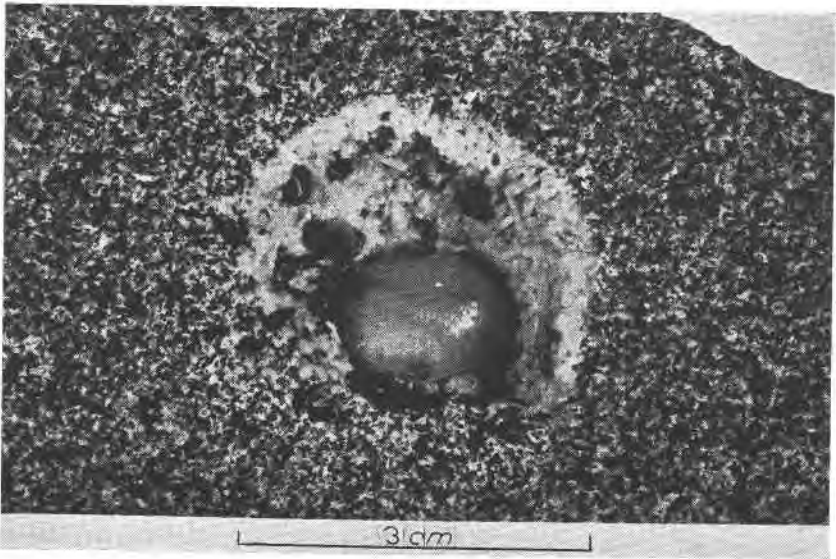

Fig. 4. Monzonite with a typical drusy vug containing albite tablets, a single rounded mass of prehnite, and smaller masses of calcite.

measured is 3 inches, but most are less than one inch. The vugs are individual units and none coalesces with another.

Pegmatitic shell

The shell is the outer rim of the vug and separates the cavity from the monzonite. In every specimen the shell is feldspar-rich, and for this reason it is sharply separated from the dark-colored monzonite. The shell is a syenite facies of the monzonite, and because of its much coarser grain size, it can perhaps also be considered the pegmatitic facies of the monzonite.

The shell is composed essentially of microperthite and albite tablets. Hornblende prisms are present in most of the specimens and magnetite octahedra in a few. Sphene, biotite, and zircon are rarely present. The microperthite has grown continuously from monzonite into the shell, but in larger size. The albite forms tablets projecting edgewise into the cavity. The hornblende and microperthite are of the same composition in both the monzonite and the pegmatitic shell. Andesine and augite, so common in the monzonite, are absent in the shell, and magnetite and albite are present only in the shell.

Rarely does the pegmatitic shell have a uniform thickness and there is a wide range in the proportions of feldspar and hornblende. In some specimens one side of the shell contains most of the hornblende prisms, conspicuous because the feldspathic shell is also thinnest or almost absent there. Commonly the bases of the hornblende prisms are intergrown with the feldspar tablets, and the terminal parts extend well into the cavity, either in free space or projecting through later-formed minerals.

The proportion of the shell to the size of the vug varies indirectly with the size of the vug; that is, the largest proportion of open space occurs in the largest vugs.

Residual cavity

The minerals that have formed in the cavities of the vugs are perched on or attached to crystalline faces or edges of albite, hornblende, and magnetite, and they themselves commonly form the loci for deposition of later-formed minerals. No one vug contains all of the minerals. The complexity of the mineral association has no apparent relation to the size of the vug. In many specimens one side of the inner wall of the shell is much richer in the late-formed minerals than the other.

The minerals attached to the cavity walls include:

1. Actinolite fibers.
2. Ball-like rosettes of green chlorite.
3. Sheaf-like forms of greenish-yellow epidote.
4. Aggregate plates of axinite.
5. Etched or rounded masses of calcite, datolite, prehnite, and analcime.
6. Tufts of radiating thomsonite.
7. Pyritohedra of pyrite.
8. Two unidentified silicate minerals.

Only a single mass of datolite or prehnite is found in any one vug, but several masses of the other minerals have formed in different parts of the same vug.

Hornblende and epidote are rare or absent in those vugs containing magnetite, and epidote is most abundantly formed in those vugs where

hornblende is scarce and magnetite is absent. Tufts of thomsonite are present in almost all of the cavities.

MINERAL SEQUENCE

The exact order of formation of the crystals in the vugs cannot be determined with any assurance for two principal reasons: (1) no one vug contains the entire array of minerals; and (2) selective deposition of some minerals offers a clue as to age relative to only one or a few other minerals in the same vug.

The sequence listed below is the best arrangement of the order of appearance (from top to bottom):

1. Albite (tablets), magnetite (octahedra), hornblende (prisms).
2. Actinolite (asbestiform).
3. Epidote (sheaves).
4. Axinite (aggregates of platy crystals).
5. Chlorite (rosettes of radiating scales).
6. Pyrite (pyritohedra).
7. Calcite (etched, rounded masses), datolite (white, glassy crystals), prehnite (rounded aggregates of plates).
8. Analcite (rounded crystals), thomsonite (moss-like tufts of needles).

In one specimen, hornblende engulfs a magnetite crystal; in another, datolite engulfs the corner of a calcite crystal. The position of pyrite in the sequence is not known with certainty, but it is older than calcite. The two unidentified minerals are both later than epidote, and perhaps also later than the calcite-datolite-prehnite group.

DESCRIPTIVE MINERALOGY

General Statement

In the general description of the minerals only the data pertinent to identification and occurrence are given. Refractive indices are correct to ± 0.003 but in some determinations the range is less.

Minerals of the monzonite

The *augite* in the monzonite is a zoned aegirine-augite, whose outer zones are pale green. The Z_n varies from 1.717 for the core to 1.725 for the outer zone.

The *hornblende* replaces augite in part. The following optical data are pertinent: Z = dark green; pleochroic; $Z_n = 1.706$; Biaxial (−).

On cleavage plates, the mean n of the *biotite* is 1.657.

The discontinuously zoned *plagioclase* has a composition ranging from andesine (An_{50}) for the cores to oligoclase (An_{20}) for the outer zones.

The *sanidine*, locally microperthitic, is the coarsest mineral in the rock and encloses most of the others poikilitically. The clear mineral is biaxial (−); $Y_n = 1.525$.

A much higher proportion of *microperthite* is present in the monzonite adjacent to the vugs, and it is rarely free of alteration.

Minerals of the drusy vugs

The last-formed plagioclase tablets in the shell are glassy in character and pure *albite* in composition; whereas earlier-formed chalky-white tablets are near oligoclase in composition.

Magnetite octahedra are imbedded in the earlier albite tablets. In one specimen the magnetite is clearly older than a hornblende prism that envelops it.
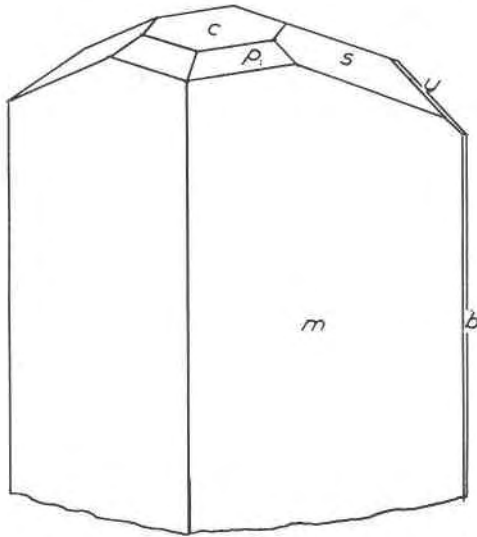

FIG. 5. Idealized drawing of hornblende crystal from the vugs in the monzonite dike.

A few crystals of zircon were recovered from a recess in the shell, but the relative age of its formation is obscure.

A special study of the *hornblende* prisms attached to the shell and projecting into the cavity was made by the writers. The crystals are are black, splendent, and, for the most part, well-terminated.

The optical data of the hornblende are:

Orientation	n	Pleochroism	
X	1.690	greenish-yellow	
Y	1.702	green	Bx neg. $(-)$
$Z \wedge c = 16°$	1.705	blue-green	2V very small

A composite drawing of the well-formed crystals, studied on a 2-circle goniometer, is shown in Fig. 5. Its crystallographic elements are listed

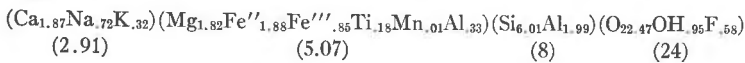TABLE 2. CRYSTALLOGRAPHIC ELEMENTS OF HORNBLENDE FROM THE VUGS IN MONZONITE, BEAVER CREEK QUARRY, BEARPAW MTS., MONT.

$$a:b:c = 0.5451:1:0.2927$$
$$p_0:q_0:r_0 = 0.5370:0.2825:1$$
$$r_2:p_2:q_2 = 3.5400:1.9010:1$$
$$p_0' = 0.5563 \quad q_0' = 0.2927 \quad x_0' = 0.2706$$
$$\beta = 105°08' \quad \mu = 74°52'$$

Forms		ϕ	ρ	ϕ_2	$\rho_2 = B$	C	A
c	001	90°00′	15°18′	74°42′	90°00′	0°00′	74°42′
b	010	0°00′	90°00′	90°00′	0°00′	90°00′	90°00′
m	110	61°43′	90°00′	0°00′	61°43′	76°42′	28°17′
s	021	24°40′	32°55′	74°53′	60°25′	29°35′	76°54′
p	111	70°34′	41°17′	50°22′	77°19′	27°26′	51°31′
d	$\bar{1}11$	315°40′	22°09′	105°53′	74°22′	15°38′	105°16′
u	$\bar{1}31$	341°47′	42°36′	106°02′	49°59′	40°01′	103°13′

TABLE 3. CHEMICAL ANALYSIS (BY F. A. GONYER) OF HORNBLENDE FROM THE VUGS IN THE MONZONITE DIKE, BEAVER CREEK QUARRY, AND THE CALCULATED FORMULA

	Per cent Oxides	Mol. No.	O	M	Mf
SiO_2	38.92	.648	1.296	.648	6.01
TiO_2	1.51	.019	.038	.019	.18
Al_2O_3	12.68	.125	.375	.250	2.32
Fe_2O_3	7.42	.046	.138	.092	.85
FeO	14.64	.203	.203	.203	1.88
MnO	.09	.001	.001	.001	.01
MgO	7.86	.196	.196	.196	1.82
CaO	11.24	.201	.201	.201	1.87
Na_2O	2.38	.039	.039	.078	.72
K_2O	1.58	.017	.017	.034	.32
H_2O+	.93	.051	.051	.102	.95
F	1.20	$F_2 = .031$	.062	—	.58
	100.45		2.617		
$O = F$	.51		−.031		
	99.94		2.586		
			$f = 9.281$		

Formula:

$$(Ca_{1.87}Na_{.72}K_{.32})(Mg_{1.82}Fe''_{1.88}Fe'''_{.85}Ti_{.18}Mn_{.01}Al_{.33})(Si_{6.01}Al_{1.99})(O_{22.47}OH_{.95}F_{.58})$$
$$(2.91) \qquad\qquad (5.07) \qquad\qquad (8) \qquad (24)$$

in Table 2. A chemical analysis of the hornblende is given in Table 3. The specific gravity obtained with the Berman Density Balance is 3.35 ± 0.02). The optical data are like those for the variety known as *hastingsite* and are remarkably similar to the hornblende that has formed in the host monzonite.

The *actinolite* is asbestiform in habit, either (1) as a thin coating on the prism faces of the hornblende, or (2) as extensions of the prism from solid material to many single fibers, or (3) as solitary needles attached or enclosed by other minerals. The color is grass green to light green. The variable optical data indicate that the mineral has a range in composition. Z is pale green; X is yellow; $Z \wedge c = 14°$; and $Z_n = 1.662$.

Epidote occurs as sheaf-like aggregates of plates having a brownish-yellow color on the surfaces but brilliant yellow color on broken faces. The optical data are listed below:

	n	Pleochroism	Bx neg. ($-$)
X	1.730	Colorless	$2V = 65°$
Y	1.740	to	Dispersion $r < v$, perceptible
Z	1.745	pale yellow	Parallel extinction

Axinite occurs as aggregates of crystal plates projecting edgewise into the cavities from their base on albite. The color is light brown on the surface and pinkish brown on broken surfaces.

$$X_n = 1.680; \quad Y_n = 1.687; \quad Z_n = 1.690$$
$$\text{Bx neg. } (-). \quad 2V = 70°. \quad \text{Dispersion } r < v, \text{ strong.}$$

In one vug, axinite is coated with chlorite, and in others it seems to be contemporaneous or younger than epidote and actinolite.

Chlorite occurs as aggregates of plates arranged in a great number of clumps, or rosettes, that are perched on other minerals. The rosettes are soft and dark green in color.

Optical data are: Bx pos. ($+$), $2V = $ very small (almost uniaxial). Z $\perp$ cleavage. $Y_n = 1.612$. Chlorite is the youngest of the dark-colored minerals to form, and is one of the most common minerals. It is generally deposited on albite.

Pyrite in one cavity occurs as a pyritohedron truncated by subordinate octahedral faces. Pyrite is younger than albite and older than calcite.

Calcite, prehnite, and *datolite* are all younger than epidote and chlorite, but the relative ages of the prehnite and the other two are not clearly established. Datolite is younger than calcite. The three minerals each have a characteristic habit. Calcite appears as rounded, etched crystal masses; prehnite ($2V = 65°$. Bx pos. ($+$). $Y_n = 1.625$. Z $= c$.) as bladed, spherical aggregates light green in color; and datolite ($2V = 85°$. Bx neg. ($-$). $Y_n = 1.651$. $r > v$) occurs as glassy crystals with a pearly luster.

Analcite was observed in a few cavities as rounded, glassy crystals.

Thomsonite occurs principally as tufts, or as delicate moss-like coatings, composed of brilliant, radiating prismatic crystals. The mineral is principally formed on albite. Optical data are: Bx pos. $(+)$. $2V = 35°$. $Y_n = 1.535$, $Y =$ elongation. In one vug, long fibrous aggregates of the thomsonite have different optical properties: $2V = 50°$, $Y_n = 1.530$.

Two unidentified minerals were seen in the cavities. One, spherulitic balls composed of minute fibers, has refractive indices: lowest $= 1.606$; highest $= 1.615$. Other optical data are uncertain. The other mineral, composed of an aggregate of long, parallel, white fibers is uniaxial $(-)$; $\omega = 1.557$; $\epsilon = 1.548$.

Origin

General

Any hypothesis of origin of the drusy vugs must first explain the formation of the original cavities and then the process of deposition of the minerals on the walls of these cavities. In reviewing the evidence bearing on origin, the following features seem to have special significance:

1. The drusy vugs occur only near the top of the dike.

2. The contact surface of the drusy vugs with monzonite is rounded and clearly defined.

3. The larger drusy vugs have a higher proportion of residual open space than smaller ones.

4. Mineral assemblage and relative proportions of minerals vary in drusy vugs of the same or different size.

5. Hornblende and microperthite are the only minerals common to both the monzonite and the drusy vugs, and they are coarser-grained in the vugs.

6. All of the minerals in the drusy vugs that formed later than albite and magnetite contain one or more of the following: H_2O, F, B, S, CO_2.

Therefore, the writers believe that the cavities were formed by resurgent boiling and that the minerals were deposited in them by moving hot solutions.

Formation of the original cavities

The original cavities, that later became the drusy vugs, were a result of globules of vapor formed after the magma was intruded and before the magma was completely consolidated. Hypotheses postulating the formation of the cavities by solution of solid monzonite or by solution of inclusions are untenable.

The appearance of such globules of vapor, composed principally of water vapor but perhaps also of a subordinate amount of F, B, S, and CO_2, can best be explained by the process of "resurgent boiling." The

rapidly crystallizing magma froze around these globules, leaving gas-filled cavities in hot rock. Vapor was also trapped in the interstices of the monzonite groundmass.

Considerations of temperature and pressure

If, as is held by the writers, resurgent boiling occurred before complete crystallization of the magma, some considerations of the temperature and pressure that prevailed may have a bearing on the geologic significance of such gases.

An ascending magma of monzonite composition and in the process of precipitating pyroxene was implaced at a probable temperature of 600°C. to 800°C. Although the cooling process was a rapid one, the vapor phase could have appeared at a temperature above 400°C.

The height of the column of rock above the pinnacle of the dike was, from field evidence, at least 3,000 feet and may have been as much as 7,000 feet. Under such conditions, the weight of the column exerted a confining pressure of at least 200 Kg/cm² and probably not more than 1,000 Kg/cm.² The hydrostatic pressure of the magma fluid at the time of its implacement was, therefore, probably in excess of 200 atmospheres.

It is reasonable to conclude that the resurgent gases appeared at supercritical conditions for water vapor, that is, above 374°C. and 218 Kg/cm.² The physical nature of gaseous material at such elevated temperature and pressure and its behavior with falling temperature are still puzzling problems. Perhaps the term "fluid" can best connote our present ignorance.

Deposition of the vug minerals

Two possible processes should be considered to explain the deposition of the minerals in the vugs: (1) condensation of the gaseous fluid in the original rock-walled cavities with concurrent precipitation of dissolved material; or (2) continuous migration of fluid into the cavities as temperature was lowered.

The heterogeneity of the mineral assortment, both quantitatively and qualitatively, is evidence against a simple hypothesis of condensation and resultant precipitation. It is reasonable, however, to postulate tentatively that a gas, or fluid, probably existing under supercritical conditions, could have effectively reacted with the already crystallized monzonite, both along the cavity walls and in the rock itself.

The change of pyroxene to hornblende, in the rock, involving the addition of H_2O and F to the mineral structure was probably caused by such a late-magmatic fluid, as was the apparent alteration of the feldspars in the groundmass of the hard, unweathered monzonite. Such reactions involve an exchange or removal of materials.

The writers support the hypothesis that such an exchange or removal of materials was responsible for adding to the residual fluid of the crystallized magma certain constituents that had already been utilized in making the magmatic minerals. In this regard the bulk composition of the vug minerals may have some significance.

A rough estimate was made of the proportions of the different minerals in the vugs and the approximate bulk composition of the vug minerals was calculated therefrom. Because of the method used, only the principal oxides were considered. Microperthite was not included as a vug mineral because of its apparent seriate textural gradation from the groundmass of rock to the shell of the vugs. Of the remaining minerals, albite makes up about 75 per cent; hornblende and actinolite 15 per cent; epidote 5 per cent; and prehnite about 5 per cent.

The bulk composition of the vug minerals and its relation to the composition of the monzonite is shown in Table 4 below:

TABLE 4. APPROXIMATE BULK COMPOSITION OF THE VUG MINERALS

	Vug Minerals	Relation to rock analysis
SiO_2	· 61%	+10
Al_2O_3	19	+ 3
Fe_2O_3	2	− 1
FeO	3	− 3
MgO	1	− 3
CaO	5	− 3
Na_2O	8	+ 4
K_2O	1	− 4

The main difference between the two compositions is the greater proportion in the vug minerals of SiO_2, Al_2O_3, and Na_2O.

Proposed hypothesis

The hypothesis proposed by the writers to explain the distribution and origin of the drusy vugs in the monzonite dike is as follows:

1. The magma was implaced as a vertical dike whose form at the top was a pinnacle.

2. A gas phase appeared as crystallization was proceeding.

3. Gas globules, collecting near the top of the dike, were trapped by the rapid consolidation of the rock.

4. The residual volatile constituents both in the rock-walled cavities and in the groundmass of the rock, perhaps existing as a fluid in or near the super-critical state, reacted with the pyroxene, plagioclase, and sanidine of the rock.

5. A part of the constituents of the residual fluid reacted with the rock minerals to form, for example, hornblende from pyroxene. This process furnished material, which when added to the solutes already in the fluid, formed the minerals of the drusy vugs.

6. The greater alteration of the monzonite near the vugs than elsewhere in the dike suggests that the reworked constituents were obtained principally from the rock adjacent to the original cavities.

7. The mobile fluid that entered the cavities as temperature was falling augmented the supply already there. The vug minerals were precipitated from this hydrothermal solution.

The relative proportion of all the minerals in the drusy vugs to the quantity of monzonite containing them is so insignificant that the magma cannot be called volatile-rich.

As the temperature of the consolidated monzonite fell, the vapors originally filling the globular cavities contracted and thus provided space for additional fluids to enter, accumulate, and eventually precipitate. The transition of the gaseous fluid to the hydrothermal solution was probably gradual rather than abrupt, and it is quite likely that no sharp phase boundary was passed.

The basic physico-chemical principles of hydrothermal process have been ably reviewed by Morey and Ingerson (1937), and the nature, transition, and structure of pure fluids near and in the critical region have been investigated recently by Clark (1938), Maass (1938) and Barnes (1938).

Relation to miarolitic cavities

The term miarolitic cavity has often been used in the literature with reference to residual, crystal-lined cavities in intrusive, igneous rocks. This kind of mineral occurrence in diabase has been described by Shannon (1926) and Cannon (1937). Granite, however, is a much more common host for such cavities. The terms "druse," "drusy granite," "druse minerals," "miarolite," and "miarolitic cavity" have all been employed by writers describing such occurrences: Fournet (1841); Becker (1868); Schwantke (1890); Koenigsberger (1901); Gillson (1927); and Gallagher (1937).

The term drusy vug, however, is preferred in reference to such mineral occurrences, and it would be applicable to a wide assortment of occurrences irrespective of origin or rock composition. Miarolitic cavities could be more properly restricted to the original rock-walled, gas-filled cavity formed during consolidation of intrusive rocks through appearance of a gas phase in the late magmatic stage.

Conclusions

The drusy vugs in a monzonite dike in the Beaver Creek Quarry, Bearpaw Mountains, Montana, represent miarolitic cavities whose walls have been lined with minerals deposited by later-formed hydrothermal solutions. The minerals that compose the shell of each vug (microperthite, hornblende, albite, magnetite) represent a transitional stage (pegmatitic?) between the magmatic and hydrothermal stages.

The constituents making up the minerals of the drusy vugs were in large part derived through reaction on already crystallized rock-minerals by late magmatic volatile fluids that existed at or near supercritical conditions for water. In the groundmass of the rock this reaction is evidenced by the partial alteration of pyroxene to hornblende. In the monzonite adjacent to the drusy vugs the reaction has also resulted in noticeable alteration of feldspars. Na, Si, and Al have been more susceptible to transfer from rock to vug than K, Ca, Mg, and Fe; and in combination with volatile and other residual constituents these elements were precipitated from mobile hydrothermal solutions that entered the cavities probably by movement along the grain boundaries of the monzonite and by diffusion through it.

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