IDDINGS, J.P.

...On a group of volcanic rocks from the Tewan Mountains, New Mexico... 1890.

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No. 66

ON A GROUP OF VOLCANIC ROCKS FROM THE TEWAN MOUNTAINS, NEW MEXICO, AND ON THE OCCURRENCE OF PRIMARY QUARTZ IN CERTAIN BASALTS.

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UNITED STATES

GEOLOGICAL SURVEY

No. 66

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1890

UNITED STATES GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

ON

A GROUP OF VOLCANIC ROCKS

FROM THE

TEWAN MOUNTAINS, NEW MEXICO,

AND ON

THE OCCURRENCE OF PRIMARY QUARTZ IN CERTAIN BASALTS

BY

JOSEPH PAXSON IDDINGS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1890

CONTENTS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 24, 1888.

SIR: I have the honor to transmit herewith a paper by Mr. Joseph P. Iddings, "On a group of volcanic rocks from the Tewan Mountains, New Mexico, and on the occurrence of primary quartz in certain basalts."

It is the result of an investigation of a suite of rocks collected by yourself in northwestern New Mexico in the autumn of 1887.

Its special value consists in showing a gradual transition in mineralogical composition from acid to basic lavas and adds one more to the volcanic areas of the Far West which have been investigated by the searching analytical methods of modern science. Such studies as this of Mr. Iddings will enable us finally to elucidate some of the more important geological problems connected with the crystallization of eruptive rocks.

I recommend that the paper be published as a bulletin of the Geological Survey.

Very respectfully, your obedient servant,

ARNOLD HAGUE,
Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

ON A GROUP OF VOLCANIC ROCKS FROM THE TEWAN MOUNTAINS, NEW MEXICO, AND ON THE OCCURRENCE OF PRIMARY QUARTZ IN CERTAIN BASALTS.

BY JOSEPH P. IDDINGS.

INTRODUCTION.

Maj. J. W. Powell, Director of the U. S. Geological Survey, and Mr. William H. Holmes, in the course of their explorations in the Tewan Mountains, in New Mexico, during the field-season of 1887, collected a suite of rocks, which exhibit petrographic features of special interest. The collection embraces a number of varieties of volcanic rocks and presents a series of transitions from acid rhyolite, through andesite, to quite basic basalt. This series, however, is interrupted in two places by the absence of varieties which occur in neighboring regions and, possibly, may exist in this one in places not yet visited. The greater part of the collection is made up of rhyolite, obsidian, and rhyolitic tufas and ashes, which cover a large area of the country explored. But the small number of andesites and basalts accompanying the rhyolites, by the variations in their mineral composition and physical habit, emphasize the fact that the rocks of the region present a series which grades in composition from one extreme to the other, rather than a number of well-defined types. It is the object of this paper to call attention to the mineralogical relations existing between the rocks of this locality, as another example of that which has been found to exist throughout the series of volcanic rocks occurring in the regions of the Great Basin,[1] including the Washoe district,[2] and of the volcanoes of the Pacific coast,[3] and the Republic of Salvador,[4] Central America; and also to

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[1] Hague and Iddings. Notes on the volcanic rocks of the Great Basin. Am. Jour. Sci., 3d series, vol. 27, 1884, pp. 453-463.

[2] Ibid. Notes on the volcanoes of Northern California, Oregon, and Washington Territory. Am. Jour. Sci., 3d series, vol. 26, 1883, pp. 222-235.

[3] Ibid. On the development of crystallization in the igneous rocks of Washoe, Nevada, with notes on the geology of the district. Bull. U. S. Geol. Survey, No. 17, 1885.

[4] Ibid. Volcanic rocks of the Republic of Salvador, Central America. Am. Jour. Sci., 3d series, vol. 32, 1886, pp. 26-31.

describe the occurrence of porphyritical secretions of quartz in various members of the series, particularly in the basalt, and to offer some suggestions as to their probable origin.

PETROGRAPHICAL DESCRIPTION.

In order to bring out more clearly the connection between the varieties of these rocks it will be necessary to describe as briefly as possible their mineral composition and general characters.

RHYOLITES.

Normal porphyritic varieties.—The rhyolites are light-colored rocks, varying from white and gray to buff, flesh-colored and light red. They are mostly porous and earthy in texture, and grade into pumice on the one hand and into fine-grained ash on the other. They are characterized by abundant porphyritical crystals of quartz and sanidine having a brilliant, glassy habit. The quartzes are mostly crackled and rounded, but in some of the rhyolitic tufas they have a perfect crystal form, and may be separated from the rock as dihexahedral pyramids, with very short prism faces. The sanidines frequently exhibit the intense blue iridescence or sheen, common to many occurrences in the Great Basin and the Rocky Mountains, and which is probably occasioned by a submicroscopic parting along planes parallel to an orthodome.[1] Sanidines exhibiting strong blue iridescence occur in the rhyolites from the following localities in New Mexico: right fork of Coyote Creek; Middleton's Ranch; seven or eight miles above Jemez Pueblo; and from the vicinity of Jemez Springs. The rhyolitic tufas range from fine grained earthy masses, without macroscopic crystals or fragments, to aggregations of rhyolitic ash with various sized fragments of pumice and dense rhyolite.

In thin sections, under the microscope, nearly all of the rhyolites present the same characters: a more or less glassy groundmass with numerous phenocrysts of quartz and sanidine. The quartz seldom exhibits crystal boundaries, being usually in rounded grains or angular fragments. It is poor in inclusions, many individuals showing none at all, others carrying a few glass inclusions. The sanidine is of very pure substance, frequently exhibiting crystal boundaries, though often in angular fragments, and is occasionally twinned according to the Carlsbad law.

Most of the rhyolite sections are free from plagioclase; nearly all contain a few scattered fragments of rather dark green augite; a smaller number carry a little brown hornblende, and rarely magnetite and zircon.

The groundmass is glassy and colorless, with a variable structure, being micro-cryptocrystalline to microcrystalline in patches, as well as

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[1] Whitman Cross. Contributions to the Mineralogy of the Rocky Mountains. Bull. U. S. Geol. Survey, No. 20 1885, p. 75.

axiolitic. In most cases it is marked by irregular, short, curved streaks, shaped like the minute fragments of glass in the tufas. In a few instances it is spherulitic, and in others, pure glass.

A highly inflated and fibrous pumice is found at the old ruins, Te-yi, west of Española. It is light gray with a satin luster on the sides of the fibres, and carries phenocrysts of quartz and sanidine.

Obsidian.—A very beautiful jet-black obsidian occurs at Obsidian Hill. It is free from porphyritical secretions, except a few small spherulites and lithophysæ, the latter being abundant in a specimen from Rio San Diego. The spherulites and lithophysæ resemble those from Obsidian Cliff, Yellowstone National Park,[1] except that no fayalite has been observed in them. In the obsidian from six miles above San Antonio Springs there are curious flattened, dish-like spherulites. The obsidian from these localities is remarkably transparent, even in quite large flakes, being gray to smoke-colored. The color appears to be due to minute black specks, recognizable with a pocket-lens, the glass itself being colorless. The glass is hydrated, and upon being fused before an oxyhydrogen blowpipe, it boils up into white pumice through the escape of its water of hydration.

In thin section the glass is found to be almost free from microlitic secretions. There are scattered black grains, probably magnetite, and a few microscopic feldspars, mostly in minute groups of crossed crystals. The few small spherulites are like those just mentioned. Occasionally there are microscopic crystals of apatite and zircon.

Lithoidite.—In this connection may be mentioned a lithoidal, vesicular rhyolite without porphyritical secretions, from the peak near Pelado camp. The cavities are coated with glassy crystals of tridymite. In thin section it exhibits a spherulitic groundmass with radiating groups of feldspar microlites and branching spherulitic growths, quite similar to the microstructure of the lithoidal portion of Obsidian Cliff, Yellowstone National Park.

Mica-bearing rhyolite.—Another variety of porphyritic rhyolite is represented by specimens from the head of San Antonio Valley, from a conical hill in the Valle Grande, and from San Diego Cañon, east side of Jemez Springs. These rhyolites are light gray and white, with abundant porphyritical quartz and feldspar crystals and numerous small plates of biotite. Two of them are full of irregular cavities, the third is pumiceous. The quartz is in crackled grains and has a light amethystine color.

In thin section, the phenocrysts are found to be quartz, large sanidines and numerous plagioclases with some red mica. One thin section contains a little brown hornblende. The groundmass of the first two forms is microcrystalline and spherulitic, while that of the pumi-

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[1] J. P. Iddings. Obsidian Cliff, Yellowstone National Park, Seventh Annual Report U. S Geological Survey, 1889. The nature and origin of lithophysæ and the lamination of acid lavas. Am. Jour. Sci., 3d series, vol. 33, 1887, pp. 36–45.

ceous form is pure glass filled with gas cavities. The latter carries a small amount of microlites, which are abundantly included in some of the feldspars. Both the quartz and feldspar crystals of this rock are rich in glass inclusions. The plagioclase probably belongs to the oligoclase series. Its presence together with that of mica in this variety of rhyolite gives it a dacitic character; for it approaches the composition of the dacites of the Great Basin, already referred to, which are characterized by abundant biotite, besides plagioclase and quartz, with less sanidine.

Tufa.—The rhyolitic tufas appear to be composed of the variety of rhyolite first described. They bear similar porphyritical crystals: quartz and sanidine, without plagioclase; and also carry small fragmentary crystals of augite. The groundmass is mostly glass, showing some micro-cryptocrystalline and microcrystalline portions, and the irregular markings which suggest minute fragments of glass. The groundmass is brecciated and exhibits various structures, the larger fragments being pumiceous. The tufas also contain fragments of other rocks which are mostly andesitic.

Ash.—The rhyolitic ashes are made up of minute angular fragments of glass and crystals. In some instances they contain a variable amount of gneissic fragments, consisting of angular particles of quartz, microcline and small fragments of schist. This archæan material sometimes occurs in such quantities as to constitute a whole layer of the rock.

ANDESITES.

The andesites of the collection number twenty-three different specimens, and may be divided into four classes according to their mineral composition. But these classes grade into one another so that no sharp line of demarkation can be drawn between them. They are:

I. Mica-andesite.
II. Hornblende-mica-andesite.
III. Hornblende-pyroxene-andesite.
IV. Pyroxene-andesite.

GENERAL CHARACTERISTICS.

The first class is characterized by the presence of mica, without hornblende or pyroxene.

The second class may be subdivided into two varieties, one containing mica and hornblende without pyroxene, and one containing mica, hornblende, and pyroxene.

The third class, also, may be subdivided into two varieties, one containing hornblende and pyroxene with a little mica, and one containing hornblende and pyroxene without mica.

The fourth class is characterized by the presence of pyroxene; some specimens containing a very little hornblende and some being free from it.

Within the last three classes there is a great variation in the physical habit of the rocks, but the microscopical characters of the minerals composing them are quite uniform. Thus the colors of the hornblende-mica-andesites range from light to dark shades of gray, brown, and red, some being mottled bluish gray and red. The nature of the groundmass varies from lithoidal and porous to glassy and compact. Most of the varieties are characterized by large porphyritical feldspars, 5 to 10^{mm} long, with smaller hornblendes and micas, and more or less numerous rounded grains of quartz. Two of the specimens have no large porphyritical crystals, but carry a multitude of small ones.

The colors of the hornblende-pyroxene-andesites are darker and include red, brown, gray and black. The groundmass varies from lithoidal to glassy. The porphryritical crystals consist of abundant feldspars about 5^{mm} long, with less noticeable ferro-magnesian silicates.

The five specimens of pyroxene-andesite differ considerably from one another. One is light purplish gray, full of small cavities, with numerous porphyritical feldspars and smaller pyroxenes. Another is a light red tufa inclosing darker red and black fragments. The remaining three specimens are bluish-black dense rocks, one of which is very vesicular. They carry porphyritical feldspars and smaller pyroxenes, and one of them bears a few small grains of brilliant crackled quartz. The last three forms closely resemble basalt.

Class I.—Mica-andesite.—Of this class there is but one representative, from one-half mile below Sulphur Spring, west of Pelado Peak. It is a gray pearlite full of dull white feldspars, with small inconspicuous micas. In thin section it is found to be a colorless glass rich in microlites, and having a well-marked pearlitic structure; there are numerous porphyritical plagioclases and brown biotites; several plagioclases appear to be surrounded by orthoclase, which does not occur in separate individuals. Magnetite, apatite, and zircon are accessory minerals.

Class II.—Hornblende-mica-andesite.—There are two specimens of hornblende-mica-andesite which contain no pyroxene, and eight which carry more or less hypersthene and augite besides the mica and hornblende.

In thin section they all agree in having a glassy groundmass, with one exception, in which it is holocrystalline with numerous aggregates of tridymite. The glassy groundmass in most cases is full of microlites of feldspar and augite with grains of magnetite, which give it the so-called felt-like structure. The glass is colorless except in one specimen, where it is brown. The groundmass carries microscopic crystals of pyroxene, which are often colored red and sometimes are quite opaque, besides feldspars and occasionally small crystals of hornblende and mica. The porphyritical crystals are plagioclase, mica, hornblende, hypersthene, and augite. The plagioclase forms the largest individuals and carries a great number of glass inclusions; in some cases the amount of glass exceeds that of the feldspar substance. At times the feldspar appears to be made up of a group of small individuals with nearly parallel orientation, between which there is more or less glass. From their optical behavior the plagioclases appear to belong to the andesine-labradorite series.

The mica is biotite; its color is brown and reddish brown, sometimes with a greenish tinge in sections inclined to the base. It has a very strong absorption and a small optic angle. Occasionally it is almost entirely replaced by iron oxide.

The hornblende is dark brown with strong pleochroism, in some cases being greenish brown, but more frequently reddish brown. The color is sometimes different at the two ends of a crystal. The hornblende also is occasionally replaced by an opaque iron oxide.

The hypersthene and augite are usually in smaller crystals than the hornblende. The hypersthene is distinctly pleochroic, being green parallel to the longitudinal axis, ċ, and light reddish brown at right angles to it. It has quite the same character as the hypersthene found in the andesites of the Great Basin and Pacific Coast volcanoes. The augite is light greenish and is not pleochroic.

The iron oxide occurs in small irregular crystals whose form indicates magnetite. Apatite and zircon are found in almost all of the thin sections. The apatite is often colored reddish brown and exhibits a decided absorption parallel to the longitudinal axis. The quartz grains which are observed in most of the hand specimens are found in only four of the thin sections, partly because they are not very abundant and partly because they fall out during the preparation of the section. The quartzes observed are of the purest substance with perfectly uniform optical orientation throughout each individual grain. They are almost entirely free from inclusions; in some cases they contain one or two dihexahedral glass inclusions, and in one instance a small prismatic crystal of apatite.

Class III.—Hornblende-pyroxene andesite.—Of the rocks referable to this group five specimens carry a little mica, while two contain none. They are quite similar to the hornblende-mica-andesites, but are somewhat darker colored with less prominent porphyritical crystals. In thin sections they exhibit the same miscroscopical characters as the rocks just described, differing from them only in the relative proportions of the mineral constituents. Three specimens, however, deserve special mention. Two are andesitic pitchstones from the cliff near the Warm Spring on the north side of the cañon, east branch of San Diego Creek. They are black, resinous glasses, with abundant white phenocrysts of feldspar and some rounded grains of crackled quartz.

In thin section they are found to consist of colorless glass, rich in trichites and microlites, which are not uniformly distributed through the glass, but are arranged in layers and streams, which curve around the crystals and produce a strongly marked flow structure. The porphyritical crystals are: plagioclase crowded with glass inclusions, brown hornblende, hypersthene and augite, and in one section a little biotite. The quartz grains are not found in the thin sections.

The third rock is from about the same locality; it is red, streaked with black pearlitic glass, with small fragments of light purple rock. It bears numerous porphyritical feldspars, and considerable quartz in brilliant, crackled grains, none of which are found in the thin sections made from it. Under the microscope the rock appears to be a microscopic breccia of different kinds of glass: colorless, yellow and brown, in some places trichitic, in others clouded. The porphyritical secretions are like those of the previous varieties, with a little mica.

Class IV—Pyroxene-andesite.—Within the group of pyroxene-andesites there is a range from a variety quite similar to the hornblende-pyroxene-andesite to one which resembles andesitic basalt without the olivine.

The first variety is represented by a bluish-black rock with irregular cavities, from a coulée two miles northeast of Polvadera Rancho. The phenocrysts consist of medium-sized feldspars and small pyroxenes, with a few small grains of brilliant quartz. In thin section the groundmass is found to be glassy with a felt-like structure, produced by the microlites of feldspar and augite. The porphyritical plagioclase has the same character as that of the hornblende-pyroxene-andesites, being full of glass-inclusions. The hypersthene and augite have the same characters as those already described. There is a very small amount of reddish-brown hornblende present.

The light red andesitic tufa from Santa Clara Cañon has the same mineral composition as that just described, but shows no quartz grains.

Another variety of pyroxene-andesite occurs eight miles from the head of Coyote Cañon. It is light purplish gray with numerous irregular cavities, and bears porphyritical feldspars and inconspicuous pyroxenes. In thin section the groundmass is found to be glassy, and full of microlites of feldspars and augite with grains of iron oxide. The phenocrysts are plagioclase, hypersthene, and augite, with accessory iron oxide and apatite. The plagioclase crystals differ from those in the andesites just described. They are sharply rectangular, with fewer glass inclusions, and appear to belong to more basic species, probably to the labradorite-bytownite series. Hypersthene is more abundant than augite, both having the same characters as those in the other andesites.

The dense, bluish-black variety, from seven or eight miles above Jemez Pueblo, bears numerous porphyritical feldspars, and in thin section is found to have a groundmass of dark brown, globulitic glass with microlites. The porphyritical feldspars are rich in brown glass inclusions. The small porphyritical pyroxenes are mostly hypersthene.

The vesicular variety of pyroxene-andesite taken from an Indian metate, or grinding-mill, found five miles above Jemez, is similar in composition and structure to the previous rock, the brown globulitic glass being particularly fine.

Owing to the preponderance of orthorhombic pyroxene or hypersthene in these pyroxene-andesites they belong to the variety hypersthene-andesite.

BASALTS.

The basalts of the collection are mostly compact, fine grained rocks, differing in color from light gray to greenish black, in two cases being dark red.

Normal basalts.—The basalt from a dike on the south side of Rio Chama, one and one-half miles west of Abiquiu, is light gray, very fine grained and dense. In thin section it is found to be glassy with abundant lath-shaped plagioclase, and long augite crystals with grains of magnetite and some trichites. There are almost no porphyritical secretions. There is considerable iron oxide and nearly opaque secondary matter, which appears to replace the olivines that have been decomposed. There is no hypersthene in this nor in any of the other basalts in the collection.

A dike four miles northeast of Abiquiu is formed of another variety of basalt. It is a dense black rock with a few small phenocrysts. In thin section it is seen to be composed of microscopic crystals and grains of violet-brown augite and magnetite, with a small amount of lath-shaped plagioclase and much colorless olivine in small porphyritical crystals; the whole is cemented by a colorless glass bearing black trichites.

The basalts which form the second and fourth ledges from the top of the wall of the Rio Grande Cañon are very much alike; they are light-gray dense rocks with small phenocrysts. In thin sections they are found to be holocrystalline, with much lath-shaped plagioclase and less augite in grains and stout crystals, besides magnetite and much colorless olivine in crystals and grains. There are a few porphyritical crystals of olivine and augite and very abundant microscopic needles of apatite.

Quartz-bearing basalt.—Of the seven remaining specimens of basalt from the neighborhood of Rio Grande Cañon, two are light-gray dense rocks, three are greenish black, dense and fine grained, and two dark red and vesicular.

The light gray basalts are somewhat like those just described, but bear more porphyritical secretions of olivine, besides abundant small grains of crackled quartz. These quartz grains are surrounded by light green shells, composed of microscopic augites. In some cases the shells cover the quartz grains on the surface of the handspecimen; in others, especially on weathered surfaces of the rock, the quartz has dropped out, leaving the augite shell firmly adhering to the rock. The quartz grains are distributed through the rock quite as uniformly, though not so abundantly, as the crystals of olivine are.

In thin section these two basalts are alike and resemble those forming the second and fourth ledges on the cañon wall, except that they are slightly coarser grained. They are holocrystalline, and are composed of lath-shaped and tabular plagioclase, light violet-brown augite in crystals and grains, with magnetite and much olivine in grains and porphyritical crystals. None of the quartz grains appear in the thin sections of these two basalts, but the augite rings and clusters indicate where they were located before the grinding of the sections. The three specimens of greenish black basalt also exhibit microscopic secretions of olivine and grains of quartz like those just described, being even more abundant. The quartz is sometimes quite compact and free from cracks.

In thin section these basalts have the same microstructure as those just mentioned, but are finer grained and contain rather more augite. The olivine is partly altered to dark green serpentine, which is also scattered through the rock and gives it its green color. In one thin section there are seven quartz grains or indications of their former presence, in another there are two, and in a third there are ten.

The red vesicular basalts also bear many porphyritical grains of quartz; on the surface of one side of a small specimen 7.5^{cm} long by 6^{cm} wide (3 by 2½ inches) there are seventy-five grains, and they are no more abundant on this surface than on the others. In thin sections these red basalts resemble the general structure of the gray, compact varieties, but they do not appear to be holocrystalline; there is probably a little glass present. The rocks are filled with red oxide of iron, which also colors the margins of the porphyritical olivines. They contain a little more augite than the gray basalts do. Most of the quartz grains have dropped out in grinding, but fragments remain, and in most cases the augite rings still indicate where they were formerly located. From these indications it appears that in one thin section which is 2^{cm} in diameter there were once five grains of quartz.

MINERALOGICAL GRADATIONS.

From the foregoing descriptions it is evident that the volcanic rocks from this portion of New Mexico present a number of varieties grading from one extreme of mineral composition to another, which, judging from other localities, corresponds to a variation in chemical composition. This transition may be expressed by the following table, which gives the essential mineral constituents of the different varieties.

Table showing the variation in the essential minerals of the rocks from the Tewan Mountains.

Rocks.	Component minerals.								
Obsidian									
Rhyolite	quartz	sanidine					ac		ac.
	quartz	sanidine	plagioclase	mica	ac				ac.
*Dacite**	*quartz*	*ac*	*plagioclase*	*mica*	*ac*	*ac*	*ac*		*ac.*
Mica-andesite		ac	plagioclase	mica					ac.
Hornblende-mica-andesite	ac		plagioclase	mica	hornblende.				ac.
	ac		plagioclase	mica	hornblende.	hypersthene	augite		ac.
Hornblende-pyroxene-andesite	ac		plagioclase	ac	hornblende.	hypersthene	augite		ac.
	ac		plagioclase		hornblende.	hypersthene	augite		ac.
Pyroxene-andesite	ac		plagioclase		ac	hypersthene	augite		magnetite.
			plagioclase			hypersthene	augite		magnetite.
*Olivine-bearing andesite or hypersthene-bearing basalt**			*plagioclase*			*hypersthene*	*augite*	*olivine*	*magnetite.*
Basalt	ac		plagioclase				augite	olivine	magnetite.

* Not in the collection from this region.

In this series the most persistent constituent expressed in general terms is feldspar, but this passes through a series of variations. Thus it is wholly orthoclase in the first variety of rock ; orthoclase and oligoclase, possibly with albite, in the second. But in the following varieties, since the particular species of the plagioclase has not been definitely determined, no attempt has been made in the table to separate them. It can be said, however, that the plagioclase becomes more basic as basalt is approached, passing through andesine to labradorite and possibly bytownite and anorthite. The composition of dacite is indicated in italics; it is similar to that of the second variety of rhyolite but the relative proportions of the minerals are different. It is possible that the glassy mica-andesite may have the chemical composition of dacite.

Mica, as an essential constituent, makes its appearance before hornblende does, and disappears sooner. Hornblende bears a similar relation to hypersthene and augite, which make their appearance together in these rocks, with the exception of the accessory augite in the first variety of rhyolite, which differs slightly from the other augites. Hypersthene runs its course before augite, which reaches its greatest development in the basalts, where olivine appears.

The intermediate forms of olivine-bearing andesite or hypersthene-bearing basalt, which are so abundant in other regions of the West, are not represented in this collection; their composition is indicated in italics in the table.

Magnetite is an accessory constituent of the acid rocks of the series, and with the gradual increase of basicity assumes the role of an essential constituent in the more basic members of the series. The occurrence of quartz as an accessory constituent of various members of this series will be fully discussed later.

Owing to the limited size of the collection it would be unwise to offer any generalizations as to the preponderance of one variety over another in this region. And, except for the abundance of rhyolite, the collection illustrates the variable character of the rocks, which is still more noticeable in larger collections from other regions, and becomes still more apparent when large bodies of volcanic rocks are studied in the field, for the mineral composition of a rock-mass varies within certain limits in nearly every case, and the greater the number of occurrences the more difficult it is to select a particular combination of minerals as a typical one. Moreover the predominance of any one variety in a given region may be an actual predominance or only an apparent one due to geologic conditions, such as the covering up or the denudation of other varieties; and a predominant variety of volcanic rock in one locality may be a subordinate variety in a neighboring district.

THE OCCURRENCE OF PRIMARY QUARTZ GRAINS IN BASALTS.

BASALT FROM RIO GRANDE CAÑON.

Turning now to a consideration of the occurrence of quartz in the form of porphyritical secretions in the basalt from Rio Grande Cañon, it is to be observed that:

The quartz is not an alteration product of other minerals, for the rocks are quite fresh, and exhibit only a very slight alteration on the surface of the olivines. On the contrary, it is evident that the quartz grains existed in the rock-mass in their present form previous to the final consolidation of the magma. For each grain is closely surrounded by a shell of augite crystals intimately connected with the inclosing rock-mass. This augite shell forms a narrow border or ring in thin section, and is composed wholly of short crystals of augite radiating from points along the side of the rock-mass toward the quartz. The augite crystals crowd closely against the surface of the quartz grains, but between them and the rock-mass there is no line of demarkation; the outside augite crystals lie among the feldspar and magnetite individuals, and take part in the general structure of the rock. In the holocrystalline and coarser-grained varieties the feldspar sometimes incloses a number of the augites situated on the outside of the shell, and the feldspar is thus proved to be a later crystallization than the shell.

The substance of the quartz composing these grains is perfectly pure, without inclusions of gas, fluid or glass; in one instance there was a minute crystal of zircon. Each grain is a single individual, with uniform optical orientation throughout its entire extent; occasionally two individuals are in juxtaposition. But there is nothing like aggregates of quartz, the form in which secondary quartz usually appears. The grains are rounded or subangular, in only one instance did the shape and optical orientation indicate a bipyramidal form.

The substance and shape of the quartzes are like those of the porphyritical quartz grains in other volcanic rocks when they are free from inclusions, which sometimes happens in the rhyolites. They are not like the quartzes of granites and gneisses or of their derivatives, the sandstones, which are more or less filled with inclusions of gas and fluid, and frequently with individualized inclusions.

It is evident, therefore, that the quartz grains are primary constituents of the rock; that they are more like the porphyritical quartz secretions of other volcanic rocks in their microscopical habit than like fragments of quartz from granitic or gneissic rocks or sandstones. Moreover, their mode of occurrence in these particular basalts militates against the theory that they may be fragments of foreign rocks which have been caught up by the basalts during their eruption; for they are uniformly and intimately distributed through each of the seven hand-specimens, which were collected from different parts of a large basalt flow, at least four miles long, and which represent portions of it differing in crystallization and general habit. Further, the grains are isolated individuals, and not clusters, and never exhibit indications of having been crystallized together with other minerals. They have every appearance of being primary secretions, or crystallizations from the rock magma.

The occurrence and distribution of very abundant quartz grains throughout the recent basalt flow near the Cinder Cone, ten miles northeast of Lassen Peak, California, has been described by Mr. J. S. Diller,[1] and as claimed by him leaves no reasonable doubt of the primary and essential nature of the quartz in that particular basalt.

Two new occurrences of quartz-bearing basalt may here be described, since they show that such basalts are scattered over a large area of country, having been found in California, Nevada, Arizona, New Mexico, and Colorado.

BASALT FROM ARIZONA.

That from Arizona is a fine example of quartz-bearing basalt, it is a red, compact rock from the cañon near granite tanks, in the vicinity of Santa Maria Basin, Arizona, and was collected by Mr. Clarence King. In the hand-specimens the only porphyritical secretions are rounded grains of glassy quartz from 1 to 8^{mm} in diameter, together with somewhat smaller olivines. The quartz grains are so numerous that one small specimen about 6^{cm} (less than two and one-half inches) square shows as many as thirty grains on all its surfaces. In thin sections the basalt is glassy with abundant lath-shaped plagioclases and red oxide of iron scattered through it, which obscures the other constituents. The groundmass bears small porphyritical crystals of light-green augite and olivine. In the dense specimens the olivine is partly fresh and colorless, partly colored orange and red. In the porous specimen the olivine has been entirely removed, leaving only its characteristic outlines marked by iron oxide, and the augite is more or less reddened. The quartz is the same in both varieties, of which seven thin sections were made showing quartz. It forms rounded and subangular grains, of very pure substance, almost free from inclusions; the few inclusions observed consist of colorless glass, in one instance gas, besides a small zircon and an apatite. One large quartz grain has two inclusions of red glass with microlites like that on the outside of the same grain,

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[1] Am. Jour. Sci., 3d series, vol. 33, pp. 45–50, 1887.

and it is probable that these apparent inclusions are cross-sections of pockets or pipes of the outer glass.

Only in a few instances do the quartz grains possess a continuous shell of augite crystals, which in these cases is very narrow and close fitting. Most of the grains are bordered directly by the groundmass of the rock, or have a fragmentary augite shell, which is sometimes separated from the quartz grain by red glass, sometimes by a strip of groundmass whose flow-structure indicates that it has forced its way between the augite shell and the quartz grain. Fragments of augite shell are observed at some distance from the quartz, or even entirely isolated in the rock-mass, from which it appears that the quartz grains were at one time surrounded by a shell of augite, as in most other occurrences of quartz-bearing basalt, but that in this instance the subsequent movement of the magma broke the shells and dislocated them.

BASALT FROM COLORADO.

The second occurrence to be described is that of a dark-colored, fine-grained basalt from Elk Head Creek, at the southeast base of Anita Peak, fifteen miles northeast of Hayden, Colorado, in which basalt porphyritical quartz grains are very abundant. Dr. Whitman Cross kindly furnished me with the thin sections of this rock for study and description. They represent two modifications of the basalt, and show that the rock is partly altered, the olivines having been converted into serpentine, which is disseminated generally through the rock. The mineral composition and structure of this basalt are about the same as those of the basalts from Rio Grande Cañon, New Mexico, but the quartz grains, which are equally abundant in both basalts, have a somewhat different microscopical character.

In the basalt from Elk Head Creek the quartz grains are surrounded by an augite shell or ring in every case. But the shell is quite thin and its connection with the quartz substance is more intimate. In places crystals of augite penetrate the quartz or are entirely inclosed within it, but they are always located along the margin of the quartz grain. In some instances the quartz exhibits sharp-edged crystal boundaries, which are usually adjacent to an area of serpentine or calcite, which may now occupy what was formerly glass or a cavity. At times the straight, crystal edge is bordered by a narrow rim of augite. The quartz grain is sometimes made up of two or three individuals crystallized together. The inclusions are numerous, and consist of zircon and occasionally apatite, with frequent gas cavities and less abundant glass inclusions. The microscopical character of the quartz resembles that of certain porphyries.

Its primary nature is shown by the presence of glass inclusions and the encircling shells of augite and by its uniform distribution through the rock. The existence of crystal boundaries to the quartz grains indicates that there was little, if any, resorption of the quartz by the inclosing magma. And the inclosure of augite crystals near the margin of grains containing dihexahedral glass inclusions suggests that the crystallization or secretion of the quartz took place in a molten magma in the presence of augite crystals similar to those forming the inclosing shell. It should be observed in this connection that partially corroded quartz and quartz with crystal boundaries occur together in rhyolites and related quartz-bearing rocks.

Quartz grains occur in the same manner but to a much less extent in some of the basalts near Eureka, Nevada, especially in those forming Basalt Peak and covering the country southeast of Richmond Mountain.

They are very abundant in certain basaltic rocks from near Crescent and Whitehead Peaks and Camel Mountain, Colorado.

POSSIBLE ORIGIN OF THE PORPHYRITICAL QUARTZ.

Its exceptional occurrence.—The occurrence of primary quartz in rounded grains in basaltic rocks is exceptional, and is contrary to the laws which appear to govern the development of the mineral constituents of volcanic rocks, so far as our present knowledge goes. The minerals which crystallize in a rock magma result from the chemical affinities inherent in a complex solution of silica, alumina, alkaline earths and alkalies, including iron, lime, magnesia, potash, and soda, between the various demands of which there must be a mutual accommodation. Hence it is evident that the component minerals of a given rock must be those which, under the conditions attending their crystallization, satisfy all the chemical demands imposed by those conditions.

Variation of conditions.—That changes in the conditions under which crystallization takes place in a mixed solution affect the nature of the crystallization is well known, and has been demonstrated experimentally. From the generally uniform nature of the crystallization of most volcanic rocks the correspondingly uniform conditions attending their solidification are indicated. Where variations in the products of crystallization occur the condition affecting them may often be recognized. Hence variations from the general order and nature of crystallization within certain limits have become generally accepted facts, consequently the mineral composition of rocks is not expected to be in rigid accord with their chemical character within these limits.

While in the great majority of cases the mineral composition of volcanic rocks indicates a generally uniform range of condition which must have attended their consolidation, yet there are exceptions to the ordinary grouping of minerals in these rocks that emphasize the influence of certain attendant conditions, which are evidently physical. An instance of this is the mineral association in the lithophysæ of some rhyolitic obsidians, especially in that of Obsidian Cliff, Yellowstone National Park, and of Cerro de las Navajas, Mexico. These holocrystalline portions of the acid lavas are composed of alkali feldspars, quartz, tridymite and fayalite, an iron-olivine, that is, an orthosilicate of iron. This latter mineral is in very small amount compared with the free silica, quartz and tridymite. The chemical composition of the lithophysæ is essentially the same as that of the remainder of the rock, and is like that of normal rhyolites. Hence we are forced to seek the cause of the development of the fayalite in something besides the chemical character of the magma.

Influence of absorbed water.—In a paper on this occurrence[1] I have discussed the matter at length, and after calling attention to the experiments of M. Daubrée on the action of superheated steam on acid glass, and to experiments of others who have undertaken to produce these minerals artificially, I arrived at the conclusion that the most reasonable explanation of what in petrology seems an anomalous association of primary igneous minerals is the reference of their occurrence to aqueo-igneous action, which was induced by the presence of a considerable amount of water-vapor absorbed in the molten magma. The strong mineralizing influence of the water-vapor under such conditions is apparent both in the structure and mineral composition of the lithophysæ and in the alternating crystalline and glassy layers in the laminated lithoidal portion of the same flow of lava. For in the latter case the thin horizontal laminæ of the magma in any particular portion of the mass must have been subjected to like rates of cooling and the same pressure, yet these laminæ solidified alternately holocrystalline and glassy.

Comparison of exceptional occurrences.—The occurrence of iron-olivine in a rhyolite with 75 per cent of silica and less than 2 per cent of iron oxide is as remarkable and as exceptional as that of quartz in the form of porphyritical crystals in basalt. They are both of the same kind, in that they are the occurrences of extremely acid and basic silicate minerals together in rocks, where we are generally accustomed to see silicate minerals of intermediate or of more closely related composition. In the first instance, however, most of the conditions under which the minerals crystallized can be surmised, but in the second case there must necessarily be great uncertainty, for the quartz was evidently crystallized in some early period in the history of the rock, when the conditions then existing made its separation necessary. Whether the quartz was the only mineral crystallized at that time or whether there were others associated with it can not be determined in most of these basaltic occurrences. But in the basalt from Elk Head Creek, Colorado, the small augites which penetrate the margin of the quartz crystals were evidently contemporaneous with the close of the quartz crystallization.

From the rounded form of the quartz grains in most of its occurrences it is probable that the quartzes were in process of resorption by

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[1] Am. Jour. Sci., 3d series, vol. 33, 1887, pp. 36-45. Also Seventh Annual Report, U. S. Geological Survey, 1889.

the basic magma when the final solidification of the rock took place. A similar resorption of porphyritical minerals which have crystallized in an early period of a rock's existence is frequently observed in all varieties of volcanic rocks, as, for example, partly resorbed hornblendes and feldspars, and the rounded quartz grains of rhyolites and porphyries. The idea that these phenomena indicate changes in the physical conditions experienced by the magma and not in its chemical composition is a generally accepted one.

Changes of physical conditions.—Let us consider what may be some of the changes of condition experienced by rock magmas within the crust of the earth. In the case of a molten, viscous magma situated at some depth beneath the earth's surface the two physical factors which at first appear to exert the greatest influence on its existence as a plastic or fluid magma are *temperature* and *pressure.*

Other things remaining constant, the magma will be more plastic the higher the temperature, and with a decrease of the temperature below a certain point consolidation will take place. Consolidation under these circumstances, that is, at considerable depths within the earth, would be ordinarily accompanied by crystallization, as a rapid chilling is only possible when small bodies of magma are brought in contact with cold rocks. The nature of the crystallization will undoubtedly vary within certain limits with the rate of cooling.

If, on the other hand, the temperature of the magma is supposed to remain constant and the pressure to vary, and if we assume that an increase of pressure diminishes the mobility of the molecules of the magma by condensing them, we should expect that an increase of pressure would tend to solidify the mass. The latter supposition appears to be the most rational, and has received support from the experiments of Dr. William Hallock.[1] This is also the conclusion reached by Reyer in his work on the physics of eruptions and of eruptive rocks.[2] Dr. Hallock's observations show that cubical pressure unaccompanied by an increase of temperature simply increases the rigidity or viscosity of a body, but that in cases where pressure is allowed to produce motion by the crushing or yielding of the molecules of a substance the internal friction may generate heat enough to fuse the substance, and thus reduce its rigidity.

The solidification of a molten, amorphous mass by increasing its viscosity might convert it into a solid glass, since Lagorio[3] has observed that solid glass is denser than the same glass when molten, or it might convert it into a crystalline mass, according to whether the viscosity was suddenly increased or slowly increased; the changes being analogous to the rapid increase of viscosity by chilling or the slower increase

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[1] William Hallock. The Flow of Solids. Am. Jour. Sci., 3d series, vol. 34, 1887, pp. 277-281. Also, Bull. U. S. Geological Survey, No. 55, 1890.

[2] E. Reyer. Beitrag zur Fysik der Eruptionen und der Eruptiv-Gesteine, Vienna, 1877, p. 119.

[3] Tschermak's Mineral. u. petrog. Mittheil., new series, vol. 8, 1887, p. 510.

by gradual cooling. The latter permits the molecules to arrange themselves in obedience to certain chemical and physical affinities into crystalline minerals, while the former prevents such an arrangement.

Moreover, if we consider rock magmas as saturated solutions of silicate salts, as Lagorio[1] has done in the paper already alluded to, we may apply to them the law which Sorby deduced for aqueous solutions of salts, namely, that the solubility of those salts, which, like the silicates, expand upon solution and condense upon crystallization,[2] is decreased by increasing pressure. In other words, in such solutions an increase of pressure would tend to crystallize the salts from solution. Hence in a molten rock magma an increase of pressure alone would tend to induce the crystallization of certain silicate minerals from the magma, or might lead to the crystallization of the whole magma.

From the foregoing argument concerning the effect of increasing pressure on the viscosity of magmas and on their crystallization it appears that an increase of pressure might lead to the consolidation of rock magmas at temperatures above their melting point for lower pressures. It might therefore happen that a highly heated magma exists within the earth under such great pressure that it is a solid mass, which may be either amorphous or completely crystalline, or partly amorphous and partly crystalline. Such a condition would be one of *unstable consolidation*, for upon a relief of the pressure the temperature would be sufficient to melt the mass.

Influence of water-vapor.—It is becoming more and more evident that a small amount of absorbed water-vapor in molten rock magmas plays an important part in their liquifaction as well as in their crystallization. The influence of water-vapor upon the viscosity of lavas has been suggested long ago by Scrope and others, who asserted that its presence in molten lavas increased their fluidity. Its part as the explosive agent in volcanic eruptions is well established, and its presence in larger or smaller amounts in every volcanic rock has often been demonstrated.

The increased fusibility of hydrated glass has been noted by M. Daubrée,[3] and may be easily recognized in the case of hydrated obsidian like that from Obsidian Cliff and from New Mexico. These obsidians, containing about 0.5 per cent of water upon being fused before an oxyhydrogen blowpipe, melt at something less than white heat to an inflated glass, which, at first, is quite fluid, and flows away rapidly from the strong current of the blowpipe flame. It is so fluid that it curls over the edge of the unmelted portion of the rock and sometimes forms pendent drops. Upon heating this glass until it loses its water and contains no more gas bubbles, and allowing it to cool, a colorless or pale yellowish glass is obtained, which melts before the same blowpipe flame only at an intense white heat, and then forms a very viscous glass

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[1] Tschermak's Mineral. u. petrog. Mittheil., new series, vol. 8, 1887, p. 421.

[2] J. Roth. Allg. u. Chem. Geol., vol. 2, 1885, p. 52.

[3] Études Synthétiques de Géologie Expérimentale. Paris, 1879, p. 161.

which moves sluggishly before the same blowpipe current, and presents a decided contrast to the obsidian glass first melted.

The bearing of Dr. Guthrie's experiments with chryohydrates or eutectic substances upon this problem has been pointed out by Prof. J. W. Judd[1] in a paper on The Natural History of Lavas as Illustrated by the Materials Ejected from Krakatoa. Dr. Guthrie demonstrated that the melting point of certain compounds is considerably below that of either of their components; they therefore behave like alloys. He experimented chiefly with hydrated substances, though not entirely. Prof. Judd has taken niter as an example. Under ordinary conditions this substance melts at 320° C.; upon the addition of 4.89 per cent of water its melting point is reduced to 262° C., and when it contains 29.07 per cent of water it melts at 97.6° C. Hence a mass of niter within the earth would be solid at 300° C., but at the same temperature upon the accession of 15 or 20 per cent of water it would be molten or in a condition to become molten if the pressure did not prevent it. Inversely, some substances may exist as fluids at temperatures considerably below their ordinary point of solidification by being combined with water; there is a point, however, at which solidification sets in. Mr. J. J. Harris Teall, who has been studying some of Dr. Guthrie's eutectic compounds, finds that upon solidification they separate into their component parts, which interpenetrate one another like quartz and feldspar in granophyre or micropegmatite. Prof. Judd, in his paper, suggests that the mixed silicates in rock magmas may be entectic substances, and Prof. Lagorio, in the paper already mentioned, states that the feldspars of the lime-soda feldspar series behave like eutectic substances. Prof. Judd also calls attention to the power of the water of hydration to lower the melting point of zeolites and siliceous glasses such as tachylites, hydrotachylites and palagonites.

While we are ignorant of the actual influence of absorbed water-vapor upon deep-seated molten magmas, it seems reasonable to assume that it is of the same kind as upon molten magmas at or near the surface of the earth. For the most apparent difference between the condition of a deep-seated and a surface magma is the pressure under which each exists. Hence it is probable that the presence of water-vapor tends to increase the liquidity of the mass. But since the accession of water-vapor would increase the tension of the magma, a point may be reached when the resistance of the inclosing rocks is overcome, and the absorbed vapor becomes an active agent in the eruption of the magma.

If we consider the action of water-vapor in increasing the liquidity of molten magmas as simply a physical one, it must consist in a tendency to increase the mobility of the molecules of the mass among themselves. One effect of absorbed water, then, would be to retard an increase of viscosity, which was being produced in a magma either by cooling or an increase of pressure upon it. And this retardation might permit the

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[1] Geol. Mag., new series, vol. 5, 1888, pp. 1-11.

crystallization of the more hydrated portions of the mass, while the less hydrated parts became too viscous for crystallization, a condition of affairs which undoubtedly existed in the obsidian magma at Obsidian Cliff, where holocrystalline portions occur irregularly scattered through amorphous ones.

It is to be remarked that the crystallization which was in this instance specially induced by the influence of superheated water-vapor differs from that which usually takes place in acid lavas upon cooling, and that the result was the production of *extremely basic and acidic minerals by the side of one another*, or the production of chemical extremes; a result in a measure analogous to the dissociation of the base and acid of a chemical compound by heating. In this case the absorbed water-vapor apparently weakened the affinity between the bases and the silica, which separated into basic silicates and quartz and tridymite. Hence, we may reasonably expect that in deep-seated magmas conditions may obtain by which the water-vapor in them influences their crystallization, and produces minerals of extreme chemical character.

Application to quartz-bearing basalts.—The application of the foregoing general considerations to the occurrence of porphyritical quartz in basalts is at once apparent. The crystallization of the quartz would seem to have been occasioned by the supersaturation of the magma through changes of pressure or temperature accompanied by the special mineralizing action of absorbed water-vapor. The rounded or corroded form of the quartzes indicates that the conditions under which they were crystallized were not the same as those under which the subsequent crystallization of the rock took place, and that they were to that extent abnormal. Reyer (loc. cit.) suggests that pressure and different degrees of saturation with absorbed water may lead to metameric processes, and also states that the development of quartz in rock magmas requires a considerable saturation of the magma with water.

Prof. Lagorio, in the paper already quoted, discusses the question of the formation of minerals in molten magmas, when they are considered as supersaturated solutions of silicates. He states that they may become supersaturated with silica, as well as with the oxides of the heavy metals and the alkalies; and that upon cooling the elements dissolved in excess crystallize out; and that in this way the concurrence of such minerals as olivine and quartz is to be explained.

Accepting the idea of supersaturation and its accompanying laws of crystallization, we still find its power to explain the phenomena of rock structures and mineral combinations limited. For all rock magmas that we have yet become acquainted with have been saturated or supersaturated solutions, whose *degree*, as well as *kind*, of supersaturation is dependent on both temperature and pressure, as well as on their chemical composition. Their kind of supersaturation, that is, the nature of the chemical compound which supersaturates the magmas, varies with the physical conditions under which the magmas exist. And the laws governing the solubility of salts under such varying conditions have not yet been ascertained, as Lagorio himself states. Thus the formation of fayalite in a rhyolitic obsidian with 75 per cent of silica and less than 2 per cent of iron oxide could scarcely be referred to supersaturation as generally understood.

We are still confronted by the fact that magmas of similar chemical composition have crystallized to rocks, which differ both in mineral composition and in structure, and which have in each case obeyed the laws governing the crystallization of saturated or supersaturated solutions. Therefore, we are forced to consider such variations of mineral combination and of structure as more especially the results of the variable physical conditions attending the consolidation of the magmas.

CONFIRMATORY OBSERVATIONS.

If the foregoing explanation, which refers the production of the quartz in these basalts to physical conditions apart from chemical ones, is correct, we should expect to find such anomalous associations of minerals in other varieties of volcanic rocks, and should not expect to find a necessary correspondence in the chemical composition of all basalts which carry porphyritical quartzes. Nor should we expect to find the quartz-bearing varieties, which are exceptional, necessarily holding a definite relation in point of age to the other volcanic rocks with which they are associated. These expectations, I think, are realized by the following observations.

Porphyritical quartz in other volcanic rocks.—The suite of rocks in the collection from New Mexico shows that similar quartz grains occur in most varieties of volcanic rocks from this region, and that their occurrence is not uniform throughout the series.

Thus in most of the rhyolites rounded or partially resorbed grains of quartz are very abundant, but in some specimens they are absent (obsidian and lithoidite). In the glassy mica-andesite, of which there is but one specimen, there are no quartz grains. In the hornblende-mica-andesites, of which there are ten different specimens, six show a considerable number of quartz grains, one shows a few, and three show none. Duplicate specimens show similar amounts of grains. In the hornblende-pyroxene-andesite, of which there are seven different specimens, one shows much quartz in grains, two considerable, one shows a few, and three show none; of the five different specimens of pyroxene-andesite, one shows a few grains of quartz, and four show none; of the twelve specimens of basalt, seven show much quartz in grains, and five show none. In other respects the specimens within each group resemble one another.

Another group of volcanic rocks, specially characterized by abundant rounded grains of quartz, is found in the vicinity of Crescent Peak, Colorado. The collection of the U. S. Geological Exploration of the fortieth parallel contains thirteen specimens from this group, which range from basalt through andesite to what is probably trachyte. They all bear rounded grains of quartz, and some of the olivine-bearing varieties also carry hornblende paramorphs, which furnish additional evidence of a change of physical condition from one which induced the crystallization of certain minerals to a later one which partially resorbed them.

In these two localities, then, it would appear that the physical conditions which are supposed to have produced the crystallization of quartz in the basalts were also imposed on the magma or magmas from which the other varieties of rock were derived.

Chemical similarity of basalts with and without quartz.—That the chemical composition of quartz-bearing basalts is not characteristic of a particular modification of rock magma will be seen from the accompanying analyses.

	I.	II.	III.	IV.	V.	VI.
SiO_2, silica	52.57	52.37	51.57	52.38	57.25	56.28
TiO_2, titanic acid	1.49	1.60	1.43	1.22	0.60	0.84
Al_2O_3, alumina	17.68	17.01	17.72	18.79	16.45	14.23
Fe_2O_3, ferric oxide	2.51	1.44	6.24	2.88	1.67	4.69
FeO, ferrous oxide	5.00	5.89	1.78	4.90	4.72	4.05
MnO, manganese oxide	0.23	0.32	0.45	0.18	0.10	0.16
CaO, lime	8.39	7.59	8.82	7.70	7.65	7.94
MgO, magnesia	6.05	6.86	4.91	4.91	6.74	6.37
BaO, barria	0.06	0.06	0.16	0.11	0.00	....
SO, strontia	....	....	....	....	Trace.	....
K_2O, potassia	1.58	1.59	1.99	1.76	1.57	1.23
Na_2O, soda	4.19	3.51	3.59	3.99	3.00	2.98
Li_2O, lithia	....	....	....	....	0.00	0.01
H_2O, water	0.82	1.29	0.64	0.53	0.40	0.93
CO_2, carbonic acid	Trace.	0.37	0.58	....	....	....
SO_3, sulphuric acid	....	....	....	....	....	Trace.
P_2O_5, phosphoric acid	....	....	....	0.56	0.20	0.40
Cl., chlorine	Trace.	Trace.	....	....	....	.17
	100.27	99.90	99.88	99.91	100.35	100.28
O for Cl (less oxygen for chlorine)	....	....	....	....	....	.04
						100.24

I. Quartz-bearing basalt (70), Rio Grande Cañon, New Mexico. (L. G. Eakins.)
II. Quartz-bearing basalt (81), Rio Grande Cañon, New Mexico. (L. G. Eakins.)
III. Quartz-bearing basalt (71), Rio Grande Cañon, New Mexico. (L. G. Eakins.)
IV. Basalt without quartz (64), Rio Grande Cañon, New Mexico. (L. G. Eakins.)
V. Quartz-bearing basalt, Cinder Cone, Lassen Peak, California. (W. F. Hillebrand.)
VI. Quartzose diorite (2669), east slope of Electric Peak, Yellowstone National Park. (J. E. Whitfield.)

The first three are of three forms of quartz-bearing basalt from Rio Grande Cañon; the first is a light gray dense basalt; the second, a greenish-black dense basalt; and the third, a dark red vesicular basalt, They have practically the same composition, with slight variations, which correspond to slightly different mineral composition. The higher oxidation of the iron in the red rock (III) is indicated by the high percentage of ferric oxide.

The fourth analysis is of a gray, dense basalt from the same locality, Rio Grande Cañon, which resembles the basalt from which the first analysis was made, except that it exhibits no quartz in either macroscopic or microscopic grains. These four are normal basalt analyses, resembling one another as closely as analyses of similar rocks ordinarily do. There are no greater differences between the analysis of the variety without quartz and those of the quartz-bearing varieties than exist between the analyses of the three quartz-bearing varieties, so that the occurrence of the quartz in this instance can not be ascribed solely to the chemical composition of the magma.

Chemical differences between basalts with quartz.—The fifth analysis is that published by Mr. Diller in his paper on the quartz-bearing basalt from near Lassen Peak, California. It shows a different chemical composition for this form of quartz-bearing basalt, which is more acidic than typical basalt, and corresponds closely to some andesitic forms of volcanic rocks.

It is probable that additional analyses of other quartz-bearing basalts will show as great a variation in their chemical composition as exists between that of basalts free from quartz grains.

Different mineral development of chemically similar magmas.—The sixth analysis is presented for comparison with analysis V. It is that of a magma of very nearly the same chemical composition, slightly more basic, which has consolidated under different conditions. It may serve to illustrate two points: First, the mineralogical extremes to which chemically similar magmas may be developed. Second, the possibility that a basaltic magma existed at some previous period in a condition in which quartz might have been crystallized out. Analysis VI is of a coarse-grained quartzose diorite, perfectly fresh and unaltered, of quite recent geological age, and which is composed of plagioclase-feldspar, quartz, hornblende, biotite, pyroxene (hypersthene and augite), with accessory magnetite, apatite, and zircon. The quartz is in considerable quantity, very much more than the amount of quartz observed in quartz-bearing basalts.

For a more extended discussion of this question and a fuller description of the diorite just mentioned the reader is referred to a recent paper on The mineral composition and geological occurrence of certain igneous rocks in the Yellowstone National Park,[1] in which the writer has shown that chemically identical magmas crystallize into mineralogically different rocks under the influence of different physical conditions.

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[1] J. P. Iddings, Phil. Soc. of Washington, 1890. Bull., vol. 11, pp. 191-220.

SUMMARY.

In conclusion, the principal points brought out by this study may be briefly stated as follows:

The collection of rocks from the Tewan Mountains, New Mexico, though small, shows a gradual transition in mineral composition from rhyolites through andestic rocks to basalts.

The whole series is characterized by a variable amount of porphyritical quartz in rounded grains, which is very noticeable in some of the basalts.

These quartzes are primary secretions or crystallizations from the molten magma, and exhibit no definite relation to its chemical composition, being present in or absent from rocks of similar chemical composition.

Their production is to be referred to certain physical conditions attending some earlier period of the magma's existence.

From analogy with the occurrence of iron olivine in rhyolitic obsidian it seems probable that the formation of primary quartz in basalt took place through the influence of water-vapor while the magma was under considerable pressure.

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