

ART. XX.—*On the Origin of Primary Quartz in Basalt*;†
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A VERY interesting suite of volcanic rocks has recently been collected in the Tewan Mountains, New Mexico, by Major J. W. Powell and Mr. William H Holmes.

The collection, though not a large one, embraces several varieties of rhyolite and obsidian, with numerous forms of andesite and basalt. The whole group constitutes a graduated series of varieties, which range from rhyolite through andesite to basalt, with two slight interruptions, at dacite and olivine-bearing hypersthene-andesite. The general characters of the minerals and of the rocks themselves correspond to those of the volcanic rocks occurring throughout the Great Basin‡ of Utah and Nevada, and of those forming the volcanoes of the Pacific coast,§ and of the Republic of Salvador, C. A.¶

Without entering upon the study of all of these rocks, a description of which will be found in a forthcoming bulletin of the U. S. Geological Survey, it is the intention of the present paper to describe certain specimens of basalt which

* Kohlrausch: Pogg. Ann., cxxviii, p. 419, 1866.

† Read before the Philosophical Society of Washington, April 29, 1888, and published by permission of the Director of the U. S. Geological Survey.

‡ Hague and Iddings, this Journal, vol. xxvii, June, 1884.

§ Ibid., vol. xxvi, Sept., 1883.

¶ Ibid., vol. xxxii, July, 1886.

exhibit a remarkable number of porphyritic grains of quartz and to offer some explanation of its occurrence.

The basalts in question occur in the vicinity of Rio Grande Cañon. Those which form the second and fourth ledges from the top of the wall of the cañon are very much alike; they are light gray, fine grained, dense rocks with small porphyritic crystals. In thin section 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 porphyritic crystals of olivine and augite, and very abundant microscopic needles of apatite.

Seven other specimens of basalt were collected from a large flow, covering the country for four miles; two of them are light gray and dense; three are greenish black and dense; and two are dark red and vesicular. All are very fine grained.

The light gray basalts are somewhat like those forming the two ledges on the cañon wall, but carry more porphyritic olivines, besides abundant, small grains of cracked quartz.

These quartz grains are surrounded by light green shells, which are composed of microscopic augites. In some cases the shells cover the quartz grains on the surface of the rock; in others, especially on weathered surfaces, the quartz has dropped out, leaving the augite shell adhering to the rock. The quartz grains are distributed through the rock quite as uniformly, though not so abundantly as are the crystals of olivine.

In thin section these two specimens of basalt are alike and resemble those from 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 porphyritic crystals. None of the quartz grains appear in the thin sections of these two specimens, 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 macroscopic olivine and abundant quartz grains. The quartz is more compact and freer from cracks than in the previous specimens.

In thin sections, this form of the basalt has the same microstructure as those just described, but is finer grained and contains more augite. The olivine is partly altered to dark green serpentine. In one of these thin sections there are seven grains of quartz or indications of their former presence, in another section two, and in the third there are ten.

The red, vesicular variety also bears many porphyritic grains of quartz. On the surface of one side of a small specimen 7.5^{cm} long by 6^{cm} wide, there are 75 grains, and they are not especially abundant in this particular specimen.

In thin section these red varieties resemble the general microstructure of the gray, compact ones, 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 porphyritic olivines. They contain a little more augite than do the gray varieties. Most of the quartz grains have dropped out in grinding, but fragments remain, and the augite rings indicate where they were once located.

As to the nature of the quartz which forms these porphyritic grains, it is evidently not an alteration product of other minerals nor an infiltration product, for the rocks are quite fresh and exhibit a very slight alteration on the surface of the olivines. On the contrary, the quartz grains undoubtedly 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 enclosing rock-mass.

This augite shell forms a narrow border or ring in thin section, and is composed wholly of crystals of augite radiating from points along the side of the rock-mass toward the quartz. The augite crystals crowd against the surface of the quartz grains, but there is no line of demarcation between them and the rock-mass; the outside augites lie among the feldspar and magnetite individuals and take part in the general structure of the rock. In the coarser grained varieties the feldspars sometimes enclose a number of the augites situated on the outside of the shell, thus demonstrating that the augite shell existed prior to the final consolidation of the rock.

The substance of the quartz composing these grains is perfectly pure, and free from 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 substance. Occasionally two individuals are in juxtaposition. But they are never made up of aggregates of small grains, the form which secondary quartz usually assumes. The grains are rounded or subangular.

The substance and shape of the quartzes are like those of the porphyritic quartz grains in other volcanic rocks when they are free from inclusions, as often happens in rhyolites. They are not like the quartzes of granites and gneisses or of 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 in these basalts are primary constituents of the rock; that they are more like the porphyritic 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, and represent portions of it which differ in crystallization and general habit. Furthermore, 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.

Similar occurrences in other localities.

Mr. J. S. Diller (this Journal, Jan., 1887) has described the occurrence and distribution of very abundant quartz grains throughout the recent basalt flow near the Cinder Cone, ten miles northeast of Lassen's Peak, California. And his argument for the primary and essential nature of the quartz in this particular basalt appears to me to be conclusive.

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

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, and was collected by Mr. Clarence King. In the hand specimen the only porphyritic secretions are rounded grains of glassy quartz from one to eight millimeters in diameter, together with somewhat smaller olivines. The quartz grains are so numerous that one small specimen about 6 cm. square shows as many as 30 grains on all its surfaces.

In thin sections the basalt is glassy, with abundant lath-shaped plagioclase and much red oxide of iron scattered through it, which obscures the other constituents. The ground-mass bears small porphyritic 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 specimens, the olivine has been entirely removed, leaving its

characteristic outlines marked by iron oxide. The augite is more or less reddened.

The quartz is the same in both varieties. 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.

In only a few instances do the quartz grains possess a continuous shell of augite crystals. Most of the grains are bounded 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 shells 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.

The second occurrence to be described is that of a dark colored, fine-grained basalt from Elk Head Creek, at the south-east base of Anita Peak, 15 miles northeast of Hayden, Colorado, in which porphyritic quartz grains are very abundant. Dr. Whitman Cross kindly furnished me with the thin sections of this rock for study and description. They present two modifications of the basalt, and show that the rock is partly altered, the olivines having been converted into serpentine, which is disseminated through the rock. The rock resembles the basalt from the Río Grande cañon, N. M., in mineral composition and structure, but the quartz grains, which are very abundant, have a somewhat different microscopical character. They are surrounded by an augite shell in every case. But the shell is quite thin and its connection with the quartz substance is more intimate. In places the augites penetrate the quartz substance. In some instances the quartz exhibits sharp-edged crystal boundaries. The quartz grain is sometimes made up of two or three individuals crystallized together. The inclusions are numerous and consist of gas cavities and less abundant glass inclusions, besides zircon and apatite. 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 shows that there was little if any resorption of the quartz

by the surrounding magma. The enclosure of augite crystals near the margin of grains containing glass inclusions indicates 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 enclosing shells.

Quartz grains occur in the same manner, but to a much less extent, in some of the basalts near Eureka, Nevada. They are very abundant in certain basaltic rocks from the neighborhood of Crescent and Whitehead Peaks and Camel Mt., Colorado.

Possible origin of the porphyritic quartz.

Exceptional occurrence.—The occurrence of primary quartz in more or less rounded grains in basaltic rocks is exceptional, and contrary to the laws which appear to govern the development of the mineral constituents of volcanic rocks. The minerals developed being the result of the chemical affinities inherent in a complex solution of silica, alumina, with certain alkaline earths and alkalis (mainly iron, lime, magnesia, soda and potash), between the various demands of which there must be a mutual accommodation, it is evident that the resulting minerals must be those which under the conditions attending their crystallization satisfy all the chemical demands imposed by those conditions.

Limited variation of conditions.—That a change in the conditions under which crystallization takes place in a mixed solution affects 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 crystallization are indicated. Where variations in the products of crystallization occur, the conditions effecting them may often be recognized. Hence, variations from the general order and nature of crystallization within certain limits have become generally accepted facts, so that no one expects the mineral composition of rocks to be in rigid accord with their chemical composition within these limits.

An exception emphasizing greater variations.—While in the great majority of cases the mineral composition of volcanic rocks indicates a generally uniform range of conditions 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 must be regarded as physical. An instance of this is the mineral association in the lithophysæ of the rhyolitic obsidian from Obsidian Cliff, Yellowstone National Park, and from Cerro de las Navajas, Mexico. These holocrystalline

portions of the acid lava are composed of alkali-feldspar, quartz, tridymite and fayalite, an iron olivine. The latter mineral is in very small amount compared with the free silica, quartz and tridymite.

Influence of absorbed water.—In a paper on this occurrence (this Journal, xxxiii, Jan., 1887) 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 the experiments of others who have undertaken to produce these minerals artificially, I arrived at the conclusion, that this anomalous association of primary igneous minerals was most probably brought about by aqueo-igneous action, induced by the influence of water vapor absorbed in the molten glass. The strong mineralizing influence of the water vapor under such conditions becoming apparent both in the structure and composition of the lithophysæ and of 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 similar 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 porphyritic secretions 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 is much more 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 from the magma necessary.

Indications of altered physical conditions.—From the rounded form of the quartz grains it is probable that the quartzes were being resorbed by the basic magma when the final solidification of the rock took place.

A similar resorption of porphyritic minerals, which have crystallized in an earlier period of a rock's existence is of common occurrence in nearly all volcanic rocks, as for example, partly resorbed hornblendes and feldspars, and the rounded quartzes of rhyolites and porphyries. And the idea that these phenomena indicate changes in the physical conditions and not

in the chemical composition of the magma is a generally accepted one. What some of these changes of condition probably were may be indicated by the following considerations.

Consideration of possible changes of physical condition.—If we conceive of a molten, viscous magma situated at a great depth beneath the earth's surface, the two factors which at first appear to have the greatest influence on its existence as a plastic or molten magma are *temperature* and *pressure*.

Influence of temperature.—Other things remaining the same, the magma will be more plastic the higher the temperature, and with a decrease of temperature below a certain point consolidation will take place.

Consolidation under these circumstances would undoubtedly produce crystallization, as a rapid chilling at great depths within the earth is scarcely conceivable. However the nature of the crystallization would vary within certain limits with the rate of cooling.

Influence of pressure.—If, now, the temperature remains the same and the pressure varies, assuming that an increase of pressure diminishes the mobility of the molecules of the magma by condensing them, which from a theoretical standpoint appears the most rational supposition, and which has received support from the recent experiments of Dr. Wm. Hallock;* and it having been demonstrated that the silicate minerals† and glasses‡ belong to that class of substances which contract upon solidification, we should expect that an increase of pressure alone would tend to consolidate the mass. This is the conclusion reached by Reyer in his work entitled, "Beitrag zur Physik der Eruptionen und der Eruptiv-Gesteine." Vienna, 1877, p. 119.

Increased viscosity.—Dr. Hallock's observations show that cubical, statical pressure, unaccompanied by heat, simply increases rigidity or viscosity. 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, that is, to reduce its rigidity or viscosity.

The solidification of a glassy, amorphous mass by increasing its viscosity might convert it into a solid glass or 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 by gradual cooling, the latter allowing the molecules to arrange themselves in obedience to certain chemical affini-

* This Journal, October, 1887.

† Roth, Allg. u. Chem. Geol., Bd. II, p. 52.

‡ Lagorio, T. M. P. M., vol. viii, 1887, 510.

ties into crystallized minerals, the former preventing such an arrangement.

Moreover if, as Professor A. Lagorio has done in a recent paper (T. M. P. M., vol. viii, 1887, 421) we consider rock magmas as saturated solutions of silicate salts, and 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, is decreased by increasing pressure; or, in other words, that increasing pressure tends to crystallize such salts from solution; then an increase of pressure alone would induce the crystallization of certain silicate minerals from a molten magma, or might lead to the crystallization of the whole magma.

Unstable consolidation.—According to these views of the effect of pressure on the viscosity of magmas and on their crystallization, we should expect that an increase of pressure would lead to the consolidation of magmas at temperatures above their melting point for lower pressures. And we might therefore have a highly heated magma within the earth under such pressure that it exists as a solid mass, which may be either crystallized or amorphous, or partly crystallized and partly amorphous. Such a condition would be one of unstable consolidation.

Influence of water vapor—Another agent or force undoubtedly plays an important part in the liquefaction as well as in the crystallization of heated magmas. The influence of water vapor on the viscosity of lavas has been suggested long ago by Scrope and others, and of its part as the explosive agent in volcanic eruptions there can be little doubt. Its presence in larger or smaller amounts in almost every volcanic rock has often been demonstrated.

Eutectic substances.—The bearing of Dr. Guthrie's experiments with cryohydrates or eutectic substances upon this problem has been brought out by Professor J. W. Judd in a recent paper. (Geol. Mag., Jan., 1888.) The characteristic feature of these mixed compounds is that their melting point is considerably below that of the component substances; they, therefore, behave like alloys. Most of the substances experimented with were hydrates, of which niter is chosen as an example. Under ordinary conditions this substance melts at 320°C ., upon the addition of 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 temperatures 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. Professor Judd calls attention to the power of the water of hydration to lower the melting point of zeolites and siliceous

glasses, such as tachylites, hydrotachylites, palagonites, etc. Professor Lagorio states that the feldspars of the lime-soda feldspar series behave like eutectic substances.

Increased liquidity of magmas.—The increased fusibility of hydrated glass has been demonstrated by M. Daubrée (*Études Synthétiques de Géologie Expérimentale*. Paris, 1879, p. 161), and may be easily recognized in the case of obsidian carrying 0.5 per cent. of water, like that from Obsidian Cliff. When this is fused before an oxyhydrogen blowpipe it melts 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. After driving off all the water from this glass and allowing it to cool, a colorless glass is obtained which only melts before the same blowpipe flame at an intense white heat, and then forms a very viscous glass which moves sluggishly before the same blowpipe current.

Retarded viscosity and greater crystallization.—If we consider the influence of water-vapor in increasing the liquidity of molten magmas as simply a physical one, it must tend to increase the mobility of the molecules among themselves. One effect of absorbed water, then, would be to retard the increasing viscosity of a rapidly cooling magma, which might permit the crystallization of the more hydrated portions, while the less hydrated parts became too viscous and solidified as glass. A condition of affairs which undoubtedly existed in the obsidian magma at Obsidian Cliff, where holocrystalline areas occur irregularly scattered through glassy ones.

Different kind of crystallization.—It is to be remarked that the crystallization which was in this instance specially induced by the influence of superheated steam, 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 extremes. A result, which is in a measure, analogous to the dissociation of the base and acid of a chemical compound by heating. The absorbed water-vapor apparently weakened the affinity between the bases and the silica and permitted them to separate into more basic silicates and quartz or tridymite.

Potential mobility.—Exactly what influence absorbed water-vapor has upon deeply seated molten magmas we do not know, but it seems reasonable to assume that its physical influence is of the same kind as that upon molten magmas on the surface of the earth, for in the two cases the most noticeable difference is that of the pressure under which each exists. Hence we may assume that its most potent influence lies in the increased mobility, which it tends to impart to the molecules of the mass. But in a confined magma this must be combined with

an increase of pressure against and from the retaining walls, which pressure we have assumed tends to decrease the mobility of the molecules. And of course the actual mobility or liquidity of the magma will depend on the relation between these two tendencies, which, if balanced, will result in the storing up of potential mobility, which would show itself should the pressure be relieved.

Heated, hydrated magma under pressure; unstable rigidity.

—We may then imagine a heated, hydrated magma within the earth under such a pressure that it has become solid, the rigidity being an unstable one; and we may further assume that this solidification is either to an amorphous, glassy mass, or to a more or less crystallized one, that is, to one which is wholly crystallized to an aggregation of minerals, or to one which is made up of crystallized minerals and rigid amorphous material; a glassy, porphyritic mass. Under these conditions the solid magma will possess a potential mobility or liquidity, which will exert itself to melt the solid mass, if the pressure is relieved or lessened, as may happen when the fracturing of the earth's crust ruptures the retaining walls and permits the escape of this pent-up body, stored with gigantic expansive energy.

Refusion.—The melting up of an unstable, solidified mass by the heat inherent in it would undoubtedly proceed differently in the different minerals or the glass composing it, some fusing more rapidly than others. The difference would be the greatest between anhydrous refractory minerals, like quartz, and hydrated glass, through which they might be scattered porphyritically. If the refusion is complete, nothing will remain to indicate a former state of solidification. If the process of fusion is checked by the cooling of the magma in consequence of its eruption through cooler rock masses, there might remain in the cooling magma remnants of the minerals previously existing in it.

Final consolidation.—Moreover it is evident that the nature of the minerals of final consolidation will be affected by the nature and amount of the minerals formed at the time of unstable consolidation which remain unmelted. If these are highly acid the minerals of final consolidation will be proportionately basic, and *vice versa*.

Application to quartz-bearing basalt.—Applying the foregoing general considerations to the occurrence of porphyritic quartz grains in basalts, it seems reasonable to suggest that the production of extremely acid and basic silicate minerals in deep-seated magmas may have been brought about, like their production in certain magmas after they have reached the surface, by the influence of absorbed water acting under favorable conditions of pressure and temperature, which combined to

solidify the magma more or less completely for the time being, but which, as the quartz grains themselves show, was an unstable solidification, which subsequently yielded to the potential liquidity of the magma, resulting in the partial resorption of the quartz crystals before the final consolidation of the rock to its present form.

Reyer, (l. c. p. 166), suggests that pressure and different degrees of saturation with absorbed water may lead to metamorphic processes. And also states that the development of quartz in rock magmas requires a considerable saturation of the magma with water.

Prof. Lagorio (l. c.) refers the concurrence of quartz and olivine in the same rock to the super-saturation of the magma with silica and magnesia, but this idea of itself is not sufficient to account for the occurrence of quartz in magmas with the normal basaltic composition, where it generally does not occur, as it is not sufficient to explain the occurrence of fayalite in rhyolitic obsidian, having 75 per cent of silica and less than 2 per cent of iron oxide.

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 porphyritic 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.

Porphyritic quartz in other volcanic rocks.—The first point is beautifully illustrated in the suite of rocks in the collection from New Mexico, for it shows that similar quartz grains occur in almost all of the varieties of volcanic rocks from this region, and that their occurrence is not uniform throughout the series.

Thus in most of the rhyolites rounded grains of quartz are very abundant, but in some specimens they are absent (obsidian and lithoidite). In the single specimen of mica-andesite they are wanting. In the hornblende-mica-andesites, some specimens show a considerable number of quartzes; one, a few, and others, none. In the hornblende-pyroxene-andesites, one specimen shows many quartz grains; others, considerable; and some, none. Of the five specimens of pyroxene-andesite, one shows a few grains of quartz; the rest, none. And of the twelve specimens of basalt, seven show much quartz; the others, none.

Another group of volcanic rocks, specially characterized by abundant rounded grains of quartz, occurs in the vicinity of Crescent Peak, Colorado. The group embraces basalt, andesite and possibly trachyte. These 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, in which they were partially resorbed.

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 ----	52.27	52.37	51.57	52.38	57.25	56.28
TiO ₂ ----	1.49	1.60	1.43	1.22	0.60	0.84
Al ₂ O ₃ ----	17.68	17.01	17.72	18.79	16.45	14.23
Fe ₂ O ₃ ----	2.51	1.44	6.24	2.88	1.67	4.69
FeO ----	5.00	5.89	1.78	4.90	4.72	4.05
MnO ----	0.23	0.32	0.45	0.18	0.10	0.16
CaO ----	8.39	7.59	8.82	7.70	7.65	7.94
MgO ----	6.05	6.86	4.91	4.91	6.74	6.37
BaO ----	0.06	0.06	0.16	0.11	0.00	----
					SrO tr.	
K ₂ O ----	1.58	1.59	1.99	1.76	1.57	1.23
Na ₂ O ----	4.19	3.51	3.59	3.99	3.00	2.98
Li ₂ O ----	----	----	----	----	0.00	0.01
H ₂ O ----	0.82	1.29	0.64	0.53	0.40	0.93
CO ₂ ----	tr.	0.37	0.58	----	----	----
P ₂ O ₅ ----	----	----	----	0.56	0.20	0.40
Cl ----	tr.	tr.	----	----	----	0.17
SO ₃ ----	----	----	----	----	----	tr.
	<hr/> 100.27	<hr/> 99.90	<hr/> 99.88	<hr/> 99.91	<hr/> 100.35	<hr/> 100.28

- I. Quartz-bearing basalt, Rio Grande Cañon, N. M. (L. G. Eakins.)
 II. " " " " " "
 III. " " " " " "
 IV. Basalt without quartz, " " " "
 V. Quartz-bearing basalt, Cinder Cone, Lassen's Peak, Cal. (W. F. Hillebrand.)
 VI. Quartzose diorite. Electric Pk., Yellowstone 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. The higher oxidation of the iron in the red rock is indicated by the high percentage of ferric oxide in analysis III.

The fourth analysis is of a gray, dense basalt from Rio Grande Cañon, which resembles the basalt from which the first analysis was made, except that it exhibits no quartz, either in macroscopic or microscopic grains. These four are normal basalt analyses resembling one another as closely as analyses of

similar rocks usually do. There are no greater differences between the analysis of the variety without quartz and those of the quartz-bearing varieties than there are between the analyses of the three quartz-bearing varieties. So that the occurrence of the quartz in this instance cannot be ascribed to anything exceptional in the chemical composition of the magma.

Chemical differences between basalts with quartz.—The fifth analysis is that published by Mr. Diller in the paper already cited. It shows a different chemical composition for this form of quartz-bearing basalt, which is more acid than typical basalt, and corresponds more 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 of a basaltic magma having existed at some previous period in a condition of unstable consolidation, 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 and pyroxene, 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. The discussion of this diorite is reserved for another paper, which is in process of preparation.

Summary.

The principal points brought out in this paper may be briefly stated as follows:

The quartz-bearing basalt from Rio Grande Cañon belongs to a series of volcanic rocks, characterized by a variable amount of porphyritic quartz in rounded grains.

These quartzes are primary crystallizations from the molten magma, and exhibit no definite relation to its 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 under the influence of water-vapor at a great pressure.