DEPARTMENT OF THE INTERIOR

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OF THE

UNITED STATES

GEOLOGICAL SURVEY

No. 17

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J. W. POWELL DIRECTOR

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WITH

NOTES ON THE GEOLOGY OF THE DISTRICT

BY

ARNOLD HAGUE AND JOSEPH P. IDDINGS

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., February 16, 1885.

SIR: I have the honor to present herewith a paper by Mr. Joseph P. Iddings and myself, on the development of crystallization in igneous rocks, the result of an investigation of the extensive and well-selected lithological material collected by Mr. George F. Becker during his examination of the Comstock lode.

Many field geologists have maintained that the acidic lavas and pumices occurring on or near the surface would be found changed to granite, if it were possible to trace them downward to great depth. This has been denied, especially of late years, by other equally eminent authorities, who have claimed that geological periods were characterized by crystalline rocks, differing in composition and structural features.

Although much has been written upon the relation between surface flows and deep-seated igneous rocks, the problems have never been solved. Indeed they could not be solved before the application of the searching methods of microscopical research now employed in the study of crystalline rocks. Few localities afford the necessary conditions, and none surpass the Washoe district in furnishing the requisites for a proper investigation of such questions.

So far as I know, the results of no similar investigation showing the gradual transition in crystallization under pressure in continuous rock-masses have ever been published.

As the results of the work lead us to definite conclusions upon some important questions and bear directly upon the geology of the Comstock lode, it seems desirable that they should be published by themselves in a special bulletin as early as possible.

Very respectfully, your obedient servant,

ARNOLD HAGUE,
Geologist.

Hon. J. W. POWELL,
Director United States Geological Survey,
Washington, D. C.

ON THE DEVELOPMENT OF CRYSTALLIZATION IN THE IGNEOUS ROCKS OF WASHOE.

By Arnold Hague and Joseph P. Iddings.

INTRODUCTORY.

The Great Basin of Utah and Nevada, which has been the center of such widespread volcanic activity, presents the greatest possible variety of phenomena connected with the geology of igneous rocks. Within this well-defined area outbursts of lavas occur, forming high, rugged peaks, low, monotonous ridges interspersed with broad tables, extending for such long distances and covering such wide tracts of country as fairly to deserve the title of plateaus. Again, extravasated lavas may be seen as small isolated craters, as massive eruptions breaking out through lines of fissure and faults, and stretching out for miles along the base of the longitudinal ranges, or they may occur in small irregular hills, and occasionally in narrow dikes scattered over the country without any apparent law as to their distribution. Probably most geologists who have studied the region would agree that the country has nowhere been subjected to any extensive erosion since the outbursts of the greater part of these lavas. In consequence nearly all the later extrusions exhibit on the surface much the same features as they presented at the time they were forced upward through the underlying sedimentary strata or older crystalline rocks. While the region is one characterized by lavas of both acidic and basic types, presenting various glassy forms, there occur innumerable rocks showing every variety of microstructure, from nearly pure glass to others not only wholly crystalline but with a decided granitoid structure in the groundmass. The dikes which penetrate the older rocks are found in most cases to show a more crystalline structure than the massive eruptions or surface flows. This is especially the case with basic rocks; and although their connection with larger masses can seldom be traced, the conclusion seems inevitable that they must form portions of the same original magma, crystallized under different conditions. Although there has been collected throughout the area of the Great Basin a large amount of material which pointed in one direction and suggested a common origin and close geological connection between these extreme forms of rock structure, the subject has not been before closely studied, and direct proof of such an identity has been wanting. This is in part owing to the fact that erosion has failed to cut deeply into any great flow showing variations of structure, and in part to the want of sufficient data and material from any one locality upon which a searching mineralogical and microscopical examination could be undertaken, which would afford the necessary proof to warrant the assertion that difference in structure was mainly the result of consolidation under varying degrees of heat and pressure, or an expression of the rate of cooling.

In studying the collections of lavas from the Pacific coast volcanoes[1] we were forcibly impressed with the insensible gradations in the microstructure in the groundmass of rocks of the same mineral composition from a purely glassy form to one wholly crystalline, and corresponding exactly in structure to a fine-grained granite-porphyry. The chain of microscopical evidence seemed so complete that we were convinced that the glassy and crystalline rocks were simply the extreme forms of the same magma, and that a highly crystalline rock brought in for diabase from one of the ravines of Mount Rainier could be nothing less than a crystalline variety of the hypersthene-andesite, which, judging from the collections, makes up the greater part of the volcano.

In seeking a locality in the Great Basin which could afford the necessary conditions for carrying out such an investigation as we desired to make, showing the actual transition from the glassy to the granitic structure, it was readily seen that the Washoe district was the only place offering sufficient material for the work. Indeed, there are few localities in the world presenting conditions which would permit of such an inquiry, and so far as we know the investigation has nowhere been previously undertaken, at least upon material adequate for a satisfactory solution of the problem. For the means of making this investigation we are greatly indebted to Mr. George F. Becker, who placed at our disposal the large lithological collections which he and his assistants had gathered in the course of their field-work preparatory to his report on the geology of the district. Owing to the unprecedented activity in mining which has characterized the district during the twenty-five years of its existence, we are enabled to examine the interior of the mountain by actual sections in a way unsurpassed in any other place. In addition to the magnificent horizontal section, over 4 miles in length, shown by the Sutro tunnel, and numerous vertical sections cut by shafts from 2,000 to 3,000 feet in depth, it is estimated from the official maps and records of the mining surveyors that over 180 miles of galleries and other openings have been run, and although a large part of these galleries pass through quartz and ore-bearing material of the vein many miles of levels in exploring new ground penetrate in every direction the east and west country, laying bare the internal structure of the mountain.

[1] American Journal of Science, Vol. XXVI, September, 1883.

If the Virginia range were split asunder across the center of Mount Davidson it would not be possible to gain a more accurate knowledge of the region than is presented by this net-work of underground explorations. In the former case we should get a section of the mountain down to the level of the surrounding plain, but now we have, by means of the many deep shafts, a knowledge of the lower rocks many hundred feet below the level of the Carson Desert. And instead of a section cut on a vertical plane we have a mountain honeycombed in every direction by the untiring miner in search after bonanzas. Thus no natural section could surpass it for purposes of studying internal rock structure at great depths.

A mining region which has proved of such vast economic importance as the Comstock lode has necessarily excited intense geological interest, and owing to the great liberality of the National Government, scientific investigation of the district has gone on, with brief intervals of a few years, almost simultaneously with the exploitation of the precious metals. The amount of geological literature on the district which has been published is by no means inconsiderable, and a very large share of the space in the reports has been devoted to a consideration of the igneous rocks.

A brief summary of the results obtained by the more important investigators, including those of Baron von Richthofen,[2] Mr. Clarence King,[3] Prof. Ferdinand Zirkel,[4] and Dr. John A. Church,[5] is given by Mr. Becker in his elaborate work on the Geology of the Comstock Lode, recently issued. Since the publication of von Richthofen's report, nearly twenty years ago, followed quickly by his monograph on The Natural System of Volcanic Rocks, the knowledge of crystalline rocks has advanced with rapid strides, and the science of microscopical petrography has been almost wholly developed. In this advancement the study of the Tertiary volcanic rocks of the Washoe district has played a conspicuous part. In selecting, then, this district for the special purpose of this work, we have been guided by the knowledge that the principal geological features of the region are within the reach of all students of petrography. The results of our investigation, undertaken merely as incidental to a study of the volcanic rocks of the Great Basin, have proved so much more satisfactory and convincing than we were at first led to hope that we have no hesitancy in publishing them at this time. Moreover, the geological conclusions reached from the study of the lithological material are in many ways so diametrically opposed to those of our predecessors that we offer no apology for adding another

[2] The Comstock Lode, etc. Ferdinand von Richthofen. San Francisco, 1868.

[3] United States Geological Exploration of the Fortieth Parallel, Vol. III. "Mining Industry." Clarence King. Washington, 1870.

[4] *Id.*, Vol. VI, "Microscopical Petrography." Ferdinand Zirkel. Washington, 1876.

[5] The Comstock Lode, etc. John A. Church. New York, 1879.

brief paper to the many already published on the geology of the Washoe district.

Mr. Becker, in agreement with his predecessors, divided the igneous rocks of Washoe into Tertiary and Pre-Tertiary species, differing with them widely, however, as to where the lines should be drawn, and adding one or two more varieties of Pre-Tertiary rocks to those already recognized. His work possesses the very great advantage over the labors of those who preceded him, in that not only the Suttro tunnel, but all the deeper shafts and galleries were accessible to him, a large amount of ground having been opened since the earlier geological investigations were made. This recent material is of great value. The rocks obtained from these lower workings, when subjected to microscopical examination, so closely resemble in structure the so-called Pre-Tertiary types, that Mr. Becker extended the domain of the "older" rocks over a considerable area at great depths below the surface. This same material from the deep-seated localities affords, it seems to us, abundant evidence that the so-called Pre-Tertiary and the Tertiary rocks pass by insensible gradations into one another, and that evidence of a difference in geological age is wholly wanting.

Mr. Becker classified the rocks under the following heads: Granular diorite, porphyritic diorite, micaceous diorite-porphyry, quartz-porphyry, earlier diabase, later diabase, earlier hornblende-andesite, augite-andesite, later hornblende-andesite, basalt.

Representing these rocks from all parts of the Washoe district, we have had placed at our disposal more than two thousand hand specimens, six hundred from the surface, and over fourteen hundred from underground. From this collection there are now more than five hundred thin sections, including a number recently prepared to fill up certain gaps in the chain of our argument. Of these specimens those from underground, with the exception of the Sutro tunnel rocks, were collected mainly within the immediate neighborhood of the Comstock lode, while the surface specimens are confined to an area about 5 by 7 miles in extent.

Let us begin our analytical work by submitting the rocks to a searching microscopical and macroscopical scrutiny, to show what points of agreement exist between the so-called Pre-Tertiary and Tertiary eruptions, comparing rocks of the same mineral composition with each other.

DIABASE AND AUGITE-ANDESITE.

In considering the relation between these closely related rocks we will first make a comparative study of the thin sections prepared from both series. In the collection there are about one hundred and forty thin sections determined as unquestionably diabase or augite-andesite, and of these about twenty from each have undergone too much decomposition to allow of a satisfactory study of their feldspars, although they evidently agree in general characters with the fresher sections of the same class of rocks. Of the remaining one hundred thin sections forty were classed as diabase and sixty as augite-andesite.

Upon examining them somewhat hastily under the microscope two points are brought out in the most impressive manner. The first is the absolute identity in the nature and occurrence of the mineral constituents of the two rocks, and the impossibility of distinguishing many of those classed under one head from those classed under the other; the second is the gradual transition from a microlitic glassy groundmass to one holocrystalline, and from a microcrystalline groundmass of the minutest grain to one in which even the smallest grains are recognizable in thin section with the aid of an ordinary pocket lens. In studying them they may be arranged under eleven heads, according to the size and development of the grains of their groundmass, placing those with glass base at one end and those of the coarsest grain at the other. The different grades of crystallization may be stated approximately as follows:

1. *Groundmass* consisting of colorless glass, through which are scattered relatively few microlites of feldspar and pyroxene, and magnetite grains with contorted trichites. *Porphyritic crystals*, abundant plagioclase varying from 3^{mm}. long to very small size, averaging 1 or 2^{mm} long; pyroxene crystals less numerous. Example, thin section 50.

2. *Groundmass* of colorless or light-brown glass crowded with microlites of feldspar and pyroxene, and magnetite grains, showing a typical "felt-like" structure. *Porphyritic crystals* the same as in grade 1. Examples, thin sections 239, 426.

3. *Groundmass*, holocrystalline, composed of feldspar microlites, and indistinct grains about $.005^{mm}$ in diameter, with grains of pyroxene and magnetite. *Porphyritic crystals* as in grade 1. Example, thin section 422.

4. *Groundmass*, holocrystalline, composed of feldspar microlites and grains of pyroxene and magnetite, the cementing material being crystallized in irregular patches with uniform orientation for the space of about $.03^{mm}$. *Porphyritic crystals* as in grade 1. Examples, thin sections 121, 122.

5. *Groundmass*, holocrystalline, the same structure as in grade 4; but the indistinct patches about $.05^{mm}$ in diameter, though not of uniform size throughout the thin section. The feldspar microlites measure about $.02^{mm}$ long. It is sometimes composed of grains from .01 to $.02^{mm}$ in length with feldspar microlites. *Porphyritic crystals* as in grade 1. Examples, thin sections 35, 420.

6. *Groundmass*, holocrystalline, the same structure as in grade 5; the patches averaging as high as $.1^{mm}$, full of feldspar grains $.01^{mm}$ in diameter and feldspar microlites $.05^{mm}$ long by $.01^{mm}$ wide. *Porphyritic*

crystals, abundant plagioclase varying in different thin sections from an average of 1.5^{mm} to 2.5^{mm}; pyroxene as in the preceding. Examples, thin sections 125, 389.

7. *Groundmass*, holocrystalline, composed of feldspar microlites about 0.1^{mm} long with granitoid grains of feldspar and quartz from .01^{mm} to .04^{mm} in size, together with grains of pyroxene and magnetite. *Porphyritic crystals*, plagioclase average about 2.5^{mm}, and begin to lose the sharpness of their outline. The same is true for the outline of the pyroxene sections. Examples, thin sections 169, 441.

8. *Groundmass*, holocrystalline, composed of granitoid grains of feldspar and quartz about .06^{mm} in diameter, and lath-shaped plagioclase, in variable proportions, besides pyroxene and magnetite. *Porphyritic crystals*, plagioclase 2.5^{mm} and smaller; the outlines of some rather indistinct; pyroxene as in grade 7. Examples, thin sections 53, 173.

9. *Groundmass*, holocrystalline, granitoid grains of about 0.1^{mm} and ill-defined lath-shaped plagioclase. *Porphyritic crystals*, plagioclase of 3^{mm} and smaller, some with very irregular border; pyroxene as in grades 7 and 8. Example, thin section 215.

10. *Groundmass*, holocrystalline, granitoid grains, about 0.1^{mm} in size, with porphyritic crystals nearly equaling the groundmass in amount. *Porphyritic crystals*, plagioclase 3.5^{mm} and smaller; pyroxene showing little change. Example, thin section 55.

11. *Groundmass*, holocrystalline, composed of plagioclase feldspar of 1.5^{mm} and smaller, with fewer granitoid grains of about 0.1^{mm}. In places it shows fine pegmatoid structure, formed of quartz and plagioclase, surrounding plagioclase crystals. *Porphyritic crystals*, plagioclase 3^{mm} long; the sharply-defined zonal structure of the main mass of the crystal surrounded by a poorly-defined border of feldspar, which loses itself among the adjacent grains; pyroxene, sometimes in well-defined, frequently in irregular-formed, crystals. Example, thin section 213.[6]

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[6]Agreeing with Professor Rosenbusch in general as to the origin of granular and porphyritic Structures in eruptive rocks; "Ueber das Wesen der körnigen und porphyrischen Structur bei Massengesteinen" in Neues Jahrbuch, 1882, II Band. We would briefly define the structural terms used throughout this paper as follows:

Granular.—The structure presented by an aggregation of grains of nearly the same size, or an aggregation in which there is a range in the size of grain, but with such a gradual transition that no particular individual stands out from the others in strong contrast.

Granitoid.—A structure in which the grains have an irregular form, produced by the mutual interference of adjacent crystals during their growth. The structure common to normal granites.

Porphyritic.—The structure which is produced when more or less well-defined crystals are imbedded in a groundmass, which is either glassy or holocrystalline, composed of crystals or grains of much smaller size than the imbedded crystals.

Pegmatoid.—The structure produced by the intergrowth of two or more minerals, usually quartz and feldspar, in such a manner that when seen in thin section they

In other words, we see that the porphyritic crystals show but slight modification in the different grades, the sharp outlines of the feldspars and pyroxenes being lost as the grains in the groundmass become larger, the nature of the inclusions in the feldspars also varying, as noticed further on. The essential variation takes place in the groundmass, which starting with a glass bearing few microlites, grows richer in them, then crowded until a very small amount of glass remains as a cementing base. This may be crystallized in microscopically cryptocrystalline particles, whose mineral composition is not determinable. As the size of the grain increases the cementing material assumes the appearance of uniformly oriented patches which, with increasing grain, are found to be in part quartz. In the higher grades the microlites have larger dimensions, and the cementing grains a granitoid form with or without pegmatoid structure.

In the highest grade (macroscopically a fine-grained porphyritic rock) it is difficult to draw any line between porphyritic crystals and groundmass, the more or less well-defined feldspars ranging from 3^{mm} in length to the size of the average granitoid grains of feldspar and quartz.

It is interesting to notice the appearance of a small amount of quartz as the last crystallizing mineral in the coarser-grained varieties of this pyroxene rock. It corresponds to the free silica, which remains after calculating the theoretical mineral composition from the chemical analyses of this rock, the excess being from 3 to 6 per cent.

Though the difference in the degree of crystallization between any two divisions of the scale is so slight, yet it represents more than actually exists, for the forms pass by imperceptible gradations into one another. If now the thin sections of both rocks are arranged according to this classification in columns as shown in Table I, we get at a glance some very striking results.

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appear as groups of grains of more or less regular form, each group having one optical orientation throughout. It is similar to the structure in graphic granite.

Granophyre.—The variety of pegmatoid structure in which the intergrown minerals are arranged in radiating, plumose or feather-like forms.

Microcrystalline.—An aggregation of crystalline grains which can only be recognized as such by the aid of the microscope. This includes many rocks which would be macroscopically cryptocrystalline, aphanitic, or lithoidal.

Microcryptocrystalline.—An aggregate of crystalline particles so small that the highest magnifying power fails to resolve them into individual grains.

TABLE I.—*Grades of crystallization.*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Augite-andesite	......	......	......	499	......	......	......	......	......	......	......
	......	......	.....	377	465	......	......	......	......	......	......
	......	......	......	322	447	......	......	......	......	......	......
	......	......	......	318	440	......	......	......	......	......	......
	......	......	......	243	323	......	......	......	......	......	......
	......	......	......	187	321	......	......	......	......	......	......
	......	......	......	186	315	......	......	......	......	......	......
	......	......	......	184	296	......	......	......	......	......	......
	......	......	......	147	180	378	......	......	......	......	......
	......	......	......	140	178	181	......	......	......	......	......
	......	428	453	122	177	175	......	......	......	......	......
	......	426	422	74	143	125	......	......	......	......	......
	......	239	316	62	44	124	......	......	......	......	......
	......	45	138	39	42	69	......	......	......	......	......
	......	43	137	33	36	38	158	173	......	......	......
	50	37	41	32	35	31	441	72	......	......	......
Diabase	......	......	......	115	308	16	15	1	14	55	27
	......	......	......	121	344	114	18	53	215	......	280
	......	......	......	338	346	341	54	349	348	......	......
	......	......	......	374	365	357	77	433	......	......	......
	......	......	......	410	405	389	169	......	......	......	......
	......	......	......	......	420	......	312	......	......	......	......
	......	......	......	......	276	......	336	......	......	......	......
	......	......	......	.....	......	......	339	......	......	......	......
	......	......	......	......	......	......	340	......	......	......	......
	......	......	......	......	......	......	350	......	......	......	......
	......	......	......	......	......	......	386	......	......	......	......

The numbers in this and the following tables refer to the thin sections in the Washoe collection.

It appears that the coarsest-grained rocks with a well-defined granular structure are found only in the so-called diabase, while the extreme forms of andesite, as seen in column 8, show a tendency to a development of the same structure. On the other hand, the glassy and cryptocrystalline varieties are confined exclusively to the andesites. Moreover, the rocks of medium grain include much the larger number of thin sections from both series, the greater part of the diabase showing a coarser structure than most of the andesites, with, however, only a difference of about .02^{mm} in the size of grain. Now, each of the five grades (4 to 8 inclusive) for one rock has its exact counterpart in the other in size and shape of grain and structure of groundmass. On comparing the thin sections it becomes apparent that not only is the groundmass in each rock absolutely the same, but the porphyritic crystals are identical, giving the same results to every possible test that can be applied. They consist of the same species of triclinic feldspar, pyroxene, and occasional hornblende. The feldspars in rocks of corresponding grade present the same outlines, striations, similar extinction angles, zonal structure, and the same amount and character of inclusions. So much stress has been laid upon the nature of the inclusions in the feldspars[7] that an exhaustive study was made of them, comparing thin sections from rocks of the same degree of crystallization without discovering any difference. In each thin section the individual feldspars exhibit great diversity in the nature and amount of their inclusions, some bearing scattered rectangular glass bodies, others abundant smaller ones

[7] Geology of the Comstock Lode, page 50.

with rounded outlines, others being rich in grains of pyroxene and magnetite, others, again, combining all three, or, what is by no means uncommon, being nearly free from all inclusions. Fluid inclusions which might be considered primary are scarce in the medium-grained rocks, but were not found more abundantly in the "diabase" than in the andesite. As might be supposed, glass inclusions in the feldspars are more numerous in the glassy and fine-grained rocks, but upon careful search they may be observed in every thin section of the "diabase," from the finest to the coarsest. No line of demarcation can be drawn between these rocks based upon the glass-inclusions in their feldspars. In general, however, it may be said that the number of glass-inclusions decreases with increase in the degree of crystallization. In other words, they are a function of crystallization. This includes all thin sections given in the table, those in which the feldspars are clouded by decomposition being unfit for such a study. The fresh pyroxene consists of the same hypersthene and augite in both rocks, the hypersthene equaling or exceeding the augite in amount, and being the first to yield to decomposition.

Owing to the number of thin sections from these rocks and their various degrees of alteration, it is easy to trace the decomposition of hypersthene through all its stages, the augite in the same section remaining intact.[8]

This investigation leads then to the conclusion that in the thin sections of both rocks of the same degree of crystallization not only is the composition and structure of the groundmass identical, but that the relative abundance, size, and character of the porphyritic crystals scattered through this groundmass are the same.

Arranging now the hand specimens from which the thin sections were prepared in rows with the diabase and augite-andesite of the same degree of crystallization opposite each other, their macroscopic characters are seen to be identical. They agree in color, texture, fracture, and porphyritic crystals. Variations in one rock arising from stage of decomposition and amount and size of porphyritic secretions find their exact counterpart in the other. The conclusion then is inevitable that the greater part of the diabase is identical microscopically and macroscopically with the greater part of the augite-andesite and presents the transition between the glassy forms at one extreme and the coarsely crystalline forms at the other, and further, that the presence of a large percentage of hypersthene removes these rocks from the type of augite-andesite, properly so called, and places them under the head of pyroxene-andesite.

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[8]Notes on the Volcanic Rocks of the Great Basin, American Journal of Science, June, 1884.

SUTRO TUNNEL SECTION.

Having carefully examined all the specimens in the collection classed as diabase and augite-andesite, and shown that they belong to identical rock masses, let us now take up and study step by step the transition which occurs in a continuous rock mass along a definite line. For this work the Sutro tunnel, constructed for the purpose of draining the Comstock lode, furnishes an exceptionally fine geological section through 20,400 feet, or nearly 4 miles, of igneous rocks lying east of the vein. The tunnel enters near the lower foot-hills in Carson Valley, and runs a little north of west, approximately at right angles to the course of the vein and trend of the range, and directly toward Mount Davidson, the highest and largest mass of the mountain group. Probably few lines could have been selected more advantageously situated for exhibiting the structure of the region. A collection of two hundred and seventy specimens, carefully selected at intervals of 100 feet and less, together with their numerous thin sections studied in connection with the surface rocks immediately above ground, shows clearly the different kinds of rock which the tunnel penetrates and their variations in structure.

Referring to Sheet VI of the Atlas[9] we observe that, starting from the mouth, the tunnel, according to Mr. Becker, passes through later hornblende-andesites with occasional masses of older augite-andesite, and at 10,000 feet enters the main body of the latter rock. Thin sections from about this point show it to be holocrystalline, of the grades 4, 5, and 6. The rocks for the next 2,000 feet are much decomposed, many of them full of pyrite. Between 11,400 and 11,700 feet occurs a dike of dense white rock, resembling a broad dike met with further in the tunnel. From 12,000 to 13,700 feet the andesites show more or less alteration, the porphyritic crystals being small, and the iron magnesia silicates indeterminable in the hand specimens. Of the five rocks in this part of the tunnel, of which we have thin sections, four carry hornblende associated with pyroxene, two showing a large amount of the former. At 13,700 feet a dike of quartz-bearing hornblende-pyroxene rock is met with possessing quite a different groundmass structure from that of the andesite through which it cuts. Between 13,800 and 13,900 feet another white dike occurs like that already mentioned, followed by a hornblende-pyroxene rock of coarse grain (grade 8). Here the tunnel cuts a dike 1,400 feet in width of a dense white rock carrying relatively few porphyritic crystals of feldspar and still less mica, but without hornblende or pyroxene, and having a groundmass-structure wholly unlike any found in the andesites. In the Sutro tunnel section this rock is indicated by lines of shading denoting solfataric action, but it is quite evident that it is younger than the andesite, as it is found penetrating it. The rock in every way corre-

[9] Geology of the Comstock Lode. Atlas, Sheet VI.

sponds in structure to the so-called felsitic quartz-porphyry from the surface near Roux's ranch and the Red Jacket mine.

Following this dike of white rock the next 1,000 feet of the tunnel cuts through augite-andesite, the nine thin sections of which range in grades of crystallization from four to seven, three showing hornblende. At 17,100 feet a characteristeric rock is met, rich in fresh, brown hornblende, and having the same microstructure as the andesites previously observed (grade 7), yet so much less altered than the surrounding rocks on both sides that it seems evident that it occurs here as a dike. According to the published map section, however, there begins here a continuous body 1,500 feet in width of hornblende-andesite, but the hand specimens studied macroscopically show it to correspond in every particular to the augite-andesite; and of the eleven thin sections from this body, with the exception of the fresh rock above noticed, only two show small amounts of hornblende, the remaining eight not carrying any that could be definitely determined. They range in crystallization from grades 5 to 8 eight, and have the same microscopical character as the augite-andesite to the east. It appears to be cut in three places by mica-hornblende rocks differing essentially from the surrounding andesite, and corresponding in microstructure and mineral composition to the so-called mica-diorite from the head of Ophir Ravine (thin section 459). Referring again to Sheet VI, it will be seen that the tunnel after passing through the body represented as hornblende-andesite enters the diabase. Again, hand specimens from several hundred feet upon each side of the supposed line of contact are indistinguishable from one another, and the thin sections show identical structure and the same degree of crystallization.

Examining now the twenty-seven thin sections from the diabase cut by the main tunnel and the north and south branches,[10] the first of which is 4,400 feet, and the second 4,000 feet in length, they are seen to vary in degree of crystallization (with one marked exception) from grades 5 to 10, averaging 8, or two grades higher than the average of augite-andesite. In the hanging wall west of the Savage mine connection the tunnel goes through diabase, and again also west of the vein, then passing through diorite it again cuts diabase 180 feet west of the Savage connection, and at the end encounters a mica-diorite like that observed further to the east. An examination of the thin sections recently made from the diorite showed in one case that the iron magnesia silicates, now completely altered to chlorite, were pyroxene and not hornblende, and in the other two cases, while their original nature is not determinable, the microstructure of the rocks is the same as that of the most crystalline diabase.

Let us reject for the present the thin sections which represent the dikes or later intrusions cutting through the main rock mass, and place

[10] Geology of the Comstock Lode. Atlas, Sheets VIII and IX.

the others in columns (Table II) according to the scale of crystallization, already adopted, arranging them in the order in which they occur in proceeding from the mouth to the head of the tunnel.

TABLE II.—*Grades of crystallization.*

	Distance from mouth of tunnel.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Augite-andesite	41			138								
	49				140							
	54					141						
	403					144						
	1,400					315						
	2,500			316								
	5,234				318							
	9,761				32							
	9,800					321						
	9,971				33							
	10,000				147							
	10,055						31					
	12,000						149					
	12,300			151								
	12,500				153							
	12,600				154							
	13,700						95					
	14,090								72			
	15,680						69					
	16.066					71						
	16,384				74							
	16,700				322							
	16,758					34						
	16,800					323						
	(?)16,884							158				
	16,921					324						
	16,921					63						
	17,000					325						
Hornblende-andesite	17,100							326				
	17,300								327			
	17,500					328						
	17,600						290					
	17,700					329						
	18,100					330						
	18,300					331						
	18,500								332			
	18,600							333				
	18,700								334			
	19,000						335					
Diabase	19,155								22			
	19,200								53			
	19,464							77				
	19,540							79				
	19,700							80				
	19,805							15				
	19,910							18				
	*19,910									14		
	19,971							169				
	20,100							336				
Diorite	(†)									508		
	20,120								506			
	20,160									507		
Diabase	South branch.							337				
				338								
								339				
								54				
								340				
							341					
							342					
							343					
						344						
								345				
						346						
	North branch.						16					
								350				
										348		
									17			
							347					
											55	

* Hanging wall of Savage. † Lode limit Savage.

The important points clearly brought out by the table are, first, that there is in general a gradual increase in the degree of crystallization of the rock from the outer foot-hills as the tunnel approaches the central core of Mount Davidson; second, that while the rocks classed as augite-andesite occur more at the lower end of the scale, and the diabase at the other, by far the greater part of both rocks overlap each other in the intermediate columns, and are indistinguishable from one another. The glassy forms of pyroxene-andesite, abundant enough on the surface, are unknown in the tunnel. It is worthy of note that as the north branch approaches Mount Davidson there is exhibited a tendency toward a coarser crystallization, while on the other hand the south branch, as it turns away from the central mass, indicates an equally strong tendency to a finer-grained structure

GRANULAR DIORITE

Reference has been made in the text and in Table II to the diorite at the head of the Sutro tunnel upon the west side of the Comstock lode, which we have placed with the pyroxene rocks. This rock, classed by Mr. Becker as granular diorite, forms the east front of Mount Davidson and presents the most conspicuous topographical feature in the district. Of the three specimens of granular diorite from Mount Davidson having thin sections only one (213) was originally determined as unquestionably diorite, the others being left doubtful. Thin sections recently prepared from three typical localities, namely, the summit of Mount Davidson (488), Ophir Ravine (489), and the Sutro tunnel (507 and 508), show that they are identical with those previously examined. Moreover, they agree in every particular of microstructure and mineral character with the coarsest-grained pyroxene rock found to the east of the vein from the north branch of the Sutro tunnel (55) and the C. and C. shaft (27).

The light-green, fibrous hornblende shows its uralitic nature by having the characteristic eight-sided outline of pyroxene in cross-section. Both the diabase from Ophir Ravine (216) and the diorite from the Savage mine (463) show the transition of the pyroxene into fibrous hornblende. While both rocks are at present hornblendic, it is evident that their hornblende is for the most part secondary, and that they are coarsely crystalline pyroxene rocks with the hypersthene and augite altered to uralite.[11]

The identity of the granular diorite with the coarse-grained diabase

[11] The diorite from Ophir Ravine (40th Parallel Collection, No. 22620, thin section 157) shows both uralitic hornblende and fibrous hornblende, which appears to have resulted from primary hornblende. Some of the plagioclase bears minute glass inclusions; the groundmass shows fine pegmatoid structure.

is well brought out on comparing thin sections 507, 508, 488, 489, 213, 214, 360, and 463 of the former with 14, 280, 215, 216, 27, and 55 of the latter; also on comparing hand specimens 109, 215, 303, 567, 568, and 1125 with 307, 264, and 364.

The difficulty of distinguishing between these rocks seems to have been realized by Mr. Becker, for he admits that the gray granular diroite may be mistaken for granular diabase;[12] and again, in speaking of the locality in Ophir Ravine,[13] says: "This bears a very strong outward resemblance to a granular diorite, and it seems impossible to make out a sharp contact between the two rocks. I am by no means sure that it should not be regarded as a local modification of diorite rather than an independent eruption."

PORPHYRITIC DIORITE AND EARLIER HORNBLENDE-ANDESITE.

If we arrange the surface specimens on a table as nearly as possible in accordance with their relative positions on the map, we are at once impressed with the similarity between those labeled diorite and many classed as andesites and with the difficulty of establishing any line of demarcation between the two rocks. Another remarkable fact is the gradual transition from the most crystalline forms of which Mount Davidson is chiefly made up, outward as from a center to less crystalline and glassy varieties.

It soon becomes evident, upon a cursory examination carried on in the same manner as in the study of the proxene rocks that the different varieties of porphyritic diorites have as to macroscopical habitus their exact counterparts among the earlier hornblende-andesites. The following surface specimens may be cited for the purpose of comparison:

Diorite.		*Hornblende-andesite.*
481	like	157.
478, 474	"	493.
125	"	439.
483	"	211, 78, 528, 531.
482	"	213.
306	"	116.
449, 312	"	486, 487.
185, 477, 41	"	225, 184, 158.
59, 479, 42, 40	"	217.
558	"	494, 532, 536.

Every variety is here represented; there may be found those with large porphyritic crystals, and those with very small ones, ranging from much-decomposed to quite fresh forms. They agree in texture and color of groundmass, in character of fracture and mode of weathering,

[12] *Loc. cit.*, p. 39. [13] *Loc. cit.*, p. 197.

and in size and relative abundance of porphyritic crystals. In a word, by every macroscopical test that can be applied they are indistinguishable in the hand-specimens. Taking up now the sixty thin sections representing the surface collection of both these rocks and subjecting them to the same comparative microscopical scrutiny applied to the pyroxene rocks, they still fail to present any distinguishing features. The groundmass of the porphyritic diorites varies from cryptocrystalline to microcrystalline, formed sometimes wholly of lath-shaped microlites, others having a granular structure with microscopic feldspars scattered through it. Now, for every variety of groundmass among the porphyritic diorites from the surface there can be found among the andesites identical rocks of the same degree of crystallization, corresponding in structure, size of grain, and mineral composition. The same identity holds good for the porphyritic crystals; the feldspars show the same inclusions, and the hornblendes and pyroxenes present precisely similar characters in both rocks. Quite in accordance with the observations upon the pyroxene-andesites there are a few hornblende-andesite sections which show glass in the groundmass, and at the same time a corresponding increase in the amount of glass-inclusions in the feldspars, but by far the greater number of rocks represented are holocrystalline.

MICA-DIORITE AND LATER HORNBLENDE-ANDESITE.

The rocks classed by Mr. Becker as later hornblende-andesite[14] we prefer to call hornblende-mica-andesite, for the reasons that they are characterized in distinction from the earlier hornblende-andesite by an abundance of mica as an essential ingredient, and are at the same time more acidic in composition; and while the name later hornblende-andesite answers well enough for the Washoe district, it is hardly applicable in other regions of the Great Basin where these rocks frequently occur, forming large extrusions without any association on the surface with earlier hornblende-andesite. The specimens in the collection vary greatly in the abundance and size of porphyritic crystals, in texture and color of groundmass, as well as in the relative proportions borne by the constituent minerals to one another. This variation in habitus is greater than in either hornblende or pyroxene andesite. The mineralogical features and diversity of habitus have been well described by Mr. Becker in his monograph.

The mica diorites are few in number and represent comparatively small masses scattered over the surface or exposed by the underground workings of the mines. Nevertheless when considered in connection

[14] These rocks are the "trachytes" of Baron von Richthofen, Mr. Clarence King, and Prof. Zirkel. Mr. Becker has shown that according to the modern classification now generally adopted by lithologists they belong to the andesite group.

with the other mica bearing diorites in the collection they form a much larger class, presenting an equally varied structure and composition, and for each variation, with the exception of the more crystalline forms, the exact counterpart may be found among the later hornblende-andesites. By placing the corresponding forms in parallel rows, as in the case of the diorites and earlier hornblende-andesites, it is found quite impossible to distinguish them, the great variation in macroscopical appearance bringing out all the more forcibly the absolute identity of the two rocks.[15]

The thin sections clearly show the same correspondence in minute structure, although a thorough comparative study is not always possible, as the sections from the mica-bearing diorites are mainly from underground specimens exhibiting more or less decomposition, while those from the later horneblende-andesites are for the most part fresh. The only thin section (No. 101, 1,000 feet from the Silver Hill mine) of the fine grained mica-diorites in which the feldspars still remain unattacked exhibits glass inclusions in the fresh feldspars, and in the relatively coarse-grained varieties (grades 8, 9, 10) they may be seen in profusion, while they are almost wholly wanting in those of the coarsest grain (grades 12, 13, 14) which abound in liquid inclusions, as might be sup-

[15] The following table represents the numbers of the hand specimens of the two rocks which correspond each to each:

Later hornblende-andesite.	Mica-bearing diorite.	
From Sutro tunnel collection.	*From surface collection.*	*From mining collection.*
7	505	
10, 11, 12	561	
29, 30		548, 821, 827, 755
31		867, 1459
32		804
33		764
34	563	
36	156	
43	556	
45, 112	554, 555	
75	557	
79	553	
84		578
90, 91		456
100		455
103	560	
105		802, 808 (*b*)
114		803, 1407
117		806, 807
118		458
From surfacc collection.		
26	11	
79		809 (*b*) 810 (*b*)
92	448, 475	388, 859, 1331
97		462
101	564	
103	159	
291	107, 550	1417, 1420
292	552	
293		805
302	562	405, 1247, 1271

posed. In this series of rocks also we see that the range from glass to liquid inclusions varies with the degree of crystallization, as already shown.

These last three grades of crystallization have the following characteristics, it being borne in mind that the iron magnesia silicates in the series in question differ from those of the series described on pages 13 and 14.

Grade 12.—More or less well-defined crystals of plagioclase, 3.5^{mm} and smaller, with very irregular patches of mica and hornblende, in a groundmass of most irregularly shaped, interlocking grains of feldspar and quartz, which range from 1.8^{mm} to 0.6^{mm} in diameter. Example, thin section 291.

Grade 13.—The average size of the granitoid grains somewhat larger than in grade 12, and exceeding in many cases the size of the better outlined crystals. Example, thin section 460.

Grade 14.—A thoroughly granitoid structure to all the mineral constituents, which range in size from 3.5^{mm} to others quite small, the greater part of them averaging as high as 1.5^{mm}. Example, thin section 268.

Arranging the thin sections according to their degree of crystallization (Table III), the scale adopted being approximately the same as that given in the table for the pyroxene rocks, the relation of the later hornblende-andesites to the mica-bearing diorites will be seen at a glance:

TABLE III.—*Grades of crystallization.*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Later hornblende-andesite.		483												
		478												
		477	475	471										
		476	470	467										
		474	320	390										
		472	319	75										
		48	317	66	375	397								
		47	59	65	230	70								
		46	51	64	49	67								
Mica-bearing diorite.				86	101	252		265	247	300		291	460	85
				91	119	398				429				96
				446	194	402								268
				172	195	411								
					197	443								
					200	160								
					203									
					205									
					399									
					412									
					444									
					459									
					159									
					162									

The extreme glassy form represented in the table of pyroxene rocks does not happen to occur among the thin sections of later hornblende-andesite, but a large proportion of them represent a glassy groundmass crowded with microlites, while all of them belong at one end of the series. On the other hand all of the so-called mica-diorites possess a holocrystalline groundmass, range from finely microcrystalline to a macrogranular or granitoid structure, in which the smallest grains are visible to the naked eye. They reach a somewhat coarser grain than was recognized among the pyroxene rocks, the scale being extended from eleven, in Table I, to fourteen grades. As indicated in the table, the three highest grades of the andesite correspond to the three lowest of the diorite and are identical with them in microscopical detail. Moreover more than one-half the thin sections examined fall within these three grades. A separation of the two rocks from a petrographic standpoint seems to us quite impossible.[16]

QUARTZ-PORPHYRY, DACITE AND RHYOLITE.

Baron von Richthofen, in his study of the Washoe district, evidently paid but little attention to these rocks and dismissed them with brief mention, regarding them as of slight importance in questions bearing upon the geology of the vein. He considered them, however, as earlier than the Tertiary volcanic lavas. Mr. Clarence King, after careful examination of the field, referred them upon geological evidence to the Tertiary series, and Professor Zirkel, after a microscopical examination of the thin sections, determined them as belonging to both dacite and rhyolite. The results of Mr. Becker's investigation led him to the conclusion that the absolute uniformity of the rock masses precluded their separation into Tertiary and Pre-Tertiary eruptions, while geological observation and an examination under the microscope of certain specimens, following the same methods of reasoning as adopted for other rocks, induced him to agree with von Richthofen as to their age. From our own knowledge of the district[17] and close study of the specimens and thin sections we have arrived at the conclusion reached by Mr. King as to the age of this series of rocks, and agree with Professor Zirkel as to their specific determinations.

Omitting for the present the geological evidences bearing upon the age of the rocks plotted on the Washoe map as quartz-porphyry, let us first consider their microscopical and macroscopical habitus. They are for the most part rich in porphyritic crystals of quartz, feldspar, and mica, with some hornblende, but vary greatly in the relative proportions

[16] Similar petrographic relations apparently exist among the rocks of the Banat described by J. Niedzwiedzki in an article entitled "Zur Kenntniss der Banater Eruptivgesteine." Tschermak's Mineralogische Mittheilungen. 1873. iv, 255–261.

[17] One of the writers of the present article was geological assistant to Mr. Clarence King when he made his study of the Comstock mines in the winter of 1867–'68 and is quite familiar with the occurrence of the igneous rocks of the Washoe district.

of these minerals. Those with few quartzes, but rich in feldspar, plagioclase being in excess of orthoclase, accompanied by much mica and less hornblende, correspond to dacite in mineral composition, and resemble the dacites from Mount Prometheus in the Toyabe Range. In others, characterized by abundant quartzes, plagioclase seems occasionally to predominate over orthoclase; but in most of them the latter feldspar is in excess, particularly in those poor in mica and hornblende. The region is one where not only both dacite and rhyolite occur, but one where the transition members are well represented.

In macroscopical habitus they exhibit great variations, arising from the abundance or scarcity and size of the porphyritic crystals, and from the color and density of the groundmass. Many hand specimens are perfectly fresh and show the brilliant sanidins so characteristic of the dacites and rhyolites of the Great Basin, and a microscopical examination proves conclusively their identity. The groundmass of many of them often shows within the small area of a square millimeter the greatest diversity of structure, being partly spherulitic, axioltic, and microcrystalline, with glass either clear or clouded (microfelsitic), presenting elongated, curved patches and streaks, a structure described in great detail by Professor Zirkel in his monograph on microscopical petrography already mentioned. The porphyritic quartz contains in most cases only glass, less frequently liquid inclusions, the latter, however, occurring in greater numbers than is usually met with throughout the Great Basin. As these rocks are somewhat removed from the center of mining activity, there are no good underground exposures, and in the few places where they have happened to be cut in exploration they show so much decomposition or occur so fine-grained as to offer very little variation in degree of crystallization. It may be said, however, that there exist no petrographic distinctions between these rocks and many of those found in the ranges to the eastward. We consider them as partly dacite and partly rhyolite, and, judging from the specimens in the collection, without any sharp line of demarcation between them.

YOUNGER DIABASE, BLACK DIKE, AND BASALT.

The rock considered by Mr. Becker as younger diabase and of Pre-Tertiary age is nowhere recognized on the surface. It only occurs as a narrow dike in the immediate neighborhood of the Comstock lode, where it has been followed for more than a mile along the lower levels of the mines. In the upper levels it has undergone so much decomposition that little could be made out of it by the earlier investigators, and for years mining engineers have designated it simply as the "black dike."

According to Mr. Becker, who has given careful attention to the occurrence of this rock, it has not been traced north of the Savage mine, but thence south to the Overman, "it generally marks the contact between the older diabase and the west wall with precision."[18] It extends as far south as the Caledonia, presenting everywhere great uniformity, and never measuring more than 6 feet in width. The rock was represented by only three thin sections, showing but slight variations in structure, and composed of triclinic feldspar, augite, magnetite, and what Mr. Becker described as "clouds of a smoky brownish substance" which he did not determine. Now it is quite evident that much of this substance occupies spaces with the six sided and lozenge-shaped outlines characteristic of olivine; this is well shown in thin section 274. Two new sections from the Yellow Jacket (1278) and the Belcher mines (1322) show in the former a coarser grain and in the latter a much finer grain, having a large amount of fine-grained groundmass with small porphyritic feldspars, augites, and decomposed olivines, the typical structure of many Nevada basalts.

The five thin sections, arranged in the following order, 509, 466, 289, 274, 511, present a gradual transition from coarser to finer grain, the porphyritic crystals diminishing in size and number as the rock becomes more and more porphyritic and carries more groundmass. The augites and feldspars are fresh, while the olivines are wholly decomposed to a greenish-brown fibrous substance, which is also disseminated through the groundmass. It is to be noted that the augite in this rock is quite fresh, while in many of the andesites it exhibits much alteration.

Turning now to the surface rock which has been regarded by every field observer as basalt, we find that it occupies very limited areas, only occurring in a few isolated patches, closely associated with the dacite and rhyolite in the neighborhood of American Flat. Thin sections from these surface rocks show a ground mass without the chlorite, similar to that in the underground rock (thin section 511), but with fewer and smaller porphyritic feldspars. The augite is of the same character, and the fresh olivine presents the same form and size as the spaces occupied by the "smoky brownish substance" in the black dike. Comparing hand specimens of the two rocks, those from the black dike are seen, as might be expected, to be slightly denser than the surface basalt. In specimen 1202 from the dike the decomposed olivines are especially prominent, and give the rock exactly the same habit as the basalt specimen 398, from southwest of Roux's ranch, the latter differing from it only in being somewhat porous, of a steel-gray color instead of greenish-black, and in having fresh, glassy olivines. We fail to see any petrographic distinction between the two rocks.

[18] *Loc. cit.*, p. 199.

GEOLOGICAL AND CHEMICAL EVIDENCE.

In the discussion of the igneous rocks of the Washoe district we have confined ourselves mainly to a comparative lithological study of the rocks of the same mineral composition which have been classed by Mr. Becker as Tertiary and Pre-Tertiary eruptions, and have endeavored to show that they were identical masses presenting insensible gradations from the glassy to the granular structure. We have omitted for the most part the geological and chemical evidences, which not only strengthen the position we have taken, but clearly explain many difficult problems in the structural geology of the region and the relations of many of the rock masses to each other. It is a fact of some interest that nearly all geologists who have examined the district have been impressed with the apparent great variety in the igneous rocks represented. They have all easily recognized the more characteristic types, such as the granular rock which forms the bold front of Mount Davidson, the porphyritic rocks upon the flanks of the mountain variously designated as porphyritic diorite, propylite, and hornblende-andesite, and the glassy and fine-grained rocks mainly referable to pyroxene-andesite. But the moment they tried to outline their areas they were immediately beset with what seemed insurmountable difficulties. This is in part owing to the great amount of decomposition occurring in the neighborhood of the Comstock lode, but in greater part to the gradual transition in crystalline structure. Extreme forms were readily determined, but where to draw the line between them seemed impossible to decide.

The supposed differences between the porphyritic diorite and hornblende-andesite, which we can but regard as one rock, were so obscure as to make their determination one of great difficulty and led to a most confusing entanglement.[19] That this confusion arose from superficial appearances produced by decomposition seems evident, the more decomposed forms being classified for the most part as the older rock. In his discussion of the hornblende-andesite, Mr. Becker says,[20] that through the decomposition of this rock "every variation in coarseness of grain also becomes apparent," and "all these changes tend to diminish the sharp definition of the porphyritic crystals and give the mass the look rather of an older dioritic porphyry than of a volcanic rock." Now, in speaking of the porphyritic diorite he says,[21] "From some peculiarity either in composition or texture the porphyritic hornblende-diorites have undergone extensive decomposition" and only "two or three small masses" were found in a fresh state. From a study of these rocks it seems evident that the apparent coarseness of grain of most of the so-called porphyritic diorites is derived solely from the decomposition of

[19] Geology of the Comstock lode, pp. 42, 87, 89.

[20] *Loc. cit.*, p. 58.

[21] *Loc. cit.*, p. 39.

hornblende-andesite.[22] It is a most noteworthy fact that the decomposed forms of andesite occur in areas of fresh rock, while the somewhat fresh diorites are found in areas of general decomposition. The propylite of Baron von Richthofen and Mr. Clarence King for the most part belongs to this decomposed rock, the latter geologist remarking[23] "nearly all the propylite observed by us is decomposed." The distinguishing features of propylite were considered to be its high degree of crystallization and a certain characteristic habitus of the hornblende, the former closely relating it in structure to the hornblende-porphyrites, while the latter character tended to separate it superficially from the andesites with which it is unquestionably connected geologically. On the one hand we quite agree with Mr. Becker, who has ably shown after a rigid examination that a greater part of the propylite cannot be separated from the hornblende-andesite, and that there exists no evidence of its pre-andesitic eruption. He has clearly shown that the propylite of Washoe has no claim to be considered as an independent rock species, its change in habitus depending wholly upon decomposition. On the other hand our own work, showing the transition from glassy lavas to somewhat highly crystalline forms, compels us to agree with the earlier investigators, and to relegate his Pre-Tertiary porphyritic-diorite to the Tertiary hornblende-andesite. A comparison of the geological maps accompanying the works of Mr. King and Mr. Becker shows how embarrassing the difficulties were in drawing correct lines of demarcation between the supposed Pre-Tertiary and Tertiary masses. Over a very considerable part of the area they fail to agree. In general the latter geologist regards the south flanks of Mount Davidson as covered by hornblende-andesite, and the north flanks by diorite, the former geologist considering both north and south flanks as covered by propylite and of Tertiary age.[24]

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[22] The collection contains several series of specimens showing the various stages of decomposition of the rocks, classed as hornblende-andesite and porphyritic diorites. Among the former are numbers 486, 487, and 569 to 574. Among the latter, 448, 449, 451, 497, 498, 450, and 310, 311, 312.

[23] U. S. Geological Expl. of 40th Parallel, Vol. I, p. 557.

[24] In this connection it may be profitable to review the literature upon the propylite of Schemnitz in Hungary, a region which presents in many respects a close resemblance in its geological history to Washoe. Dr. Doelter (Verhandlungen der k. k. geologischen Reichsanstalt, 1879, p. 27), after a mineralogical and chemical study of the altered rocks recognizes the microscopical distinctions pointed out by Zirkel, especially in the quartzose rocks, but finds isolated masses which unite many of the characters of both andesite and propylite. He fails to find any difference in mode of occurrence or geological age between the two rocks. Vom Rath, probably after a study of the more crystalline portions, concludes that the propylite properly belongs to diabase and presents structural features quite unlike a Tertiary andesite. With his intimate knowledge of the Schemnitz region Professor Szabó, in the same number of the geologischen Reichsanstalt, from a geological standpoint denies the independent eruption of propylite. Dr. A. Koch, in a paper entitled "Neue petrographische Untersuchung der trachytischen Gesteine der Gegend von Rodna" (Verhandlungen der

The structure of the main body of the mountain is well brought out by the Sutro tunnel. It is shown to be for the most part a body of pyroxene-andesite extending from the central core of Mount Davidson, where it is well exposed, eastward to the outer foot-hills, where it is largely concealed by hornblende-mica-andesite, which breaks through it and covers the surface, the relations between the two rocks being well exhibited by the tunnel section. As already shown, there is a gradual and steady increase in degree of crystallization as we pass toward the central core, the pyroxene-andesite which forms the west country rock being one or two degrees coarser than the east country rock. In general the body west of the lode opposite the central portion of Mount Davidson is somewhat coarser than the rock to the eastward, but this does not hold true either to the north or the south. This is explained by the fact recognized by all geologists that the vein is situated along a line of great faulting, the displacement being quite sufficient to bring different portions of the same rock mass into juxtaposition. Along the line of the vein solfataric action has produced so much decomposition, especially to the eastward, that comparative petrographic studies of the walls is a matter of considerable difficulty. Nevertheless, the distance is so great and the exposures in the many tunnels so numerous that the evidence of identity of both walls seems conclusive. Let us consider, for example, a cross-section in one mine. On the 1,450-foot level of the Sierra Nevada mine a small body of pyroxene rock has been identified to the west of the main shaft, but to the east of the shaft the country rock is so decomposed that sufficiently fresh material for accurate identification was not obtained for 1,600 feet. At this point, where unaltered material occurs, it is shown to be a pyroxene rock. Now, although the rock has undergone so much alteration as partially to preclude specific identification, there is no evidence at hand that through-

k. k. geolog. Reichsanstalt, 1880, Literaturnotizen), is of the opinion that a separation of Grünstein-trachyte (propylite) from andesite is inadmissible, since he shows that both rocks are connected through transition forms. He points out that the principal difference between them is in the structure of the groundmass, the propylite being holocrystalline while the true andesite of Hungary always contains more or less glass. He maintains that the question whether there is any difference in geological age of these rocks is not yet satisfactorily determined. Dr. E. Hussak, in a purely petrographic paper, "Grünstein-trachyte oder Propylite," published in the same journal, states that the rocks are much decomposed and agrees with Zirkel as to their microscopical habitus. He says: "Diese Gesteine ähneln den alten sogenanten Dioritporphyren wie auch den Diabas-porphyriten ungemein, sind jedoch mit den tertiaren Eruptivgesteinen eng verknüpft und wohl nicht davon zu trennen." See also Prof. J. W. Judd's valuable paper "On the Ancient Volcano of the District of Schemnitz, Hungary," Quar. Jour. Geol. Soc., August, 1876.

Unless erosion at Schemnitz, unlike the conditions at Washoe, has worn away the greater part of the superincumbent rock, we are led to believe, without any personal acquaintance with the district, that a thorough investigation of a large number of thin sections prepared from judiciously selected rocks would show a complete transition from the glassy volcanic lavas to those corresponding in texture to crystalline diorite or diabase.

out its whole length it was not originally a pyroxene-andesite. Wherever the rock occurs sufficiently fresh to allow a close study its identification with this type of andesite seems established. All these facts convince us that the Comstock lode cannot be considered as a contact vein between two different rock masses.

Owing to the intimate connection between hornblende and augite, and the fact that pyroxene-andesites with varying amounts of hornblende occur, indistinguishable from many hornblende-andesites with more or less pyroxene, it is impossible to draw a sharp line of demarcation between the two types. Great confusion arises when we undertake to map out the Washoe district, where both rocks occur in every possible gradation between the two specific types. Such transitions were recognized by Mr. Becker, who, having outlined the different areas covered by the different volcanic masses according to geological age, often considered himself forced to determine a rock quite as much from its occurrence within certain areas as from its mineral composition, regarding the variations as local modifications.

In general the hornblende-andesite here, as in many other districts, seems to be more silicious than the pyroxene types, yet analyses show many marked exceptions. In the intermediate volcanic rocks, like those which make up the greater part of the mass at Washoe, where the range in chemical composition between the two is so slight, a variation in mineral composition may easily take place.

Doubtless much of the confusion which exists in the Washoe district between the hornblende and pyroxene divisions of these rocks arises from the cutting of one rock by the dikes of the other in a far greater degree than has been heretofore recognized. Indeed, the region is penetrated by broad fissures and narrow dikes, varying in width from many hundred feet to those exposing only a few feet where cut by mining shafts and levels.

This is especially noticeable in the Sutro tunnel, which, after passing through the broad belt of hornblende-mica-andesite, enters, as has been already mentioned, a vast body of pyroxene-andesite forming the main rock mass as far as the tunnel runs. All other bodies, both large and small, cut by the tunnel present the appearance of occurring as dikes, many of them failing to reach the surface. These facts lend support to the theory that a large body of pyroxene-andesite forms the older and central mass of the mountain. At 17,100 feet from the mouth of the tunnel a remarkably fresh hornblende-andesite is cut with every indication, judging from the specimens, that it occurs as a dike. It seems quite possible that this may have served as a vent through which was extruded, a portion at least, of the hornblende rock found on the surface along the east base of Mount Davidson.

In the subjoined table are presented a series of twelve chemical analyses representing the principal variations in composition and structure of the volcanic rocks found at Washoe.

TABLE IV.—*Chemical analyses.*[1]

Number.	Determination.	Locality.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	Other components.	Ignition.	Total.	Analyst.
I	Basalt	North of American Flat Creek.	47.91	2.70	14.26	1.65	7.80	trace	9.60	10.83	3.01	1.89	Li_2O . trace	0.37 H_2O	100.02	Samuel L. Penfield.
II	Granular pyroxene-andesite.	Eldorado outcrop	56.71	......	18.36	......	6.45	......	6.11	3.92	3.52	2.38	....	1.94 H_2O	99.39	R. W. Woodward.
III	Pyroxene-andesite	Sutro tunnel, foot-wall, Savage connection.	56.40	1.14	15.99	3.26	3.82	0.12	6.98	3.54	3.83	1.91	P_2O_5 ..0.32	2.47	99.78	Gideon E. Moore.
IV	Hornblende-andesite	Center of Cedar Hill ridge.	58.55	0.83	15.48	3.93	2.07	0.11	6.44	3.60	3.99	1.69	P_2O_5 ..0.30	3.62	100.61	Do.
V	Pyroxene-andesite (hornblende bearing).	Ridge northeast of American Flat.	58.44	......	18.17	......	6.03	......	6.19	2.40	3.20	1.97	Co_2....2.87	0.76	100.03	W. G. Mixter.
VI	Pyroxene-andesite (hornblende bearing).	Silver terrace	59.22	......	18.20	......	6.69	....	5.51	2.90	3.31	1.39	....	2.80 H_2O	100.02	Do.
VII	Hornblende-andesite	Cross Spur quarry below Graveyard.	60.82	......	17.54	......	5.42	......	5.65	1.76	3.71	1.41	Co_2....1.41	2.31	100.13	Do.
VIII	Hornblende-mica-andesite.	Mount Rose	63.30	......	17.81	3.42	0.83	......	5.12	2.07	4.27	2.26	Li_2O . trace	0.88 H_2O	99.96	R. W. Woodward.
IX	Hornblende-mica-andesite.	Cross Spur quarry	63.13	......	16.00	4.34	1.52	......	4.45	2.07	3.87	2.65	....	2.00 H_2O	99.54	Do.
X	Mica-andesite	800′ east of Waller Defeat shaft.	65.68	0.98	15.87	1.78	1.25	......	3.50	1.79	3.20	3.37	P_2O_5 ..0.23	3.10	100.75	Gideon E. Moore.
XI	Dacite	Spur northeast of McClellan Peak near American Flat road.	69.96	......	15.79	2.50	......	......	1.73	0.61	3.80	4.12	....	1.53	100.07	F. A. Gooch.
XII	Rhyolite	South-southeast of McClellan Peak.	73.07	......	11.78	2.30	......	......	2.02	0.39	1.19	6.84	....	2.24	99.83	Do.

Number.	Designation in Mr. Becker's report.	Designation in Mr. King's report.	Number of thin section.	Number of specimen.	Number.	Designation in Mr. Becker's report.	Designation in Mr. King's report.	Number of thin section.	Number of specimen.
I	....	Basalt	*528	22647	VII	Hornblende-andesite	Propylite	*231	22717
II	Diorite	Diorite	(*)	22615	VIII	Later hornblende-andesite	Trachyte	*283	22631
III	Earlier diabase	....	18	270	IX	Later hornblende-andesite	Trachyte	*284	22637
IV	Porphyritic diorite	....	421	482	X	Mica-diorite	....	101	506
V	Augite-andesite	Hornblende-andesite	(*)	22719	XI	Quartz-porphyry	....	496	251
VI	Augite-andesite	Hornblende-andesite	*832	22706	XII	Quartz-porphyry	....	495	249

[1] These analyses have been revised by comparison with the original records so far as possible; those which were found to be from much decomposed rocks have been omitted.
* The numbers marked with an asterisk are from the collection of the Fortieth Parallel Exploration; the remainder are from Mr. Becker's collection.

They are mainly compiled from the table published in Mr. Becker's monograph and revised as far as possible by comparison with the original records. They are here arranged according to their acidity in order to bring out forcibly the great similarity existing in chemical composition between rocks which we have endeavored to show were identical in mineral composition and structural features. Numbers I, XI, XII, the extreme basic and acidic varieties of the series, are now published for the first time. The identity in composition of the hornblende and pyroxene-andesites, which make up the central mass of the mountain, is shown in analyses II to VII, inclusive, the extremes in silica (with a variation of a little more than 4 per cent.) lying quite within the range of most volcanic extrusions. Between the coarse-grained rock from Eldorado outcrop (II), representing the mass of Mount Davidson, and the coarse-grained pyroxene-andesite (III) from the Sutro tunnel, near the Savage connection, chemical analysis fails to detect any marked difference; while between the so-called porphyritic diorite (IV) and hornblende-bearing pyroxene-andesites the variations are such as might occur in different parts of the same volcanic flow. In a well characterized hornblende-andesite from the Cross-Spur quarry (VII) the silica reaches 60.82 per cent.

In order to strengthen and confirm these analyses silica determinations have been made of several rocks from other localities in the district, carefully selected to represent the same range in mineral composition. Those agreeing in the preponderance of hornblende or pyroxene are placed together as follows:

1. Pyroxene-andesite (granular diabase), 56.40 per cent. SiO_2.
2. Pyroxene-andesite (augite-andesite), 56.56 per cent. SiO_2.
3. Hornblende-andesite (porphyritic diorite), 55.66 per cent. SiO_2
4. Hornblende-andesite (hornblende-andesite), 55.79 per cent. SiO_2.
5. Hornblende-andesites (hornblende-andesite), 57.06 per cent. SiO_2.

They all occur near the base of Mount Davidson from the following localities:

1. Ophir ravine, southeast of Cole water tunnel.
2. 1,000 feet due west of quarry above Occidental grade.
3. Ophir ravine, southeast of Cole water tunnel.
4. Ridge north of Ophir Hill, 150 feet west of old flume.
5. Tank 600 feet northwest of Yellow Jacket shaft.

From these it will be seen that the pyroxene-andesite from Ophir ravine is identical in silica percentage with the foot-wall, Savage connection in the Sutro tunnel, and differs from the pyroxene-andesite of the surface by only 0.16 per cent. of silica. The hornblende-andesite from near the Cole water tunnel differs from that of the ridge near Ophir Hill by 0.13 per cent. of silica. The refinements of chemistry like those of the microscope fail to detect any distinctions between the rocks of the same mineral composition, which have here been classed as Tertiary and Pre-Tertiary age.

We turn now to the later rock masses of both acidic and basic character found penetrating the main body of hornblende and pyroxene andesite of intermediate composition. We will first consider the hornblende-mica-andesites (later hornblende-andesite and mica-diorite), which, though presenting variations from a porphyritic lava with a glassy and microlitic groundmass to a granular structure recognized by the unaided eye, have already been shown to be indistinguishable petrographicly. An examination of the specimens shows that it is the coarsely crystalline and decomposed middle-grained varieties which have been classed as Pre-Tertiary rocks, while the fresh and unaltered middle-grained and the glassy ones were regarded as of Tertiary age. The broad high ridge, lying to the eastward of Mount Davidson, of which Mount Rose and Mount Kate are conspicuous features, forms the principal mass of this rock breaking through the pyroxene-andesite. Upon the slopes of the ridge a considerable variation in texture of the rock is easily recognized. It is only on the surface along the ridge that glassy forms are met with. Comparing the hornblende-mica-andesite exposed through the 10,000 feet cut by the Sutro tunnel with the surface rocks, exact counterparts are observed with the exception that glassy forms are wanting. This is, however, what we should expect, and quite in accord with all the observations so far made upon the collections from Washoe, namely, that the glassy forms of the various rocks are only found at or near the surface, those from any considerable depth having cooled with sufficient slowness to become holocrystalline. Advancing now a step further we find that the more crystalline rock from this large body of hornblende-mica-andesite bears the closest resemblance to parts of the so-called Pre-Tertiary mica-diorite, which passes, as has already been shown, by imperceptible gradations into rock possessing a granular structure.

Let us consider in this place what the intermediate forms are which link together rocks of the chemical composition of a glassy hornblende-mica-andesite possessing all the characteristics of a surface lava with those having the structure of many granitic rocks. The results derived from a study of numerous rock sections[25] clearly indicate that the essential variation in the more porphyritic varieties takes place in the groundmass, which, starting with glass containing few microlities, gradually grows richer and richer in microlitic inclusions until only a small amount of glass remains as a cementing base. This in turn may be crystallized into microscopically cryptocrystalline particles. In a somewhat more advanced stage the cementing material assumes the appearance of uniformly oriented patches or of microcrystalline granitoid grains, which as the size of the grain increases is found to be partly quartz, partly feldspar. The dimensions of the cemented microlites also increase until they appear as small crystals embedded in a mass of ir-

[25] See Table III; also Table I.

regularly shaped grains of feldspar and quartz. As the number of large crystals and those of medium size increases the porphyritic appearance of the rock is lost, especially as the sharp outline of the larger crystals is no longer preserved, as already described. The character also of the feldspars changes by reason of the variation in their inclusions, those of glass growing less numerous as the rock becomes more crystalline, until they disappear entirely, occasional fluid inclusions making their appearance. When finally the grains are nearly all of one size the structure is the even granular one of a granite.

Quartz, which in the glassy forms of these hornblende-mica-plagioclase rocks occasionally is seen in small porphyritic grains, first makes its appearance as an essential ingredient among the microscopic grains of the groundmass, becoming more and more apparent as their size increases. This quartz contains in the coarser-grained forms numerous fluid inclusions, indicating that the gases disseminated through the magma, having been excluded by the first crystallizing minerals, were finally inclosed in the quartz, the last mineral to crystallize, which would necessarily occur when a magma consolidates under pressure, the gases being unable to escape. The number of mineral constituents is still further increased by the development of acidic feldspars, the uncrystallized material of which, together with the silica of the quartz, makes up the residual glass base of the vitreous forms of the rock. It has already been shown[26] that the glass of a vitreous lava grows richer in silica and alkalies as the more basic minerals crystallize out of the magma.

Thus the rock which in a vitreous state is composed essentially of basic feldspar, hornblende, and mica, with a groundmass of glass more or less full of microlites, is, when coarse-grained, formed of both basic and acidic plagioclase with some orthoclase, besides hornblende, mica, and quartz—the mineral composition of a quartz-diorite. The best examples of this decidedly granitic structure are from the 1,000-foot level of the Sierra Nevada and the shaft of the Lady Bryan mine, rocks which some geologists would call hornblende-bearing granite, but to which Mr. Becker refers in his monograph[27] as "fresh, coarsely granular, quartzose diorite." Though we know but little of the actual occurrence and field relations of the rocks represented by these two specimens, one coming from the end of a drift and the other collected from the dump of a mine, still it is noteworthy that they both come from the immediate neighborhood of the most extensive area of hornblende-mica-andesite in the district, and though geological evidence of their direct connection is wanting, the chain of petrographic evidence is so complete as to leave no doubt in our minds that these coarsely granular rocks are parts of

[26] F. Fouqué, "Santorin et Ses Éruptions," Paris, 1879, p. 11. Hague and Iddings, "Notes on the volcanoes of Northern California, Oregon, and Washington Territory," Am. Jour. of Science, Vol. XXVI, Sept., 1883, p. 230.

[27] Geology of the Comstock Lode, page 192.

the same magma as the hornblende-mica-andesites which have crystallized very slowly under considerable pressure.

With the exception of one body near the north end of the vein, the so-called mica-diorite only occurs on the surface, as shown on the map,[28] in a few isolated patches of no great elevation, where it presents the appearance of having broken through the andesite. That there is good reason for such a conclusion is borne out by the strongest geological evidence beneath the surface. It has been pointed out that the andesite of the Sutro tunnel is cut in three places by narrow dikes of hornblende-mica-andesite of a medium crystallization, showing that here at least a similar rock is younger than the main body of Tertiary andesite.

Other instances of this hornblende-mica-rock cutting the pyroxene-andesite are shown in the vertical sections through the Yellow Jacket and Belcher mines (atlas sheet VII), and can only be reasonably explained as dikes and offshoots from the main body of a later rock penetrating an older one. By reference to the geological map it will be seen that the Forman shaft is located in andesite between two small outcrops of hornblende-mica-rock only 3,500 feet apart. Now the fact that the shaft has been sunk for a depth of 2,340 feet without encountering either body seems to point to the conclusion that these hornblende-mica rocks are simply dikes cutting the andesite.

Let us consider one more fact. On the 1,950-foot level of the Utah mine a narrow body of medium-grained hornblende-mica rock is exposed penetrating the pyroxene-andesite. Now this small body is vertically beneath the later hornblende-mica-andesite of the surface, with the evidence all tending to the conclusion that the two bodies are closely connected masses.

Such geological evidence as to the position of these rocks seems all-sufficient to determine their age, but taken in connection with the proof of identity afforded by rigid petrographic analysis the arguments appear indisputable.

As already mentioned, the hornblende-mica rocks vary considerably in their mineral composition within certain limits, and a corresponding variation is observed in their chemical composition. Analyses VIII and IX (Table IV) are from the hornblende-mica-andesites of Mount Rose and Cross Spur quarry, which are rich in iron magnesia silicates, hornblende being in excess of mica in one case and equaling it in the other. Analysis X from the "mica-diorite," 800 feet east of the Waller Defeat shaft, shows less iron and magnesia, which corresponds to the small amount of iron and magnesia silicates found in the rock, mica greatly predominating over hornblende. It represents one of the most acidic of these hornblende-mica rocks.

The quartzose Tertiary rocks, as has been shown, belong both to dacite and to rhyolite, the rocks intermediate between the two being

[28] Geology of the Comstock Lode, Atlas, Sheet IV.

well developed. The surface area covered by them lies wholly in the southern and southeastern portion of the district, mainly in the neighborhood of American Flat. Their geological position is best observed in the underground workings to the north, where the main body of pyroxene-andesite occupies the surface, and although the number of exposures is limited, their evidence is clear. No stronger proof can be desired of the Tertiary age of the rocks in question than the occurrence in the Sutro tunnel of a broad dike, 1,400 feet in width, with numerous offshoots cutting the main body of pyroxene-andesite. Microscopical examination proves this rock to be the counterpart of a lithoidal variety found on the surface near Gold Cañon and the Red Jacket mine.[29] In the Overman mine a dacitic or rhyolitic rock apparently occurs as a narrow dike extending upward nearly to the surface from the 2,000-foot level. Again the occurrence in the Belcher mine can best be explained on the simplest and most plausible theory of an offshoot or stringer from the main mass. The Forman shaft, after passing through pyroxene and hornblende-andesite, exposes at about 2,340 feet from the surface a small body determined by Mr. Becker as an orthoclase rock, which he classes as quartz-porphyry. Although our knowledge of the body is extremely limited, there seems to be every reason, judging from analogy, that it also occurs as an intrusive mass penetrating the andesite but failing by many hundred feet of reaching the surface. It is worthy of note that the rock is holocrystalline and presents certain characteristics common to igneous rocks cooled at considerable depths below the surface, and which many geologists regard as evidence of their Pre-Tertiary age.

A recent analysis in the laboratory of the United States Geological Survey, by Dr. F. A. Gooch, of a dacite from near McClellan Peak, is given in Analysis XI (Table IV). It will be noticed that the potassa is but slightly in excess of the soda, and the miscroscope shows that the plagioclase is far in excess of orthoclase among the porphyritic crystals. In Analysis XII, also by Dr. Gooch, the potassa greatly predominates over soda, and the rock from which it was made is characterized by prevailing orthoclase, the habitus and chemical composition being those of a typical rhyolite.

Geological evidence having proved that the rock penetrated by the black dike is inseparable from the Tertiary pyroxene-andesite lavas, it of course follows that the later rock is also of Tertiary or still more recent age. A comparative study of the hand specimens and their sections has shown the similarity in composition and structure existing between the surface basalts, near American Flat, and the well-known black dike of the Comstock lode, they differing only slightly in degree of crystallization and state of preservation. By reference to the map (atlas sheet IV) it will be noticed that there are only five surface

[29] Compare the following hand specimens: Numbers 182 to 192 from the Sutro tunnel with 417, 370, 397, 399, 405, and 411 from the surface collection.

occurrences of basalt, all of them insignificant in area and in height. In a direct line from the basalt masses, immediately to the westward of American Flat, it is only 4,500 feet to the Caledonia shaft, where the black dike is last seen along the line of exploration on the Comstock.

The chemical composition of the surface basalt is given in Analysis I (Table IV). It is somewhat basic, but in other respects is quite similar to many of the basalts of the Great Basin. The basalt of the black dike from the Belcher mine, 1,145 feet below the surface, yielded 49.79 per cent. of silica, the difference between the two analyses being quite within the range of variation for the same flow. Now, although the black dike forms the only dike of basalt known in the district, and its direct connection with the small surface patches has never been traced, the evidence is quite sufficient to lead to the conclusion that it, like the intrusive bodies of hornblende-mica-andesite, dacite, and rhyolite, is an offshoot from a much larger mass at no great distance.

CONCLUSIONS.

As stated in the first part of this paper our investigation leads us, in many important particulars, to conclusions in respect to the geological structure of the Washoe district quite at variance with the opinions held by our predecessors. Throughout the body of the paper we have endeavored to place before the reader with considerable detail the facts upon which our opinions were based. Let us then in reviewing these results state in a few words what we consider to be the geological history of Washoe and the relations of the principal rock masses and intrusive bodies to each other, and then briefly summarize the conclusions maintained in this discussion as to the development of crystallization in the igneous extrusions which have built up this mountain pile.

We regard the main mountain mass of which Mount Davidson is the culminating peak to be formed of both pyroxene- and hornblende-andesites, of much the same ultimate chemical composition, analyses showing a variation of only 4 per cent. in silica. Both these types of andesite are so intimately connected geologically with each other as to render it extremely difficult to separate them on a basis either of physical structure or of geological age. So long as the conditions under which hornblende and pyroxene are formed in lavas of this class are so little understood it becomes a difficult matter at Washoe to determine with precision the relations of andesitic eruptions based solely upon these minerals. The fact, however, that the main mass of Mount Davidson is made up of coarsely crystalline material originally a pyroxene rock, and that the section through the Sutro tunnel after leaving the hornblende-mica-andesite body of Mount Rose and Mount Kate runs mainly through pyroxene-andesite, makes it highly probable that the earlier and larger part of the eruption was composed of this rock. Through this pyroxene-andesite hornblende-andesite is known to penetrate, and observations all point to the conclusion that vents have been opened through which both types of rock have been forced upwards, although not necessarily reaching the surface.

After these eruptions of pyroxene and hornblende andesites there was a period of rest, during which there was more or less removal of the superficial material by denudation, a study of the surface geology presenting many arguments in favor of a time of comparative inaction. These older andesitic rocks have been broken through by numerous intrusive bodies of both acidic and basic lavas represented by hornblende-mica-andesites, dacites, rhyolites, and basalts. From masses of these later rocks offshoots were pushed out and forced upwards into the older rocks, in many cases failing to reach the surface, but now exposed by vertical shafts and horizontal workings.

We find the glassy forms of these rocks only on or near the surface. Rocks from the tunnels and mining shafts from any considerable distance beneath the surface present invariably a holocrystalline structure, while the more coarsely crystalline forms come from near the central mass, from intrusive dikes, or are brought up from the lowest depth reached by mining shafts. It is not of course to be expected that development in crystallization should show an unvarying increase in any given direction through a rock mass. On the contrary, changing conditions would necessarily bring about more or less local modifications. Variations in rapidity of cooling or amount of pressure would produce local centers of crystallization, with corresponding variations in rock structure. Moreover the degree of crystallization developed in different lavas under similar conditions appears to depend upon their chemical composition, the basic lavas showing a greater tendency to crystallize than the acidic.

When we consider the evidence offered by the 4 miles of the Sutro tunnel, the vertical sections 3,000 feet in depth, and the network of long galleries run at different levels from the main shafts, the innumerable facts, all pointing in one way, present such overwhelming proof that we are led to the conclusions maintained in this paper, and briefly summed up as follows:

That the degree of crystallization developed in igneous rocks is mainly dependent upon the conditions of heat and pressure under which the mass has cooled and is independent of geological time.

That there are abundant geological and petrographic evidences in the Washoe district to show that the igneous rocks do not belong partly to Pre-Tertiary and partly to Tertiary eruptions, but are all of Tertiary age.

That the so-called granular diorite and diabase, augite-andesite are identical and belong to the same geological body.

That the so-called porphyritic diorite is identical with hornblende-andesite and should be designated by the latter name.

That the so-called mica-diorite is identical with the later hornblende-andesite and both rocks are of the same geological age.

That the quartz-porphyry is of Tertiary age and resolves itself into both dacite and rhyolite.

That the later diabase or black dike and the basalt are one and the same rock, the difference being that the former is only known as a narrow dike while the latter occurs in flat-topped bodies and low hills on the surface.

That the Comstock lode occupies a fissure along a line of faulting in rock of Tertiary age, and cannot be considered as a contact vein between two different rock masses.

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