ADVERTISEMENT.

The publications of the United States Geological Survey are issued in accordance with the statute approved March 3, 1879, which declares that—

> The publications of the Geological Survey shall consist of the annual report of operations, geological and economic maps illustrating the resources and classifications of the lands, and reports upon general and economic geology and paleontology. The annual report of operations of the Geological Survey shall accompany the annual report of the Secretary of the Interior. All special memoirs and reports of said Survey shall be issued in uniform quarto series if deemed necessary by the Director, but otherwise in ordinary octavos. Three thousand copies of each shall be published for scientific exchanges and for sale at the price of publication; and all literary and cartographic materials received in exchange shall be the property of the United States and form a part of the library of the organization: And the money resulting from the sale of such publications shall be covered into the Treasury of the United States.

ANNUAL REPORTS.

From the above it will be seen that only the Annual Reports, which form parts of the reports of the Secretary of the Interior and are printed as executive documents, are available for gratuitous distribution. A number of these are furnished the Survey for its exchange list, but the bulk of them are supplied directly, through the document rooms of Congress, to members of the Senate and House. Except, therefore, in those cases in which an extra number is supplied to this office by special resolution, application must be made to members of Congress for the Annual Reports, as for all other executive documents.

Of these Annuals there have been already published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King, 8°, Washington, 1880, 79 pp., 1 map.—A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell, 8°, Washington, 1882, lv., 588 pp., 61 plates, 1 map.

CONTENTS.

The Third and Fourth Annual Reports are now in press.

MONOGRAPHS.

The Monographs of the Survey are printed for the Survey alone, and can be distributed by it only through a fair exchange for books needed in its library, or through the sale of those copies over and above the number needed for such exchange. They are not for gratuitous distribution.

So far as already determined upon, the list of these monographs is as follows:

I. The Precious Metals, by Clarence King. In preparation.
II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.
III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker.

Published.

IV. Comstock Mining and Miners, by Eliot Lord. In press.
V. Copper-bearing Rocks of Lake Superior, by Professor R. D. Irving. In press.
VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. In press.
Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.
Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague. In preparation.
Coal of the United States, by Prof. R. Pumpelly. In preparation.
Iron of the United States, by Prof. R. Pumpelly. In preparation.
Lesser Metals and General Mining Resources, by Prof. R. Pumpelly. In preparation.
Lake Bonneville, by G. K. Gilbert. In preparation.
Dinocerata. A monograph on an extinct order of Ungulates, by Prof. O. C. Marsh. In press.
Sauropoda, by Prof. O. C. Marsh. In preparation.
Stegosauria, by Prof. O. C. Marsh. In preparation.

Of these monographs, numbers II. and III. are now published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton. 1882, 4°, 264 pp., 42 plates, and atlas of 26 double sheets folio. Price $10.12.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. 1882, 4°, 422 pp., 7 plates, and atlas of 21 sheets folio. Price $11.

Numbers IV., V., and VI. are in press and will appear in quick succession. The others, to which numbers are not assigned, are in preparation.

BULLETINS.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not come properly under the heads of Annual Reports, or Monographs.

Each of these Bulletins will contain but one paper and be complete in itself. They will, however, be numbered in a continuous series, and will in time be united into volumes of convenient size. To facilitate this each Bulletin will have two paginations, one proper to itself and another which belongs to it as part of the volume.

Of this series of Bulletins No. 1 is already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological Sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 40 pp., 8°. Price 10 cents.

Correspondence relating to the publications of the Survey, and all remittances, should be addressed to the

Director of the United States Geological Survey,
Washington, D. C.

Washington, D. C., *March* 1, 1883.

DEPARTMENT OF THE INTERIOR

MONOGRAPHS

OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME III

WASHINGTON
GOVERNMENT PRINTING OFFICE
1882

WEATHERED AUGITE-ANDESITE ON DIVIDE BETWEEN MT. ROSE AND MT. KATE
MT. DAVIDSON AND MT. BUTLER IN THE DISTANCE

UNITED STATES GEOLOGICAL SURVEY
CLARENCE KING DIRECTOR

GEOLOGY

OF THE

COMSTOCK LODE AND THE WASHOE DISTRICT

WITH ATLAS

By GEORGE F. BECKER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1882

American Museum of Natural History,
New York City.

Hon. Clarence King, *Director:*

Sir: In compliance with your instructions of March 6, 1880, directing me to report upon the Geology, Mineralogy, Chemistry, and Physics of the Comstock Lode, I have the honor to transmit the accompanying report.[1]

Although several reports on the Comstock Lode have appeared during the past twenty years, the great extension of the mine workings and the advances in geological science made it probable that additional information of value would result from a reëxamination of this famous ore-deposit. Administrative duties unfortunately prevented you from undertaking the study of the lower portions of the Lode, the upper part of which you have made so familiar to geologists. Under these circumstances, you did me the honor to select me as your substitute; yet you did not abandon all share in the investigation, since at every stage of it I have had the advantage of your cordial support and wise counsel.

Very respectfully, your obedient servant,

GEO. F. BECKER,
Geologist-in-charge.

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[1] See Second Annual Report of the Director U. S. Geological Survey, page xl.

PREFACE.

The field work for this report was begun in April, 1880, and concluded in March, 1881. In the spring of 1880 the Census of the Mineral Industries West of the Rocky Mountains was placed in my charge in addition to my duties as geologist, and occupied much of my time both during the period of field work in the WASHOE DISTRICT and since.

My assistants were as follows: Dr. Carl Barus, physicist, who was invited at my request to join the Survey for the express purpose of resuming the question of the electrical activity of ore bodies, a subject in which I had long felt an interest. He also made experiments on kaolinization, and the two chapters in this volume devoted to these subjects sufficiently attest how ably he has conducted the investigations to which he was assigned. Mr. F. R. Reade, assistant geologist, made a large portion of the collections, which embrace nearly three thousand numbers, and, with Dr. Barus, carried out many of the computations involved in the discussion of the increment of heat. I also contracted with Mr. R. H. Stretch to assist me in mapping the underground geology. Mr. Stretch was for some years one of the official surveyors of the COMSTOCK, and his familiarity with the old and inaccessible workings was of much assistance. In preparing the sections it was necessary in many cases to infer the structure of localities to which there was no approach from that shown in galleries on other planes, a difficult task in which Mr. Stretch's aid was also very valuable. I visited almost every foot of open ground, and the structural and lithological geology, as well as the conjectural portions of the sections, are my own. Mr. Stretch was very zealous in the collection of the specimens necessary to prove the lithology of the sections, and forwarded the work of the Survey in every way in his power.

The claim map was prepared by Messrs. Hoffmann & Craven, surveyors, on contract, and the mine maps were obtained through the same firm from official sources. Some additions have been made to the claim map by Mr. L. F. J. Wrinkle

All the mine officers were most courteous and offered every facility for the examination, often at great inconvenience to themselves. Mr. I. E. James, superintendent of the *Sierra Nevada*, had prepared a considerable number of slides, which, as well as his microscope, he placed at my disposal. Mr. Forman, superintendent of the *Forman Shaft;* Captain Taylor, superintendent of the *Yellow Jacket;* and Mr. I. Requa, superintendent of the *Chollar*, gave access to their collections, and to their temperature observations, as did also Mr. C. C. Thomas, superintendent of the *Sutro Tunnel.* Mr. George J. Specht, surveyor, compiled the temperature observations of the *Tunnel* and many other data, most of which will appear in another volume. Mr. Forman also presented the Survey with a duplicate collection of the rocks encountered in sinking his shaft, a specimen having been taken every five feet. Mr. W. H. Patton gave me extraordinary facilities in the series of mines (from the *Union* to the *Consolidated Virginia*) under his superintendence; and Mr. Hugh Lamb, foreman of the *Consolidated Virginia* and the *California*, spent much time in exploring with the party, and communicated many acute and valuable observations gathered in his long experience on the LODE. In short, from mine owners to common miners, an intelligent interest in the objects of the Survey and a willingness to forward them were manifested by all concerned. It is believed that the facts made out with reference to the occurrence of ore will prove of sufficient practical advantage to justify this interest.

The lithological illustrations were all drawn and colored under my constant supervision. The endeavor was to reproduce the objects with absolute fidelity, avoiding even the temptation to emphasize characteristic outlines or tints, and the figures were not considered complete so long as an addition or a change could be suggested. The work was put on the stones, of which no fewer than eighteen were requisite, by the same draughtsman who made the drawings, Mr. G. K. Gardner, and the originals have thus not suffered in lithographic reproduction. It is safe to say that no lithographic illustrations were ever more conscientiously prepared, and I have met with none which seem to represent microscopical effects more exactly.

Special thanks are due from me to Dr. Barus and to Mr. J. P. Iddings (assistant geologist on Mr. Arnold Hague's staff), with whom I have repeatedly consulted on the subjects treated in Chapters IV. and III., respectively. But for the stimulus of their criticisms the proofs offered would be less satisfactory; and in enabling me to meet the objections which occurred to them, they have placed me more in their debt than if they had made positive additions to the discussions of lithology and faulting.

The office work has been done at the American Museum of Natural History, New York, that institution having courteously placed some of its admirable working rooms at the disposal of the Survey.

G. F. B.

NEW YORK, *May* 6, 1882.

OCT. 16.—Mr. Albert Williams, jr., Statistician of the Survey, has kindly given me the benefit of his extremely efficient assistance in the proof correction of the volume.

G. F. B.

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LIST OF ILLUSTRATIONS.

LIST OF ATLAS-SHEETS.

BRIEF OUTLINE OF RESULTS.

The economical importance of the Comstock Lode appears from the fact that in twenty-one years a little over $306,000,000 worth of bullion has been extracted from it. Of this about $132,000,000 worth was gold. The mines are the deepest in America, reaching a distance of over 3,000 feet from the surface, and they contain about 185 miles of galleries.

Besides the scientific importance attaching to the occurrence of the immense accumulation of ore, the Lode and District present other features of great interest. The nature of the rocks associated with the ores, some points of structure, and even the character of the deposit, have received different explanations at the hands of different observers. A digest of the memoirs of Messrs. von Richthofen, King, Zirkel, and Church forms one chapter of the volume.

The subject of rock decomposition has received especial attention in the examination described in this report. This study has led to some lithological and mineralogical observations of interest, and to the identification of all of the Washoe rocks with well-established rock species. The greater part of the hanging wall of the Lode is diabase; the "black dike" is also a variety of diabase, and the supposed trachyte of the District is a hornblende-andesite. The so-called propylite of Washoe comprises a number of Tertiary and pre-Tertiary rocks, reduced to a nearly uniform appearance by decomposition. The erroneous determination of these altered rocks as an independent species arose mainly from a confusion between green and fibrous hornblende and chlorite. The supposed propylites from the other districts in the United States, microscopical determinations of which have been published, were also examined and found to afford no sufficient evidence of an independent rock species.

A discussion of faulting leads to an explanation of the similarity of the shape of the west wall of the Lode and the form of the adjoining face of the Virginia range. The ravines of the latter are a direct result of faulting, and are only slightly modified by erosion. A cross-section of the country on the *Sutro Tunnel* line shows that the surface forms a logarithmic curve in accordance with the theory, which is further supported by experiments. The sheeted structure of the country seems to be referable to faulting and not to eruptive bedding. The theory leads to rules applicable in prospecting disturbed but not greatly eroded districts. The details of the topography of grassy hills are chiefly due to landslips, which come under the law of faults in a modified form, and the characteristic curves of smooth hill-slopes are logarithmic.

The order of succession of rocks in the Washoe District is: Granite, metamorphics, granular diorite, porphyritic diorite, metamorphic diorite, quartz-porphyry, earlier diabase, later diabase, earlier hornblende-andesite, augite-andesite, later hornblende-andesite, and basalt. Hornblende-andesite thus followed as well as preceded augite-andesite.

Chemical evidence is offered to show that the pyrite of the region is a result of the action of soluble sulphides on the ferro-magnesian silicates of the rocks. Chlorite is held to be a product of the decomposition of hornblende, augite, or mica, while epidote forms at the expense of chlorite under certain conditions, but never from feldspar. There is extremely little kaolinization at Washoe, the feldspars having yielded to another kind of decomposition The diabase of the hanging wall when fresh was argentiferous and auriferous, and the precious metals of the Lode are traced to this rock with much probability, the lateral-secretion theory being thus affirmed. It is further supported by the dependence of the other ore bodies of the District on the character of the inclosing rock.

The hypothesis that the heat of the Lode is due to the kaolinization of feldspar is not confirmed either by theory or experiment. On the other hand, there is much geological evidence pointing to a deep-seated source of heat, probably of volcanic origin. This conclusion is confirmed by extensive temperature observations, from which it appears that from the surface downwards the increase of heat is uniform, about 1° F. for every 33 feet, while in a horizontal direction the heat decreases in a geometrical ratio to the distance from the Lode.

Experiments on the kaolinization of feldspathic rock, conducted at the boiling point of water and extending over a number of weeks, show that no heating effect due to this cause could be detected with an apparatus delicate enough to register a change of temperature of 0°.001 C.

The numerous geological sections are discussed in Chapter VIII., and the application of the explanations suggested in the preceding chapters is there shown in detail. All the important and profitable ore bodies of the Comstock, it appears, have occurred at or close to the west face of the earlier diabase; and it is near that surface, and there only, that exploration is at all likely to be successful. The mode of occurrence of bonanzas is considered, and hopeful prognostications are made for at least two portions of the Lode; but a series of bonanzas nearly on the same level, such as was found in the east vein near the surface, is not likely to recur.

Electrical surveys were made both on the Comstock and at Eureka. At Virginia only negative results were obtained. At Eureka a distinct though small difference of potential occurs near ore bodies, and with sufficiently delicate apparatus the method might there be used for prospecting. It is believed that sulphuret ores would have given results of a more convenient magnitude than the carbonate ores of Eureka.

GEOLOGY OF THE COMSTOCK LODE AND THE WASHOE DISTRICT.

BY GEORGE F. BECKER.

CHAPTER I.

THE COMSTOCK MINES.

Importance of the Comstock mines.—The geology of the COMSTOCK LODE, though of great interest from a purely scientific point of view, derives its chief significance from the economical, industrial, and technical importance of this extraordinary ore-deposit. The yield of the COMSTOCK is supposed to have exerted a seriously disturbing influence on the monetary system of the civilized world, and its treasures have been exploited with an unexampled rapidity. It is the chief focus of mining activity in the region west of the Rocky Mountains, and represents the most highly organized phase of technical mining which has been reached west of the Mississippi River.

The present report deals exclusively with the geology of the LODE, and of so much of the surrounding country as is supposed necessary to a full comprehension of the occurrence of ore. The Geological Survey, however, will issue other volumes dealing with the COMSTOCK from different points of view. Mr. Eliot Lord has prepared a report upon the history of mining on the COMSTOCK; and Mr. W. R. Eckart has in preparation a volume on the mining machinery in use. The volumes now being prepared by members of the Survey on the census of the mineral industries, will also contain much technical information concerning the mines of the LODE. Some of the readers of the present report, however, are unlikely to refer to the other volumes relating to the subject, and to them a few introductory remarks setting forth in the briefest possible manner some of the most important facts concerning the mines may be of interest.

Geographical position.—The COMSTOCK LODE lies on the eastern slope of the Virginia Range, a northeasterly offshoot from the Sierra Nevada. From Mount Davidson the snow-capped peaks of the Sierra can be seen stretching far away to the southeast, their flanks partially covered with trees; but to the east and northeast lies the desert region of the Great Basin, visible through the clear air for a hundred and fifty miles. Comparatively low ranges, running north and south, break the surface of the Great Basin at short intervals, and as seen from Virginia these appear in seemingly endless succession, like the waves on a stormy sea. They are clothed only by the low growing, gray-green desert shrubs known as "sage-brush," and every detail of the mountain sculpture is visible through the vaporless atmosphere at great distances. White alkali deserts appear here and there in the valleys, and now and then one catches a glimpse of the Carson River, which dwindles almost from its source, and is at last wholly absorbed in the parched earth. The Great Basin, which is five hundred miles wide, is bounded to the east and west by high ranges. During the greater part of the year these mountains precipitate almost all the moisture from the air-currents passing over them, and at certain stations in the Basin ordinary meteorological instruments sometimes fail to show any moisture in the air.

The parallelism of structure expressed by the disposition of the ranges in California and the Great Basin finds a correspondence in the distribution of metalliferous minerals, as was long since pointed out by Prof. W. P. Blake. The coast ranges of California carry quicksilver, coal, and chromic iron. On the western slope of the Sierra Nevada is a lower belt of copper deposits, and a higher and more easterly one of gold. Along the eastern base of the Sierra is a zone of silver deposits, the richest known point of which is the COMSTOCK, while still farther east in the Great Basin there are less sharply defined belts carrying complex silver ores and argentiferous lead.

Difficulties of mining.—Mining on the COMSTOCK began in 1859, and has been carried on ever since, but only in spite of obstacles of the most formidable character. Only the scantiest supplies of potable water existed on the spot, and that obtained from the mines was not fit even for the production of steam. After many difficulties this want was overcome by laying lines of pipe to a source in the Sierra Nevada, 25 miles from the LODE, at a cost of $2,200,000. Up to 1870 not only all the machinery, but almost all the food of the settlement was transported by wagon from beyond the Sierra, mainly from Sacramento, a distance of 165 miles. The freight charges were of course enormous; in the earliest days as high as fifty cents a pound; but later from five to ten cents. The Carson Valley, however, furnished a small portion of the necessary food supply. In 1870 a branch railroad from the Central Pacific was completed. The junction is at Reno, 22 miles from Virginia; but the railway connecting the two points is 52 miles in length, a fact which indicates the character of the country through which it passes. Fuel and timber are obtained from the Sierra at points from 10 to 30 or more miles distant; but transportation down the slopes of the range is effected in flumes by water with a great saving of expense. The difficulties to be overcome in mining on the COMSTOCK were not less formidable than those met with in establishing a settlement. The ground has been in great part very bad, the size of the ore-bodies required the development of a new system of timbering, and floods have burst into the mines which it took years to drain; but by far the greatest obstacle has been the heat, which increases about 3° Fahrenheit for every additional hundred feet sunk, and which seems likely eventually to put an end to further sinking. According to Mr. Church, the amount of air passing through the mines is nearly 300,000 cubic feet a minute, while, except at the change of shift, there are probably never 1,000 men below ground; yet there are few spots where the miners can work more than each alternate hour during the eight hours' shift, so that double gangs to relieve each other are practically always necessary, and at many points the conditions are still more disadvantageous. Besides every alleviation which artificial ventilation can afford, the men must also be supplied with unlimited quantities of ice-water both for drinking and washing. With all these unheard-of easements, many men have died from overheating, and some from contact with scalding water. Many more have fainted while coming to the surface on the cages when they met the cool air, and have been dashed to pieces in the shafts.[1] None of the miners in the hot mines receive less than $4 a day (eight hours), and a few get more.

Good condition of the miners.—In spite of the trying conditions the men are, with very rare exceptions, in excellent physical condition. This appears to be attributable to two causes. Even those who desire to practice close economy find themselves unable to live on the coarse fare on which miners in other districts frequently subsist. They must have not only fresh meat but fruit at any cost, and are large consumers of raw oysters brought from San Francisco on ice, and similar delicacies. In short, they are compelled by the physical effects of the conditions to which they are exposed, to employ a much better diet than most workingmen. Moreover, while in the mines, they are almost constantly in a perspiration as profuse as that induced by a Turkish bath, a condition almost incompatible with bilious disorders. They are thus much less liable than other workmen to derangements of the digestive system, and are well nourished and extremely vigorous. The average weight of the men is 166 pounds. It is said that short as the hours of labor are, the work accomplished per man is as great as in cool mines. In the *California* in 1877 the average amount of ore raised per man, including employés of every kind, was 1.13 tons per day.

Population.—The average number of miners employed from 1860 to 1870 was, as nearly as can be ascertained, about 1,500. From 1870 to 1880 it was probably as high as 3,200, but in January, 1880, the number had fallen off to 2,770. The population of the towns of Virginia, Gold Hill, and Silver City has fluctuated greatly with the condition of the mines and the number of miners at work. Silver City has never had many inhabitants, while Gold Hill and Virginia long since extended over the space which originally separated them, and are divided only by artificial lines. In round numbers the population of the three settlements in 1860 was 4,000; in 1870, 13,000; and in 1880, 15,500. The maximum number of inhabitants thus far was about 21,000 in the year 1876.

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[1] It may not be improper to remark that geological examinations, which cannot of course be confined to actual workings where everything possible is done to keep the air good, are exceedingly trying. All the members of my party were at times more or less overcome by heat and bad air. I once fainted on the cage, and owe my life to the firm grasp of Mr. Hugh Lamb, foreman of the *Consolidated Virginia* and *California* mines.

School statistics.—It would be easy to illustrate the wild life characteristic of the mining camps of the far West by citing the liquor consumption of Virginia and Gold Hill, or the statistics of gambling, which is a legal occupation in the State of Nevada; but it is pleasanter and, in some respects, more just, to turn to the school statistics of these towns. The methods employed in the primary and grammar schools appeared to me fully equal to those in use in the larger cities of the Union, and the results reached at least as good. The proportion of children attending school is certainly remarkable, when it is considered that of those reported as not attending either public or private schools a very large number must be considered by their parents too young to be sent, while many more have left school after a number of years' instruction. The official figures for Storey County are as follows:

School attendance.	1870.	1880.
Number of children between 6 and 18 years not attending school	62	763
Number of children between 6 and 18 years represented as attending private schools	211	543
Number of children between 6 and 18 years represented as attending public schools	493	2,565

The number of boys and girls in the schools is very nearly equal. The proportion of children to adults is of course far smaller in these towns than in ordinary settlements, a very large part of the miners being unmarried, and some having families elsewhere.

Extent of the mines.—The total length of galleries and shafts on the COMSTOCK up to January, 1881, is, as nearly as can be ascertained, between 180 and 190 miles. Of this about 154 miles is a matter of record on the official maps, but though all more important galleries are run by survey and plotted on the maps, many drifts of subordinate importance are cut without the help of the surveyor. These are estimated at a total of 30 miles, after consultation with surveyors and superintendents. An immense consumption of timber is a necessity of mining on the COMSTOCK. This is due to the shifting character of much of the ground, to the great size of the ore bodies, and to the necessity of keeping a large extent of workings open to secure rapid ventilation, and as great a diminution of temperature as practicable. The timbers are all sawn square, the commonest size being 12 by 12 inches. They are cut in lengths and the ends fitted in shops on the surface, and they are placed underground without the use of nails. The system is described in Mr. J.

D. Hague's admirable memoir, "The Comstock Mines,"[1] and has undergone no essential modification since the date of that work. The consumption of timber in the mines up to the close of 1880 is estimated at 450,000,000 board feet.

The only fuel used on the Comstock is wood, derived from the same sources as the timber. The larger part reaches the town by rail, but a considerable quantity is floated down the Carson River to convenient points, and hauled to Gold Hill in wagons. The consumption of fuel at the mines in hoisting and pumping is increasing rapidly, for the quantity of water is greater year by year, as well as the distance through which it must be forced. During the census year, ending May 31, 1880, about 110,000 cords were burned; and from 1860 to 1880 the consumption cannot have been less than about 900,000 cords. The mills have burned about as much.

Milling.—In the early days of mining on the Comstock considerable quantities of very rich and complex ores occurred, and these were treated by roasting and barrel-amalgamation. Later the ores became more facile, and the system of pan-amalgamation was developed and applied with success. For many years it has been found practicable to beneficiate all the ores met with by this process, with the aid of "bluestone" (cuprous sulphate) and salt. The success of the process is unquestionably due in a large measure to the chemical activity of the iron. Formerly the mills guaranteed a return of 65 per cent. of the assay value of the ores, but of late years 72 per cent. is guaranteed, and above 80 per cent. is often returned. The slimes and tailings belong to the mills, which work them up for their own account or sell them from time to time to other mills having especial facilities for their treatment Tailings not caught by the mills and deposited at considerable distances in the streams have also been treated with success in a small way. On the whole, however, it is improbable that more than 75 per cent. of the bullion contained in the ore has been recovered from it, and it is therefore fair to estimate that the ore received has contained at least four hundred million dollars, of which about three-quarters has reached the market.

Relative quantities of gold and silver produced.—The question of the proportion of gold to silver in the Comstock bullion is one of considerable importance in

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[1] Exploration of the Fortieth Parallel, Vol. III.

discussions upon the price of silver and kindred subjects. It has often been assumed that the product of these mines is almost wholly silver, but as will appear from the tables it would be much nearer the truth to assume that the Lode yielded an equal value of each of the precious metals. I find that the published and accessible mine reports give the assay values of nearly two-thirds of the total product, and there is every reason to suppose that Baron v. Richthofen's estimate, made when the total product was comparatively small and very recent, was a very close approximation to the truth. Some of the mining companies reported only the total value of bullion produced; and others gave the gold and silver assays in some years, but not in others, or only for certain lots of bullion. The figures, however, cover portions of all the important ore bodies excepting that in the *Justice*, and it appears certain that not far from 57 per cent. of the product of the Lode has been silver, or, say, $174,000,000, and that 43 per cent., or $132,000,000, has been gold. The table from which this conclusion is drawn is given in considerable detail, chiefly for the purpose of showing the differences in the ratio of gold to silver in the various mines. In the *Belcher*, for the time over which the record extends, about 57 per cent. of the value of the bullion produced was in gold, while in the *Yellow Jacket* only about 31 per cent. was in gold. Even in the great bonanza of the *Consolidated Virginia*, *California*, and *Ophir* mines, the *California* or central portion of the body was far richer in gold than the northern and southern ends.

The table of production is due to Mr. Eliot Lord, who has taken great pains to sift the records and to ascertain the truth as closely as is now practicable. This and the other appended tables need no further explanation.

SUPPLIES BROUGHT TO THE COMSTOCK TOWNS DURING THE CALENDAR YEAR 1879, AND ESTIMATED CONSUMPTION.

Character.	Unit.	Total amount.	Mine use.	Mill use.	Permanent construction.	Domestic use.
Wood	Cords	185, 622½	110, 000	40, 000		35, 622½
Timber	Board feet	31, 443, 771	25, 000, 000			6, 443, 771
Iron	Pounds	2, 373, 919	873, 919	1, 500, 000		
Steel	do	183, 366	122, 244	61, 122		
Candles	do	725, 092	725, 092			
Powder	do	520, 319	520, 319			
Fuse	do	51, 594	51, 594			
Mining machinery	do	5, 910, 355			5, 910, 355	
Nails	do	462, 442			462, 442	
Nuts	do	32, 514			32, 514	
Pipe	do	1, 003, 808			1, 003, 808	
Shovels	do	29, 251	27, 251	1, 000		1, 000
Lard oil	Gallons	119, 207	89, 405	29, 802		
Lubricating oil	do	16, 672	11, 115	5, 557		

ADDITIONAL, USED BY THE MILLS.

Character.	Unit.	Total amount.	Mine use.	Mill use.	Permanent construction.	Domestic use.
Quicksilver	Pounds			300, 000		
Bluestone	do			2, 500, 000		
Salt	do			450, 000		

MINE AND MILL SUPPLIES CONSUMED ON THE COMSTOCK DURING THE CALENDAR YEAR 1879.

COST.

Character.	Mine use.	Mill use.	Total.
Wood	$1, 100, 000 00	$400, 000 00	$1, 500, 000 00
Timber	500, 000 00		500, 000 00
Iron	52, 435 14	90, 000 00	142, 435 14
Steel	22, 003 92	11, 001 96	33, 005 88
Candles	123, 265 64		123, 265 64
Explosives	208, 127 60		208, 127 60
Quicksilver		135, 000 00	135, 000 00
Salt		25, 000 00	25, 000 00
Bluestone		45, 000 00	45, 000 00
Lard oil	89, 405 00	29, 802 00	119, 207 00
Lubricating oil	4, 446 00	2, 222 80	6, 668 80
Sundries	*106, 149 00	†75, 000 00	181, 149 00
Total	2, 205, 832 30	813, 026 76	‡3, 018, 859 06

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* Including ice, water, charcoal, coal oil, stone coal, tools, etc.

† Including water, tools, lights, chemicals, etc.

‡ Does not include machinery, etc., entering into permanent construction.

PROPORTIONS OF GOLD AND SILVER IN COMSTOCK BULLION.

[From official reports of the mining companies, so far as accessible. The product is not, in all cases, thus segregated into gold and silver in the companies' reports. The figures quoted are of assay (not market) values.]

Source.	Gold.	Silver.	Total.	Percentage.	
				Gold.	Silver.
GOLD HILL GROUP.					
Crown Point, from May 1, 1864, to May 1, 1877	$10, 166, 656 88	$13, 762, 812 77	$23, 929, 469 65	....	....
Belcher, from January 1, 1871, to December 31, 1873	8, 813, 196 06	6, 716, 231 05	15, 529, 427 11	....	....
Yellow Jacket, year ending June 1, 1872	170, 133 12	363, 123 80	533, 256 92	....	....
Imperial, from June 1, 1864, to May 31, 1870	1, 973, 021 60	2, 588, 138 85	4, 561, 160 45	....	....
Empire, from December 21, 1864, to December 16, 1868.	563, 121 83	786, 713 69	1, 349, 835 52	....	....
Total for Gold Hill group	21, 686, 129 49	24, 217, 020 16	45, 903, 149 65	47. 25	52. 75
CENTRAL GROUP.					
Savage, July 1, 1866, to June 30, 1873	3, 661, 220 70	7, 090, 573 61	10, 751, 794 31	....	....
Gould & Curry, December 1, 1865, to November 30, 1867.	577, 729 22	1, 219, 113 16	1, 796, 842 38	....	....
Hale & Norcross, March 1, 1866, to January 31, 1874	2, 772, 468 28	4, 774, 187 26	7, 546, 655 54	....	....
Chollar-Potosi, June 1, 1867, to May 31, 1874	3, 868, 488 14	6, 314, 261 66	10, 182, 749 80	....	....
Total for Central group	10, 879, 906 34	19, 398, 135 69	30, 278, 042 03	35. 93	64. 07
"BONANZA" GROUP.					
Consolidated Virginia, to December 31, 1880	29, 075, 338 97	35, 895, 438 98	64, 970, 777 95	....	....
California, to December 31, 1880	23, 308, 012 69	23, 428, 818 75	46, 736, 831 44	....	....
Ophir, 1865, and 1875, 1876, and 1877	2, 172, 600 57	2, 608, 744 28	4, 781, 344 85	....	....
Total for "Bonanza" group	54, 555, 952 23	61, 933, 002 01	116, 488, 954 24	46. 83	53. 17
RECAPITULATION.					
Gold Hill group	21, 686, 129 49	24, 217, 020 16	45, 903, 149 65	....	....
Central group	10, 879, 906 34	19, 398, 135 69	30, 278, 042 03	....	....
"Bonanza" group	54, 555, 952 23	61, 933, 002 01	116, 488, 954 24	....	....
Total	87, 121, 988 06	105, 548, 157 86	192, 670, 145 92	45. 22	54. 78
Baron von Richthofen's estimate of the yield of the Comstock to close of 1865	15, 250, 000 00	32, 750, 000 00	48, 000, 000 00	31. 77	68. 23
Total	102, 371, 988 06	138, 298, 157 86	240, 670, 145 92	42. 54	57. 46

BULLION PRODUCT OF THE COMSTOCK LODE TO JUNE 30, 1880.

[So far as ascertainable from the official reports of the mining companies and the assessors' returns.]

1 ounce silver=$1.2929.

Mine.	Date.	Ore treated.		Average yield per ton.	Product.
		Tons. (2,000 lbs.)	Pounds.		
Alta	1879 to June 30, 1880	463	....	$10 38	$4,808 66
American	1871	2,233	250	14 38	32,116 66
Andes	1875 to 1878, inclusive	2,532	....	16 86	42,705 00
Bacon	1867 to 1869, inclusive	22,846	....	24 99	570,931 25
Belcher	1868 to June 30, 1880	702,236	300	46 52	32,672,166 29
Bowers	1867 to 1875, inclusive	4,795	....	17 36	83,245 95
Burke & Hamilton	1868	1,008	1,000	28 22	28,465 99
Caledonia	1871 to 1873, inclusive	26,957	1,450	12 50	337,028 10
California	1876 to June 30, 1880	559,422	1,135	82 72	46,278,999 72
Challenge	1867 to 1873, inclusive	1,943	333	22 56	43,839 05
Chollar	1879	1,026	....	14 21	14,585 02
Chollar-Potosi	1866 to 1878, inclusive	556,351	1,540	24 21	13,471,917 97
Confidence	1867 and 1868	10,470	....	20 74	217,217 28
Consolidated	1867 and 1868	11,831	....	42 65	504,561 49
Consolidated Imperial	1876 to June 30, 1880	37,787	700	15 42	583,012 49
Consolidated Virginia	1873 to June 30, 1880	784,216	21	82 26	64,508,470 23
Crown Point	1864 to 1878, inclusive	815,605	1,010	36 84	30,049,673 50
Eclipse	1868	3,174	....	25 65	81,431 04
Empire	1864 to 1877, inclusive	162,164	....	21 05	3,414,594 12
Gold Hill M. & M. Co	1867 to 1872, inclusive	10,150	....	23 70	240,525 67
Gould & Curry	1860 to 1873, inclusive	306,205	256	50 70	15,525,110 13
Hale & Norcross	1866 to 1875, inclusive	320,592	230	24 91	7,986,675 49
Hartford	1871	2,101	....	9 02	18,951 18
Imperial	1864 to 1876, inclusive	223,047	1,740	23 42	5,224,672 75
Justice	1873 to 1879, inclusive	183,174	1,073	19 40	3,554,461 69
Kentuck	1865 to 1872	142,289	1,220	34 47	4,905,271 01
Luzerne	1871 and 1872	11,386	....	5 08	57,853 61
Mexican	1867	811	....	35 32	28,645 79
Midas	1871 and 1872	1,263	....	9 97	12,601 53
Ophir	1860 to June 30, 1880	*165,038	1,725	37 79	13,659,622 33
Overman	1866 to 1877, inclusive	77,623	448	18 18	1,411,489 06
Plato	1868	797	1,000	19 71	15,728 47
Potosi	1879	8	....	15 53	124 27
Savage	1863 to June 30, 1880	482,286	210	34 32	16,552,254 23
Segregated Belcher	1867 to 1871, inclusive	4,961	1,000	20 44	101,466 81
Sierra Nevada	1868 to June 30, 1880	119,660	....	8 64	1,035,363 16
Silver Hill	1873 to 1879, inclusive	13,346	....	10 53	140,657 17
Succor	1871 to 1873, inclusive	16,200	....	10 03	162,440 51
Trojan	1877 to 1879, inclusive	12,810	750	11 27	144,392 81
Union Consolidated	1879 to June 30, 1880	30,247	175	38 84	1,174,803 45
Woodville	1872 to 1875, inclusive	7,076	....	17 21	121,813 33
Yellow Jacket	1864 to 1876, inclusive	443,747	655	29 29	12,998,170 82
Total		6,281,885	221	44 26	278,012,865 08

* Tonnage from 1860 to 1870 not ascertainable; average stated is for $165,038\frac{1725}{2000}$ tons produced from 1874 to 1880, inclusive.

BULLION PRODUCT OF OTHER MINES IN THE WASHOE DISTRICT TO JUNE 30, 1880.

Mine.	Date.	Ore treated.		Average yield per ton.	Product.
		Tons. (2,000 lbs.)	Pounds.		
Brophy	1873	240	....	$8 11	$1,948 10
Lady Bryan	1868 to 1876, inclusive	3,425	....	18 83	64,507 96
Monte-Christo	1879 to June 30, 1880	1,004	....	10 98	11,033 00
Occidental	1868 to 1873, inclusive	7,849	....	19 25	151,152 87
Vivian	1875 and 1876	2,161	....	15 81	34,165 00
Total		14,679	....	17 90	262,806 93

BULLION PRODUCT FROM TAILINGS OF COMSTOCK ORES TO JUNE 30, 1880.

[So far as ascertainable from official reports of the mining companies and the assessors' returns.]

1 ounce silver = $1.2929.

Mine.	Date.	Product.
Belcher	1868	$229 97
Burke & Hamilton	1868	4,811 96
Chollar-Potosi	1868 and 1869	45,406 63
Gold Hill M. & M. Co	1871 and 1872	8,342 45
Gould & Curry	1865 to 1869, inclusive	334,918 94
Hale & Norcross	1867 and 1868	1,550 89
Hartford	1871	195 50
Overman	1870	29,362 01
Savage	1866 to 1870, inclusive	81,828 94
Sierra Nevada	1871	10,000 00
Yellow Jacket	1868 and 1869	24,983 99
Tailings worked by various mills	1871 to June 30, 1880	3,765,000 74
		4,306,632 02

RECAPITULATION.

Product of the lode traceable by mines	$278,012,865 08
Product of other mines in the district	262,806 93
Tailings	4,306,632 02
Total product directly traceable	282,582,304 03
Estimated additional production, chiefly in early years	23,598,947 02
Total yield of the Washoe District to June 30, 1880	306,181,251 05

CHAPTER II.

PREVIOUS INVESTIGATIONS OF THE COMSTOCK LODE.

v. Richthofen's report.—In 1865, Baron Ferdinand von Richthofen made an examination of the Comstock for the *Sutro Tunnel Company*, a report of which was issued by that corporation, but never published in the proper sense of the word.[1] It met the ordinary fate of mine reports, and is now scarcely obtainable. It was, however, a very important contribution to American geology, and no one who has studied the Lode has failed to acknowledge his indebtedness to it. The mines are now about six times as deep as at the date of von Richthofen's examination, but his opinions and predictions have for the most part been verified in a very remarkable manner; and had his lithological determinations been as accurate as his insight into structure was keen, I should have had little to do beyond confirming and amplifying upon his views, in spite of immensely increased facilities for observation. In lithology, as is well known, there has been almost a revolution since von Richthofen wrote, and nothing is less strange than that some of his determinations should fail to stand microscopic tests. On account of the rarity of Baron von Richthofen's report, I take the liberty of reproducing almost entire and verbatim its geological portions. In these days of diffuse writing its conciseness must be regarded as one of its important merits.

Rocks of the district.—The more important rocks of the Washoe district are as follows:

Syenite, containing both orthoclase and oligoclase,[2] mica and epidote,

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[1] The Comstock Lode: its character and probable mode of continuance in depth. By Ferdinand Baron Richthofen, Dr. Phil. (Nov. 22d, 1865), San Francisco: published by the Sutro Tunnel Company. Towne & Bacon, printers, 1866. 83 pp. 8vo.

[2] Professor Zirkel showed ten years later, by the help of the microscope, that this rock contains exclusively plagioclase, and is therefore a diorite.

but no quartz. It forms the prominent topographical feature of the district, Mount Davidson. Adjoining the syenite to the north and south are metamorphic rocks, the most recent of which Prof. J. D. Whitney has shown to be Triassic. Overlying a portion of the metamorphic strata is quartzose porphyry.[1]

The foregoing form the ancient series. Of the Tertiary rocks only two[2] have any close relation to the COMSTOCK LODE. Propylite has this remarkable peculiarity, namely: that it resembles many ancient rocks exactly in appearance, and yet is among the most recent in origin. It is prominent among the inclosing rocks of the COMSTOCK vein and, besides, *incloses several, perhaps most, of the largest and most productive silver veins in the world*, as those in the Karpathian Mountains, of Zacatecas and other places in Mexico, and probably several veins in Bolivia. Mineralogically it consists of a fine-grained paste of ordinarily greenish, but sometimes gray, red, and brown color, with embedded crystals of feldspar (oligoclase), and columns of dark-green and fibrous, seldom of black, hornblende, which is also the coloring matter of the base. A peculiarity of the rock is its ferruginous character when decomposed. Probably it contains other metals besides iron. Geologically it is an eruptive rock, but it is accompanied by vast accumulations of breccia, which is sometimes regularly stratified. The flats of Virginia City, Gold Hill, American City, and Silver City consist of propylite It lies, in general, east of the mountains consisting of the ancient formations, and contains several mineral veins besides the COMSTOCK LODE. Its distribution in other countries of the world is not very general. Several different kinds of volcanic and eruptive rocks followed the outbreak of propylite, but only one of them demands attention in reference to the COMSTOCK vein, as it probably caused its formation, besides taking a prominent part in the structure of the country. This is sanidin trachyte.

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[1] In his memoir on The Natural System of Volcanic Rocks, p. 41, Baron von Richthofen says: "Quartzose porphyry occurs to some extent in Washoe under circumstances which make the exact determination of its age difficult, but render it certain that it is intermediate in this respect between granitic and volcanic rocks." This rock was later regarded by Mr. King as quartz-propylite, and determined by Professor Zirkel as dacite. (v. Quartz-porphyry.)

[2] In his Natural System of Volcanic Rocks, p. 31, Baron von Richthofen, speaking of the Washoe district, says: "Andesite is insignificant in bulk in that region. It composes a few hillocks on the propylitic plateau, and in some cuts and tunnels andesitic dikes may be seen."

The mode of occurrence of the trachyte shows that it has been ejected through long fissures in a viscous or liquid state, and at a high temperature. In some places the eruptions were subaqueous, as in the vicinity of Dayton. The entire table-land around that place is built up of stratified trachytic tufa. The solid trachyte rises from it in rugged mountains, which form an elevated and very conspicuous range, passing east of the intersection of Six-mile and Seven-mile Cañons across the Seven-mile Cañon (where, for instance, the Sugar-Loaf Peak consists of it), and bending in a semicircle round to Washoe Lake. Farther north this rock covers the country to a great extent. Sanidin trachyte has never been found to contain silver-bearing veins, and in Washoe none occur in it; and yet it has been mainly instrumental in the formation of the COMSTOCK LODE and other veins in that region. No geological events after that epoch are worth mentioning for the present object.

Mode of occurrence of the Comstock.—In 1865 only about 11,000 feet of the LODE had been explored to any extent, mainly the ground lying between the *Ophir North* mine and the *Overman*, and a few only of the mines had reached a depth exceeding 700 feet. At an average depth of 500 feet both walls were found dipping to the east at from 42° to 60°. Above this level the west wall preserved the same slope, while the east wall curved rapidly toward the vertical, and then to the east, giving the cross-section of the vein the shape of a funnel, a great part of the space in the enlarged portion next the surface being occupied by fragments of country rock or "horses," between which was the vein matter. The width of the belt in which these branches came to the surface, and there form scattered croppings, is generally more than 500 feet. To the west of the LODE a number of small veins show as croppings. They probably unite with the COMSTOCK in depth, and form with the latter what the Germans call a "Gangzug."

The course of the west wall, as far as explored, is somewhat dependent on the shape of the slope of the range at the base of which it lies. It partakes of all its irregularities, passing the ravines in concave bends, and inclosing the foot of the different ridges in convex curves; the greatest convexity is around the broad uninterrupted foot of Mount Davidson itself. These irregularities are of importance, as they influence the ore-bearing character of the vein. The west wall of the main vein is well defined; not so the east wall, where, as is often the case with true fissure veins, the country rock is impregnated with matter similar to that which fills the fissure. It is frequently concentrated in channels running parallel to or ascending from the vein, but in fact forming parts of it.

The rocks which accompany the COMSTOCK vein change in its course. They are different varieties of propylite on the eastern side throughout its whole extent. In some places the frequent and large crystals of feldspar give it a porphyritic character, which in certain varieties is rendered more striking by green columns of hornblende; at others, the rock has a very fine grain, and the inclosed crystals are of minute size; again, the rock is either compact and homogeneous, or it has a brecciated appearance from the inclosure of numerous angular fragments; the color also changes, though it is predominantly green, and the different degrees of decomposition create, finally, an endless variety. The causes to which it is due will be considered presently.

The western country offers more differences. Along the slope of Mount Davidson and Mount Butler, from the *Best & Belcher* mine to Gold Hill, it is formed by syenite, which at some places is separated from the vein by a fine-grained and crystalline rock of black color, having the nature of aphanite, but altogether obscure as to the mode of its occurrence. It is from 3 to 50 feet thick, and the elucidation of its real nature may be expected from further developments. As syenite to the west, and propylite to the east, occur just in that portion of the COMSTOCK vein which has been most explored, and where works, more than anywhere else, extend in both directions into the country, it has been generally assumed in Virginia that the LODE follows the plane of contact between two different kinds of rock, and is therefore a contact deposit. But immediately north of Mount Davidson, where propylite extends high up on the western hills, this rock forms the western country as well as the eastern, as at the *California* and *Ophir* mines, though at the latter metamorphic rocks and syenite are associated with propylite on the western side. On Cedar Hill syenite again predominates, but farther north propylite forms the country on both sides. South of Gold Hill the syenite disappears from the western wall, and its place is taken to some extent by propylite, but in greater part by metamorphic rocks. Nowhere have syenite and metamorphic rocks been found occurring on the eastern side.

The formation of the fissure was only in so far dependent on the contact between propylite and syenite, as it follows the same accidentally in part of its course, probably because the resistance along it was inferior to that offered by the solid masses of rock on either side. It is characteristic of fissure veins in general, not only that the country rock on one side has moved downward on the other, but also that within the space formed by the opening of the fissure powerful dynamic action has taken place. Few veins present these phenomena so distinctly as the COMSTOCK, the eastern side of which has apparently moved downward on the western; and the action within the vein is amply evinced by the brecciation of the vein matter, the presence of masses and seams of clay, the crushed condition of the quartz, etc.

There is a marked difference between the western and the eastern croppings. Those of the western branches of the vein carry principally crystallized quartz of a very glassy appearance, light color, and comparatively of a pure quality. Large angular fragments of the country rock are embedded in the quartz and form centers of its crystallization. Metalliferous minerals are scarce, though nowhere entirely wanting Nothing indicates underground wealth, nor indeed has such been found by subsequent mining. The only exception is Cedar Hill, where native gold was found abundantly in places, but its scarce distribution never justified great expectations. In the eastern outcrop particles of country rock, together with those of clayey matter and metallic substances, occur finely disseminated through the quartz, which is reddened by metallic oxides.

Contents of the Lode.—The vein matter is composed of fragments of country rock, clay, quartz, and ores. Near the surface about five-sixths of the mass of the COMSTOCK vein consists of horses, the shape and size of which vary with the different nature of the rock of which they consist. Those of propylite are confined throughout Virginia City to the east side, and they are, as a rule, longer and thinner than those of syenite. From the large horses every variety occurs down to the smallest fragments. The quartz is often so thickly filled with angular pieces as to have a brecciated appearance.

Propylite is much more common than syenite. Few large veins are so abundant in clay and clayey matter as the COMSTOCK. It forms the western and eastern selvages from north to south in continuous sheets sometimes of from 10 to 20 feet in thickness. Other sheets divide horses from quartz, or different bodies of the latter from one another. Most horses terminate at the lower end in clayey substances. The differences mentioned before as prevailing in the quartz of the outcrops continue downward, but are not so conspicuous in depth on account of the general white color of the quartz. Finely disseminated particles of wall rock are always abundant where the quartz contains ore. The quartz is generally fractured, and at numerous places the effects of dynamical action on it are such as to give it the appearance of crushed sugar. The principal silver ores of the COMSTOCK are stephanite, vitreous silver ore, native silver, and very rich galena. Quartz is the only gangue, though carbonate of lime and gypsum occur in places. Zeolites are limited to the northern portion of the vein, where chabasite and stilbite fill small fissures and cavities in propylitic breccia within the body of the vein.

The ore is distributed in a different way in the northern and southern parts of the vein. The passage between the two modes of occurrence is gradual. In the northern part the ore is concentrated in elongated lenticular masses, of which the greatest axis is not far from the vertical. The different ore bodies often adjoin each other in such a way as to make a nearly continuous line, as was the case in the *Gould & Curry* and the *Savage* mines. The ore has been exceedingly rich in the center of the different bodies, where, at the same time, it was soft and could be easily removed, while the outer parts were hard, and consisted of second-class and low-grade ore.

Near the center of the LODE, at the *Bullion* mine, quartz fills the entire width of the vein from the western to the eastern wall, though it is too poor for extraction. The occurrence of ore in chimneys and in barren portions between them ceases in this neighborhood. To the south the ore is concentrated in continuous sheets, the principal one of which is very near and parallel to the eastern wall. The second sheet occurred farther to the west, extending from the outcroppings to a couple of hundred feet in depth. This sheet dipped to the west at an angle of about 60°, flattening in depth and terminating in horizontal layers of clay. It was particularly rich in gold.

The yield of the ore has decreased in general from the surface downward. The deposits of the *Ophir* and *Mexican* and of the *Gould & Curry* were the richest. The former yielded on an average $107 per ton; the latter $70 and $80, notwithstanding the imperfect processes of extraction which were formerly applied. Ores of $600 to the ton were then no rarity, and considerable shipments could be made of such as yielded from $2,000 to $3,000 to the ton. It would now scarcely be possible to collect one ton of such ore. The general average of all the ores extracted in 1865 will not be more than $37 to the ton. The proportion of gold to silver decreased during the early period of the working on the COMSTOCK LODE, but is now again on the increase.

Source of the ore.—The COMSTOCK vein has neither been filled from above nor from the sides, as none of the surrounding rocks could have yielded the immense quantity of vein matter and ore; and had it been formed in this way, the mass would have a banded and comby structure, which is by no means observable. The eastern rock may, on account of its extensive decomposition, appear to favor the assumption of lateral infiltration; but this decomposition was effected by ascending currents, which have left distinct traces, and which could not have removed any matter in a lateral way. Thermal springs, which are considered by many authorities as the agent which carried mineral matter from below into fissures and to have formed every true vein, would not explain the formation of the COMSTOCK LODE. Silica, in such cases, is accumulated round the mouth of the fissures, and though ordinarily removed by denudation, it could hardly be supposed to be so at the COMSTOCK vein, as since its formation the surface has undergone but slight changes. But, besides, the decomposition of the eastern country for miles in extent cannot be explained by the action of thermal springs.

The COMSTOCK fissure is, of course, of more recent origin than the rocks which it traverses; and as propylite is predominant in the latter, the fissure must necessarily have succeeded it in age. The only event after the outbursts of propylite capable of producing such powerful action was the eruption of trachyte, which accompanies the vein at a distance of two miles to the east. As there is other evidence of its intimate connection with the Comstock vein, we may take it for granted that it caused the rending of the fissure.

Applicability of the ascension-theory.—We have in the elements evolved during the first two periods of solfataras, namely, fluorine, chlorine, and sulphur, all the conditions required for filling the Comstock fissure with such substances as those of which the vein is composed. Steam, ascending with vapors of fluosilicic acid, created in its upper parts (by diminution of pressure and temperature, according to well-known chemical agencies) silica and silicofluohydric acid, the former in solid form, the latter as a volatile gas, which acts most powerfully in decomposing the rocks it meets on its course. The chloride of silicon in combination with steam forms silica and chlorhydric acid. Fluorine and chlorine are the most powerful volatilizers known, and form volatile combinations with almost every substance. Besides silicon, the metals have a great affinity with them. All those which occur in the Comstock vein could ascend in a gaseous state in combination with one or the other of them. They must then be precipitated in the upper parts as metallic oxides or chlorides, and in the native state. Thus the fissure was gradually filled from its upper portion downwards, with all the elements which we find chemically deposited in it. A fissure is ordinarily not stationary after its first opening; but by subsequent action may from time to time widen and frequently contract again. New channels would thus be opened where the old ones were obstructed. If such widening or opening of an empty space within the matter filling the old fissure was followed by emanations rich in metallic vapors, then the conditions would be given for the formation of a body of ore of the shape of the newly-opened chasm, which corresponds precisely to most of the bodies of ore in the Comstock Lode. Contemporaneously with the filling of the fissure, the adjoining rock would be acted upon by the ascending acid vapors, and its nature by them entirely changed. Cracks would form in it, and be filled with substances similar to those of the vein itself. As the Comstock vein has an eastern dip, and the action of forces manifests itself towards the surface, only the rock on the hanging wall, or the eastern country, would be influenced in this way. Crevices branching off from the main fissure would probably penetrate into the hanging wall, and it may reasonably be expected that deeper workings will disclose such branches filled with vein matter, and probably of ore-bearing character, east of the main body of the vein.

Alteration of minerals in situ.—A transforming action must necessarily take place from the very commencement of the decomposition of matter in the fissure. Sulphurous acid and sulphuretted hydrogen, which were among the escaping gases in the first period, together with combinations of fluorine and chlorine, gradually became predominant, marking the second period of solfataric action. But little more matter could be introduced into the fissure, as the combinations of sulphur with mineral substances are not volatile. Chemical transformation was now the principal action within the vein. Silica is deposited from its combinations with fluorine and chlorine in a gelatinous state, very different in its physical character from those of the crystalline quartz which fills the vein. It must undergo a solution in water, with which, in the form of steam, it was impregnated, in order to assume this character. Metallic oxides and chlorides were converted into sulphurets, and the presence of antimony caused the formation of sulph-antimoniurets, the principal one of which is stephanite. By such processes the entire vein matter was gradually converted from its former condition into that which it presents at this day.

Fluorine and chlorine.—It is a fact worthy of notice that there is scarcely a single chemical agent, excepting fluorine and chlorine, which would not carry metallic substances into fissures in exactly or nearly the reverse quantitative proportion from that in which they occur in silver veins. Iron and manganese are not only more abundant in rocks, but also much more easily attacked and carried away by acids than silver and gold. The proportion of these to the former ought, therefore, to be still smaller in mineral veins than it is in rocks, and lead and copper ought to be more subordinate, if their removal from their primitive place had been effected by other agents than fluorine and chlorine. Only these two will first combine with those metals which are most scarce in rocks, and relatively most abundant in silver veins; and they are probably the only elements which have originally collected them together into larger deposits, though these may subsequently have undergone considerable changes, and water may have played altogether the most prominent part in bringing them into their present shape.

Wide-spread solfataric action.—Though it seems that the COMSTOCK fissure was the principal theater for the emission of steam, and all those phenomena which may be comprised by the name of solfataric action, yet the latter left its traces over a wide extent of the adjacent country. The entire belt of rounded hills, extending east of the vein for two miles, to the foot of the trachytic range, shows its effects very conspicuously. It consists of propylite, which, however, can scarcely be recognized on account of the complete decomposition it has undergone, and which has transformed it into a clayey rock of red and yellow color, but still showing distinctly the inclosed crystals of feldspar and hornblende. It is traversed by numerous crevices from which the decomposition originated, and shows everywhere evidences of vertically ascending currents which caused it. Whoever has seen active solfataras will be struck by the resemblance of chemical action on the surrounding rocks to that displayed in the region east of the COMSTOCK LODE. Near some of the crevices the decomposed rock is strongly impregnated with silica, producing the ranges of red-colored bluffs which accompany the COMSTOCK vein to the east, and which have been partly located as outcroppings of veins, while at about two miles' distance real metalliferous veins occur, promising in their outcrops, but not yet explored. Besides this belt the former action of solfataras is plainly visible in many parts of the country. The formation of the COMSTOCK vein is but one of its manifestations.

Continuity of the Lode in depth.—As it has been shown that the vein was filled from a deep-seated source, it is certain that it is continuous in depth. The inclination is not likely to vary considerably, for not only is the west wall remarkably regular, tending to show its continuity, but the previously mentioned solfataric action to the east is an evidence that the vein underlies the country rock in this direction for a long distance. As for the mean width of the vein in depth no definite prediction can be made. In some places the vein at a distance of 500 feet from the surface forms a channel of 120 feet or more in width; at other points it is contracted. Such places must necessarily occur in an inclined vein of some magnitude, since the hanging wall, during the long periods of the filling of the fissure, required some support. The walls of every true fissure vein are uneven planes. The downward movement of one side of the fissure on the other, at the time of the formation of the vein, caused protuberances of one wall to meet such of the other, and concave places to come opposite to each other. This is the reason why every large fissure vein is liable to repeated expansions and contractions, though the former prevail largely over the latter. It is to be expected that the COMSTOCK LODE will exhibit the same feature in its downward course to indefinite depth, as it has done heretofore, though its general width will probably remain nearly equal to that which it possesses in the lowest works. The formation of large horses is, from the nature of their origin, more peculiar to upper than to lower levels, since their breaking down from the hanging wall will in every fissure be most apt to take place where the latter is of comparatively inferior thickness, than where it is hundreds or thousands of feet wide. But small fragments may separate from it at any depth, and their quantity will chiefly depend upon the nature of the rock and the power of decomposing agents. If any change as to the inclosing rocks should occur in depth, it is probable that propylite will disappear on the western side and syenite predominate there more and more.

Probable character of the Lode in depth.—All the evidences in the upper levels justify the expectation that the foot wall will continue with its smooth and regular clay-selvage, while the irregularity and indistinctness of the eastern side will not diminish but rather increase as its true character as hanging wall will become more conspicuous. The vertical sheets of clay which have from time to time been cut in the adits east of the vein, rise undoubtedly from the hanging wall. Clay seams within the body of the vein will probably diminish with the increase of unity in inclination. Those which are at present observable at upper levels are particularly occasioned by the vertical position of the vein-matter, which of course facilitates sliding motions. Larger accumulations of clay will especially continue near the old ravines.

The ores, through all the levels explored, retain the character of true silver ores which they had near the surface. The amount of lead, copper, iron, and zinc has never been large in the COMSTOCK ores, and these metals preserve now at the lowest levels nearly the same relative proportion as formerly. Their increase, especially of lead, would be the most unfavorable indication for the future of the COMSTOCK LODE; as, besides the growing difficulty of metallurgical treatment, the conclusion would be justified that lead ores would more and more replace those of silver, and the limits of profitable productiveness would soon be reached. But as it is, no deterioration is to be expected, even if an impoverishment takes place. It thus approaches in its ore-bearing character the great mother-veins of Mexico, and is different from those of Hungary.

Conclusions.—Considering these facts exhibited by the COMSTOCK vein itself, and comparing them with what is known about similar argentiferous veins, we believe we are justified in drawing the following conclusions:

1st. That the continuity of the ore-bearing character of the COMSTOCK LODE in depth must, notwithstanding local interruptions, be assumed as a fact of equal certainty with the continuity of the vein itself.

2d. That it may be positively assumed that the ores in the COMSTOCK LODE will retain their character of true silver ores to indefinite depth.

3d. That it is highly probable that extensive bodies of ore equal in richness to the surface-bonanzas will never recur in depth.

4th. That an increase in size of the bodies of ore in depth is more probable than a decrease, and that they are more likely to increase than to remain of the same size as heretofore.

5th. That a considerable portion of the ore will, as to its yield, not materially differ at any depth from what it is at the present lower levels; while besides there will be an increasing bulk of low-grade ores. We are led to this supposition by the similarity in character of all the deposits outside of the rich surface-bonanzas, and the homogeneous nature which almost every one of them exhibits throughout its entire extent.

6th. That the ore will shift at different levels from certain portions of the LODE to others, as it has done up to the present time. More equality in its distribution may, however, be expected below the junction of the branches radiating toward the surface, when the vein will probably fill a more uniform and more regular channel. Some mines which have been heretofore almost unproductive, as the *Central*, *California*, *Bullion*, and others, have therefore good chances of becoming metalliferous in depth. But throughout the extent of the vein it is most likely that the portion which lies next to the foot wall will continue unproductive, as it did from the surface down to the lowest works, while the entire portion between it and the hanging wall must be considered as the probable future source of ore. As remarked in the foregoing pages, it is also probable that repeatedly, in following the LODE downward, branches will be found rising from its main body vertically into the hanging wall, and consisting of clay and quartz. Many of them will probably be ore-bearing. Such bodies of ore should be sought for at all mines, in what is generally supposed to be the eastern country. Experience in the upper levels would lead to the supposition that such eastern bodies might carry richer ores than the average of the main portion of the vein.

7th. That the intervention of a barren zone, as is reported by good authorities to occur at the Veta Madre of Guanajuato, at the depth of 1,200 feet, is not at all likely to be met with in the case of the COMSTOCK LODE. The argument which we have to adduce for this conclusion has some weight from a geological point of view. It is a well-known fact that the inclosing rocks have usually great influence on the quantity and quality of the ores of certain metals in mineral veins, and that a rich lode passing into a different formation frequently becomes barren or poor. At the Veta Madre of Guanajuato a sudden decrease in the yield of the ore, at the depth of 1,200 feet, attends the passage of the lode into a different formation, which from thence continues to the lowest depth attained. No such change can ever be anticipated for the COMSTOCK LODE, since the structure of the country seems to indicate the continuity of the inclosing rocks to an indefinite depth.

King's memoir.—In 1867–'68 Mr. Clarence King, Geologist-in-charge of the Exploration of the Fortieth Parallel, made an examination of the COMSTOCK LODE.[1] In regard to lithology Mr. King mainly followed Baron v. Richthofen, but he recognized a much greater area of andesite than his predecessor, and the affinity between certain propylites and andesites. Of the latter he says: "The balance of probability points to a close alliance

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[1] Exploration of the Fortieth Parallel, Vol. III.

between this rock and propylite, and it will not be at all surprising if it should finally prove to be chemically identical and, in reality, only a different form." The rock determined as quartz-porphyry by Baron v. Richthofen, Mr. King regarded as quartz-propylite.

In discussing the relation of Mount Davidson to the vein, Mr. King calls especial attention to the agreement between the contours of the west wall of the Lode and those of the exposed face of the range. He considers this similarity as evidence that the wall is merely a continuation of the face of Mount Davidson, and that the syenite has undergone very little erosion since the opening of the fissure. It is not necessary to summarize Mr. King's very graphic description of the structure of the Comstock Lode in detail here, as I shall be obliged to use it in my own account of the vein, the portion which he examined having long been inaccessible.

Mr. King closes his memoir with the following summary:

King's summary.—"The ancient Virginia Range, prior to the Tertiary period, was composed of sedimentary beds of the great Cordillera system, which, in the late Jurassic epoch, had been folded up, forming one of the corrugations of that immense mountain structure which covers the western front of our continent. Accompanying this upheaval were outpourings of granite and syenite. The erosion which followed this mountain period escarped the ancient rocks, and modeled the eastern front of Mount Davidson into a comparatively smooth surface, whose average angle of slope sank to the east at about 40°. In the late Tertiary, at the time of the volcanic era, the Virginia Range shared in the dynamical convulsions which gave vent to successive volcanic outflows of immense volume and very remarkable character. The first and, so far as the Comstock Lode is concerned, the most important was of propylite, or trachytic greenstone, which deluged the range from summit to base, covering large portions of its ancient surface, and leaving here and there isolated masses, which rose like islands above the wide fields of volcanic rock. Subsequently followed the period of the andesites which, at their commencement, in the form of a thin intrusive dike, penetrated a new-formed fissure on the contact plane of the ancient syenite and the propylite. This earlier andesite period gave birth to the solfataras, which, bursting from a hundred vents, rapidly decomposed the surrounding rocks, and gradually filled the fissures of the Comstock with their remarkable charges of metal-bearing quartz. The latest flows of andesite poured out over the decomposed propylite; and since they are themselves unaltered, their appearance marks the period when solfataric action over wide areas had ceased. While it no longer maintained its energy through the broad zone of propylite, it still continued intensely active within the chambers of the Comstock Lode. Metallic contents were introduced into the quartz, the clay seams were formed by a rapid decomposition of the neighboring propylite materials, the horses reduced to a spongy, semi-plastic condition, and at last the final solidification of the quartz took place. Outside the vein two events of geological interest have occurred: first, the period of trachyte eruptions, when from the ruptures of the crust, parallel to the Comstock Lode, vast volumes of sanidin-trachyte overflowed the country; and, secondly, the less powerful but still important outpouring of basaltic rock, which marked the close of the volcanic era. Within the vein, and probably caused by one or both of these latter volcanic disturbances, a pressure has been exerted which has crushed and ground the masses of quartz into minute fragments. It is interesting to observe that while this force was great enough to crush quartz masses 150 feet in breadth into mere angular pebbles, the disturbances were insufficient to cause any actual faulting of importance. Both within and without the vein the solfataras gradually came to a close. The heated currents of water which even yet ascend into the lower levels of the mines, are evidence that at no very great depth a considerable temperature is still maintained; but this is only a faint relic of a once intense action."

Zirkel's report.—In 1875 Prof. Ferdinand Zirkel made a macroscopical and microscopical examination of the lithological collections of the Exploration of the Fortieth Parallel.[1] Among the slides which he described are thirty-three from the Washoe district He confirmed the independence of hornblende-propylite and quartz-propylite as lithological species, regarded most of the quartzose rock as dacite, corrected the determination of the granular diorite (which had been considered as syenite), and added augite-ande-

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[1] Exploration of the Fortieth Parallel, Vol. VI.

site, rhyolite, and a strange variety of basalt to the list of rocks previously recognized. Professor Zirkel formulates the diagnostic differences between propylite and andesite as follows:[1]

Propylite.—"*a* The general color of the propylitic groundmass has more of a greenish-gray, while the andesitic groundmass has more of a pure gray or brown tinge.

"*b.* In structure and in the behavior of its constituents, the propylite still resembles the older ante-Tertiary diorite-porphyries.

"*c.* The groundmass of the propylites is rich in minute particles of hornblende, while in that of the andesites this mineral appears only in the larger individuals, fine hornblende dust being wanting.

"*d.* The propylitic feldspars are usually filled with a considerable quantity of hornblende dust, while the andesitic feldspars are entirely without it: the latter not infrequently containing glass-inclusions, which do not seem to occur in the propylitic plagioclases.

"*e.* The color of the proper hornblende sections in propylite is always green (never brown), while the color of those in andesites is almost without exception brown; and the propylitic hornblende never shows the curious black border which is so common to that of andesites; and again, propylite in some cases contains, besides the largely predominating green hornblende, a few sections of the brown mineral, presenting, in many points, a strikingly peculiar aspect, while in andesites two kinds of hornblende never occur together.

"*f.* The propylitic hornblende is often distinctly built up of thin needles or staff-like microlites, and therefore is not regularly cleavable; which has never been found to be the case in andesites.

"*g.* The production of microscopical epidote (mainly by the alteration of hornblende), so very common in propylites, has, with one exception, never been observed in these andesites, and it is also unknown in the European occurrences.

"*h.* Augite often occurs as an accessory constituent in andesites, but it is comparatively very rare in propylites.

"*i.* The andesitic groundmass here and there seems to possess a half-glassy development: a glass-bearing propylitic groundmass has never been

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[1] Exploration of the Fortieth Parallel, Vol. VI., p. 132.

found; and herein is another point of resemblance to the old diorite-porphyries.

"All these differences between propylitic and andesitic hornblende also extend to both of the quartziferous members, quartz-propylite and dacite."

On page 117 Professor Zirkel states that the quartz of quartz-propylite contains fluid inclusions, and "behaves exactly like that of the ante-Tertiary dioritic porphyries, and differently from that of all other Tertiary quartziferous rocks, dacites and rhyolites, which only contain glass inclusions."

Church's memoir.—In 1877 Mr. J. A. Church made an examination of the COMSTOCK,[1] as a member of the United States Surveys West of the One Hundredth Meridian, under Captain Wheeler. Mr. Church accepted the lithology of his predecessors with some modifications a little difficult to follow, but though he mentions slides of the rocks, describes none. His memoir contains a number of ingenious hypotheses which would possess great importance if sufficient evidence in their favor could be adduced.

Lithology.—Mr. Church appears to use the terms porphyrite and propylite interchangeably for all strikingly porphyritic rocks of light color.[2] Rocks of dark color, whether from the presence of abundant hornblende or from the transparency of the feldspars, he appears to have regarded as andesite;[3] and asserts that it is quite safe to put the minimum number of north and south dikes of this rock at between twenty-five and fifty. Besides the masses which had hitherto been regarded as trachyte, he determined the rocks about the new *Yellow Jacket* shaft, and at other points, as remnants of the trachyte eruption. This leads to the supposition that he employed the term merely to designate soft, rough, light-colored, porphyritic rocks. In Mr. Church's opinion the diorite, propylite, and probably the andesite, were laid down in thin regular layers, which he compares to those of sedimentary rocks. This he considers proved by the sheeted character of the rocks in the east and west country.

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[1] The COMSTOCK LODE, its formation and history. By John A. Church, E. M., Ph. D., member of the American Institute of Mining Engineers, mining engineer. Illustrated by six plates and thirteen figures. New York: John Wiley & Sons. 1879.

[2] L. c., p. 40 to 42 and 52.

[3] L. c., pp. 37 and 47. The McKibben tunnel shows only diorites and quartz.

History of the lode.—Mr. Church divides the history of the COMSTOCK LODE into nine epochs:[1]

1. *The diorite epoch.*—The horizontal deposition of diorite, which is one of the fine-grained, thin-running lavas,[2] in stratified layers, by a series of eruptions.

2. *The subordinate pressure.*—The system of diorite strata was acted upon by a pressure which produced broad folds with east and west axes, an uplift in Virginia, and a trough in Gold Hill. This important force continued to affect the rocks through the greater part of their history, and is the dynamic cause of the LODE.

3. *The propylite epoch.*—The horizontal deposition of the propylite, also in stratified layers from successive fissures. The members of the new rock are essentially parallel to the older layers.

4. *The principal elevation.*—After the propylite, came a movement by which the two series of eruptive depositions were raised into a mountain system. This elevation took place about a north and south axis, and its folds are therefore at right angles to those of the former movement.

5. *The andesite epoch.*—A third period of eruption follows, the seat of which is the upturned strata of the diorite and propylite. These are not fractured except near the eroded surface, but the layers are separated, and the andesite rises through the crevices, establishing an extensive system of bedded dikes. The whole mass of erupted andesite is assumed to have been some thousands of feet thick, and to have played an important part in the history of the LODE by its weight and rigidity.

6. *The opening of the strata.*—The crests of folds already produced were lifted forcibly against the rigid andesite cap, while the intervening troughs were bent downward, relieving them from its weight. Under this action the uplifted portions of the strata were squeezed sidewise into the relieved troughs, opening slightly the partings between the layers.

7. *The silicious epoch.*—Through the small partings of the strata thus opened, rose currents of water holding silica in solution. The strata subjected to their action were dissolved or carried off mechanically, and quartz with "base" metals was deposited in their place. This action went on in each

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[1] L. c., p. 128.

[2] L. c., p. 153.

of the open seams, the intervening rock being attacked from both sides until the meeting of several depositions of silica composed quartz bodies, which in many cases had a thickness of several hundred feet. This quartz was not argentiferous, and no ore was formed. A second important result of this appearance of silicious waters is the almost entire removal of the immense andesite cap, which was decomposed in the same manner as the deeper-lying rocks.

8. *The trachyte epoch.*—New crevices opened in the eastern part of the district, and vast floods of trachyte poured out. Instead of resisting movement like the andesite, it loaded down the hanging wall of the LODE so heavily that it slid upon the foot wall. This action resulted in an entirely new system of openings. Near the surface the new crevices abandoned the old line of quartz deposition, and broke through the hanging wall in a more or less nearly vertical direction.

9. *The argentiferous epoch.*—Into these new crevices poured a second stream of water containing minerals in solution, but differing from the first in holding not only silica, but also silver and gold.

"The facts here brought forward," says Mr. Church, "show that no vein and nothing like a real vein exists in ground that has for years been supposed to contain the boldest example of true fissure vein formation in the world; that the largest bodies of ore can be formed from deep sources of mineral supply without the agency of a fracture even of the smallest dimensions; and that it is quite unnecessary to seek for great dynamical convulsions to account for the formation of thick masses of ore within the solid rock, a sufficient cause being found in the quiet action of the same forces which have everywhere molded the crust of the earth."

The *Justice* ore body Mr. Church regards as a deposit wholly distinct from the COMSTOCK, though attributable to the same general causes, and as formed in a similar way.

Physics.—Of the finely-divided quartz known as sugar quartz, he says:[1] "The grains are remarkable in *never* being crystalline, the microscope not revealing one crystal in millions of particles." And again:[2] "The lesson to be derived from the sugar quartz is not that it has been crushed, but that it has

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[1] L. c., p. 85.

[2] L. c., p. 151.

been preserved from crushing. It was formed in the state of powder, and since its deposition the LODE rocks have not received any addition which could weigh it down. On the other hand, the barren quartz was probably laid down in a similar state of powder, and has been consolidated by the load of trachyte upon the surface."

The heat of the LODE Mr. Church ascribes to the kaolinization of feldspar, supporting this view by the statement, that as kaolinization involves hydration, heat must be liberated; and by the assertion that flooded drifts grow hotter. He believes the heat to be diffused by hot aqueous vapor permeating the rocks. The latter, he asserts, are in large part perfectly dry.

Technical literature.—Though most of the scientific and technical journals contain papers on the COMSTOCK, or items referring to it, and much space is occupied by the same subject in the reports of the United States Mining Commissioners and of the State Mineralogist of Nevada, I am not aware of any further noteworthy contributions to its geology. The numerous geological suggestions thrown out by engineers writing from a more or less technical point of view, were never intended as matured geological opinions, and it would be unfair to treat them as such.

CHAPTER III.

LITHOLOGY.

SECTION 1.

THE ROCKS OF THE WASHOE DISTRICT.

Importance of lithology to the theory of ore-deposits.—Though the present memoir is intended as a contribution to mining geology, the importance of the lithology of the district is certainly not less than it would be, were no economical problems involved. The slightness of the advances which have been made in the theory of ore-deposits is regarded by business men as a reproach to geological science. But the influence of the inclosing rocks on the character and tenor, and to some extent upon the occurrence of ore bodies, was recognized before geology became a science; and the fact of this influence has received confirmation from more extended observation. Whatever, then, may be the true theory of the genesis of ores, the indications are clear that exhaustive studies of the nature of the inclosing rocks, and of the influences to which these have been subjected, are essential to its elucidation; for even if it should prove that ores are derived from immense depths, and are brought to the surface under conditions which are wholly removed from observation and study, the influence of the wall rocks on their deposition is still within the accessible field of inquiry. The way to such investigations is already paved. The microscopic analysis of rocks initiated by Mr. Sorby, and raised to its present rank as a science by Messrs. Vogelsang, Zirkel, Rosenbusch, Fouqué & Lévy, and their fellow workers, enables us to reach very definite conclusions respecting the mineralogical composition and physical structure of rocks; while Prof. F. Sandberger and others have of late years made great advances in proving the chemical relations which, in many cases, exist between the wall rock and the contents of veins. On the other hand, the mineralogical study of decomposed rocks under the microscope has made but little advance. Geologists who do not deal with the phenomena of ore deposits are commonly satisfied with determining the species of the rocks with which they have to do, and recording the mere fact of decomposition. They therefore select only the freshest specimens for microscopical examination. If the resources of the microscope are to be fully brought to bear upon the study of ore deposits, mining geologists must pursue a different method. They must trace the mineralogical course of decomposition-processes, and learn to recognize highly altered rocks, even when fresh specimens are unattainable.

Disputed character of Washoe rocks.—There is a further reason for the considerable and, as it may seem to some readers, the undue space which this chapter occupies. Baron von Richthofen based the independence of the new rock propylite largely upon the occurrences in the WASHOE DISTRICT. Later investigators in the same field without exception have adopted his views. Professor Zirkel's characterizations of the microscopical peculiarities of propylite were also founded chiefly on the WASHOE occurrence. Though at the beginning of the present investigation I was fully persuaded of the independence of propylite, I subsequently found reason to doubt it; but to prove a negative is notoriously difficult, and the great authority of my predecessors made the task still more onerous. It was necessary to demonstrate that the whole superficial area and all the accessible mine-workings were occupied by other rock-species, and to give in this report a sufficient number of instances, with detailed descriptions, to enable geologists to decide for themselves whether the elimination of propylite and the redetermination of some other rocks is justified by the facts.[1]

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[1] **Special localities.**—The rocks of the WASHOE DISTRICT may be advantageously studied in the following localities: *Granular diorite* in nearly all varieties occurs along the line of the Virginia Water Company's flume within a distance of a thousand feet north of Bullion Ravine. *Porphyritic diorites* can be satisfactorily examined either in the *McKibben Tunnel* or in Ophir Ravine, between the most westerly point of the flume and the more southerly of the bluffs marked "croppings" on the map. *Earlier diabase*, in all varieties, is to be found from the *Savage* connection with the *Sutro Tunnel* to the junction of the main tunnel with the *North Lateral*, and from this point to the *Mint* connection. *Younger diabase* ("black dike") is well seen on the west wall of the *Belcher* associated with black graphitic slates. The foregoing are the rocks most important to miners on the LODE.

Granite is well developed close to the *Red Jacket*, C. D. 6, and on the dump of that mine. *Quartz-porphyry* is excellently exposed by a little quarry about 2,000 feet southwest of the *Justice*. The felsitic variety occurs near the drainage of Gold Cañon (American Flat Cañon is the name given on former maps), just east of Roux' Ranch. The little *basalt* mesa in the same locality is very accessible. *Meta-*

GRANITE.

Character.—Granite does not play a large part in the geology of WASHOE. Besides the small area laid down on the map, it has been struck by a tunnel near McClellan Peak, and in the *Rock Island* and *Baltimore* mines; so far as I know, nowhere else in the neighborhood. The rock is a fine typical granite, consisting of orthoclase, quartz, biotite, a little oligoclase, magnetite, and some accessory minerals. The apatites are colorless, the zircons are numerous and beautiful, and the titanite occurs in typical rhombs, with well developed cleavages. Finally, it contains a colorless regular mineral, seemingly in ill developed rhombohedrons, which answers to sodalite. The microscopical characters of sodalite, however, are rather negative than positive, and it may be some other physically similar mineral.

Near the *Red Jacket* the granite shows very distinct parallel partings, suggesting, but by no means conclusive of, a metamorphic origin. Some of the granite has been mistaken for diorite, and a part of the metamorphic diorite has been called granite; but these are errors which can readily be avoided by careful inspection.

ERUPTIVE DIORITE.

General relations.—The development of diorite in the WASHOE DISTRICT is very extensive, and the variations of lithological character which it presents

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morphic diorite occurs close to the granite. It is found as a very volcanic looking breccia, just east of the *Volcano* at point 5,444, C. D. 6. The western portion of the small patch of this rock in C. 7 is extremely similar to the *eruptive diorite* of Mount Davidson. *Earlier hornblende-andesite* in a fresh state is found on the north Twin Peak C. D. 4. An abandoned quarry 500 feet north of this point shows the stages of its decomposition to admiration. The south Twin Peak is an occurrence of loose texture and gray color, somewhat resembling the younger hornblende-andesite of the *Utah* neighborhood. The variety with *large hornblendes* is well developed at point 5,678, about 1,000 feet east of the *Succor*, D. 5. Other varieties, including decomposition-products charged with epidote, may be found on the north flank of Cedar Hill Cañon, say 500 feet west of the Brewery. Fresh augite-andesite can be conveniently examined at point 6,158, close to the *Forman* shaft. The cuts of the Occidental Grade, say from the *Forman* shaft road to the *Prospect*, show many beautiful examples of the decomposition and disintegration of blocks. The croppings of breccia marked 6,569 on the Ophir Grade, B. 4, show many transitions and the development of epidote. *Younger hornblende-andesite* is found as a purple porphyry at the quarries 2,000 feet northeast of Shaft III. of the *Sutro Tunnel;* as a red porphyry (very augitic) at a quarry 2,000 feet east of the *Occidental* mill; as a gray, somewhat granular looking mass with fine columnar structure in the quarry close to the *Utah;* as a dense, black, glassy rock at point 6,728 E 2. The tufa modification is best seen on the Sutro road, where it crosses the divide between Mount Emma and Mount Rose.

are numerous, and often perplexing. While the varieties often differ in appearance from one another much more than is the case with separate species of the younger rocks, there is strong evidence that they all formed portions of a single extended series of eruptions. They are so intermingled that it is not even possible to lay down upon the map distinct areas of those which differ most, but it seems best to describe the principal modifications separately, and afterwards to discuss their transitions.

The mass of Mount Davidson is mainly composed of granitoid diorite of a cold gray color, which resembles a syenite in habitus and, as has been seen, was so considered until Professor Zirkel demonstrated the triclinic nature of the feldspars. Two other modifications of the granitoid diorite require attention. One of them is a very dark and fine-grained rock, represented to a slight extent upon the surface, and extensively underground. It has sometimes been confounded with the andesites. The other is a coarse black rock, much resembling highly graphitic pig-iron. It has been found mostly at great depths, particularly at the bottom of the *Union* shaft.

Granitoid diorite.—The mineralogical constituents of the ordinary light-gray and the dark, fine-grained, granular diorites are essentially plagioclase and hornblende; magnetite, apatite, and zircon seem never absent, and quartz, mica, titanite, and augite occur now and then. In one slide tourmaline has been detected. The principal constituents seem all to be crystals of "secondary consolidation;" that is to say, they have all formed simultaneously on the cooling of the rock, and have mutually interfered with one another's growth, so that there are scarcely any symmetrically developed crystals present, but only irregular grains, each limited by surrounding imperfect crystals of a similar character.

The hornblendes are generally green and fibrous. In many cases the separate fibers appear to be independent microlites, loosely aggregated in forms characteristic of hornblende crystals. In other cases they appear to be distributed entirely without reference to one another. The impression produced is as if the crystallization had taken place in a viscous or pasty mass, which mechanically prevented the union of the hornblende molecules to well defined crystals. The hornblendes give angles of extinction appropriate to that mineral, when the well known variations in this property are taken into consideration. In certain localities underground, the granular diorites contain much deep-brown and solid hornblende, and the specimens which show this variety are manifestly fresher than those from the localities where green hornblende occurs exclusively. In some cases an alteration of the brown to the green variety is strongly suggested, while in one series of porphyritic diorites it can be actually proved. It is therefore altogether probable that the surface diorite originally contained some brown hornblende, which has been changed to the green, fibrous modification by a process analagous to the formation of uralite. To what extent the fibrous hornblende has been derived from the brown mineral, there is at present no means of inferring.

Augite.—Augite is comparatively rare in the unquestionable granular diorites, though I have observed it in a few instances. It is much more common in the porphyritic diorites, and it may be that its absence from the granitoid variety is due to conversion into uralite; for since determinable crystal sections are seldom met with in this rock, it would be impossible to distinguish secondary from primary green fibrous hornblende. Close to the *McKibben Tunnel* angular fragments of what appeared macroscopically to be the dark fine-grained diorite frequently encountered in the district, and especially well developed in this tunnel, were found embedded in light-colored granular diorite. Under the microscope the inclosing mass exhibits no peculiarity; but the inclosed rock, unlike the similar occurrences in the same locality, shows abundant augite and almost no hornblende, though structurally resembling the dark diorite. As the distinct diabase eruptions are manifestly later than those of diorite, I am wholly at a loss for an explanation of this case, except on the supposition that it represents a local and exceptional substitution of augite for hornblende. This hypothesis, however, is so contrary to ordinary experience as to be exceedingly objectionable, though were it true it would also serve to explain the ill-defined patch of diabasitic rock in Ophir ravine, which is, like that just mentioned, much more granitoid than the mine diabases, and has no apparent structural connection with them. There can be little doubt that local modifications of massive rocks in which the mineralogical composition is characteristic of a distinct but allied rock-species, have been met with in various localities in the world. Such cases, however, demand very cautious treatment at the hands of the geologist. Actual contacts are often exceedingly obscure, and except where all the steps of a transition can be traced, such an explanation of an anomalous occurrence is not justifiable. Fortunately nothing further appears to depend either upon the specimen of diabasitic fragments inclosed in a dioritic mass, or upon the diabasitic area in Ophir ravine, since the evidence as to the succession of the rocks in the east country is decisive and abundant.

Other constituents.—The feldspars are nearly or quite without exception triclinic, and simple crystals are very rare, while pericline twinning is common. The stripes indicating polysynthetic structure are usually very well defined, and of moderate width. The angles of extinction of a very large number of favorably placed crystals have been noted, and seem to indicate labradorite as the only feldspar present. Zonal structure is not uncommon, but the feldspars are remarkably free from inclusions of any kind, and are in general thoroughly transparent.

Quartz is present in a large proportion of these rocks, though its distribution is very irregular, some slides containing only one or two grains, while others show hundreds of them. Secondary quartz also occurs, but it can usually be distinguished from the primitive grains with ease. Primitive quartz-grains are generally single, more or less imperfectly developed crystals, around which grains of magnetite and other small crystals are so arranged as to show that their disposition has been controlled by the presence of the quartz. Secondary quartz occurs in veins or in patches composed of granules of different crystallographic orientation, and is not sharply separated from the surrounding rock-mass. Secondary quartz, of course, frequently carries fluid inclusions in rocks of all ages. The primitive quartz of these diorites is rich in liquid inclusions, some of them vesicular in shape, and others dihexahedral. The smaller ones show active bubbles, and in some slides many contain salt-cubes. I have noticed none of the appearances which accompany inclusions of carbonic acid, and in several slides to which heat was applied no alteration in the size of the bubbles was noticeable at a temperature considerably above 40° C.

The iron ore is certainly for the most part magnetite, and I was unable to make certain of any ilmenite, while sphene, in small and irregular masses, is frequent. Apatite is not specially plentiful, and is of the ordinary colorless variety. Many small but beautiful zircons are visible with the higher objectives, mostly in eight-sided prisms terminated by the fundamental pyramid.

The granitoid diorites resist decomposition better than any other rocks in the district. On the surface erosion evidently proceeds with greater rapidity than decomposition. Slides from beneath the surface, but near the LODE, show that the hornblende is replaced by chlorite and epidote, and the feldspars by calcite and quartz.

Dark varieties.—The dark fine-grained diorite presents a much stronger contrast to the ordinary gray variety macoscropically than microscopically. The difference in its appearance seems to depend simply on the fineness of the grain, and on the percentage of fibrous hornblende, which is greater in this modification.

The dark coarse-grained diorite from the lower levels is very peculiar in appearance, and some of that from the *Union* shaft might be more readily confounded with specimens of Scotch foundry-pig than with any other rock occurring in the DISTRICT. This variety also differs from the ordinary gray diorite, principally in respect to the hornblende, which is more abundant. It is not fibrous as a rule, and has consolidated in grains simultaneously with the feldspar. As in the freshest gray diorites, the granules which show no evidences of alteration are brown, and incipient alteration seems to be accompanied by a change to a green fibrous mass. The hornblendes also contain numerous black inclusions, probably ilmenite. The feldspars are very fresh and clear, and the black color of the rock is the natural consequence of such a mineral composition. Although the difference in appearance between the three varieties of diorite is very marked, it thus depends on a variation of unessential characteristics.

Structure of the granular diorites.—The granular diorite is exceedingly hard and tough, so much so that before the introduction of nitro-glycerine explosives it was almost impossible to penetrate it where decomposition had not loosened the texture. In the *Chollar* mine, many years since, when black powder only was in use, an attempt to drive a gallery into this rock was abandoned as wholly impracticable, charge after charge being shot from the drill-holes as if they had been guns. Under the hammer it exhibits no tendency to break in one direction rather than in another, but weathering develops considerable differences in resisting power; and in Bullion ravine, as may be seen from Plate VI., ridges and pinnacles have been formed by the irregular disintegration of the rock. Immediately west of the LODE the diorite is furthermore divided into a system of approximately parallel sheets. It will be seen in the next chapter that I refer this system of fissuring to a faulting movement.

Differences from other rocks.—The gray granular diorite is unlikely to be confounded with any other rock in the district, except granular diabase. This variety of diabase seldom occurs underground, so far as the country is now open to inspection; and when it is met with, as at the *Mint* connection in the *Sutro Tunnel*, it is commonly limited to a very small body which shades off into finer-grained varieties. When decomposition has progressed too far to permit a macroscopical determination of the mineral constituents, the lath-like development of the feldspars, the tendency to cleavage in parallel planes, and a certain waxy luster will usually be found characteristic of the diabase. The dark fine-grained diorite has repeatedly been taken for andesite in the *McKibben Tunnel* and elsewhere. The only resemblance, however, is in color, for the diorite shows to the naked eye a granular structure never observed in the andesites of the DISTRICT, although the latter are uncommonly crystalline.

Porphyritic diorites.—From some peculiarity either in composition or texture, the porphyritic hornblende-diorites have undergone very extensive decomposition, and it was only after long and earnest search that two or three small masses were found, which might furnish a study of this diorite in a fresh state. A close inspection of fresh specimens shows that the rock is even macroscopically thoroughly crystalline, but that tolerably well-developed feldspars and good hornblendes are separated out in a finer groundmass of a dark color. In addition to these minerals the microscope shows magnetite, apatite, and zircon. Augite and mica also occur in limited areas.

The hornblendes when fresh are bright brown and well crystallized, often showing terminal faces as well as the prism and clinopinacoid. In a slide from Cedar Hill the curious inclusions which seem probably ilmenite needles, already referred to, are developed in great perfection. Most of the hornblende substance is concentrated in the larger crystals, but there are a few minute ones and some crystalline fragments interspersed through the groundmass. The larger feldspars are fairly well developed, but have not the sharply rectilinear outlines so common in the diabases and the volcanic rocks, nor do they display any tendency to elongated lath-like forms. They give the angles of extinction appropriate to labradorite; they contain occasional fluid inclusions, of rounded forms, and of course no glass. They are pierced by numerous apatite needles. The smaller feldspars are in part crippled grains, similar to those of the granitoid diorites, and in part elongated microlites. The angles of extinction of these latter render it probable that they are oligoclase.

The iron ore seems to be exclusively magnetic.[1] The apatite is in part of the ordinary colorless variety, and in part brown and dusty. The indeterminable inclusions in the apatites are disposed very differently in different individuals. An hexagonal brown core is sometimes surrounded by colorless apatite, while in other cases this arrangement is reversed. Longitudinal sections not infrequently show colorless ends, with a dusty middle portion. Only a few zircons have been observed in this rock, in which respect it differs from the granular diorites. The groundmass consists of small feldspars and magnetite grains, and its general effect is usually that of an excessively fine-grained granitoid diorite. Occasionally the arrangement of the microlites is such as to suggest fluidal structure.

Decomposition.—The decomposition of these rocks forms an exceedingly interesting study. It will be shown elsewhere in detail that the hornblendes pass into chlorite, and this again into epidote, quartz, and calcite. The chlorite evidently possesses a high degree of solubility, and soon diffuses itself through the groundmass, and through the feldspars so far as these latter have become porous from decomposition. The chlorite and epidote give the partially decomposed rocks their characteristic greenish hue.

Another change of great interest appears in a small dike of porphyritic diorite cutting granular diorite close to the *Eldorado* croppings. No effect whatever has been produced upon the inclosing granular diorite, but for

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[1] Excepting the acicular inclusions referred to above.

about an inch from the edge the intrusive porphyritic rock has an excessively fine grain and close texture. In consequence of this physical character it has resisted decomposition, and close to the contact is very fresh. Here it contains fine brown hornblende, but at a distance of half an inch from the contact, the texture, as seen under the microscope, becomes coarser and more open, and green fibrous hornblende makes its appearance. Certain hornblende individuals are brown towards the center, but green and fibrous near the edges and along cracks, and the dividing line is such as to leave no doubt that in this case the green fibrous modification is to be regarded as an alteration-product of the brown dense variety. This occurrence strongly confirms the indications of such a transformation mentioned in describing the granular diorites.[1]

Structure of porphyritic diorites.—No special tendency to parting in any direction is perceptible in the porphyritic diorites, but they vary in coarseness of grain and general appearance much more than the granitoid diorites. To the south of Bullion ravine there are small localities where the rock is distinctly brecciated; and in the ravine west of the *Imperial* there is a small occurrence of excessively fine-grained diorite, with a closely laminated structure, not unlike a calcareous slate. Similar spots are found in the diabase and the andesites, but in no case was any explanation apparent from the character of the surrounding masses. Some such appearance might ensue in a pasty mass if its composition were locally altered and its fusibility increased, say by the presence of a fragment of calcareous rock. There is no relation between the direction of the lamellæ of these spots and the general fissure system. Where decomposition has proceeded far enough for a diffusion of chlorite through the rock to take place, the granular texture of the groundmass is much obscured, and the similarity between it and certain partially decomposed andesites is great and misleading. A large portion of what was supposed to be propylite in the WASHOE DISTRICT, is porphyritic diorite in this stage of decomposition. Disintegration sometimes accompanies decomposition of the rock, but an astonishing coherence is often maintained when scarcely a particle of unaltered mineral is left.

Diagnostic points.—It is often very difficult to distinguish between partially

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[1] *Confer* Rosenbusch, Physiog. der Min. u. Gest., Vol. II., p. 333.

decomposed diorite and hornblende-andesite; and the only really safe course is to continue the examination until comparatively fresh specimens are obtained. The granular structure of these is not readily confounded with that of andesite. The diorites are never fissile like hornblende-andesite, and hornblende-andesite is usually pretty uniform over considerable areas, while the dioritic porphyries vary in structure almost from yard to yard.

Mica-diorites.—The micaceous diorite-porphyries do not differ greatly from the hornblendic variety, except in the substitution of biotite for hornblende; but the rock is of a looser texture, the porphyritic feldspars are generally larger, and tend more to rounded forms. I met with no occurrence of this variety in a fresh condition.

Relations of the diorites.—All varieties of diorite pass over into one another. Porphyritic and micaceous forms occur in the prevailing granular mass on the front of Mount Davidson, directly opposite the *Savage* mine, and granitoid diorites occur, mixed with the porphyritic forms, on Cedar Hill and in the *McKibben Tunnel.* Especially in the latter locality gradations of the one form into the other can be excellently followed out. The evidence of this character is sufficient to prove conclusively that no absolute separation can be established between the dioritic rocks. There is, however, also considerable evidence to show that, as a whole, one variety succeeded another in the course of the eruption of the mass. The first portion of the diorites appears to have been of the dark, fine-grained variety, and cases have been met with in which dikes of the lighter rock cut the darker. In the mines, too, the excavations show that the dark rock frequently underlies the lighter, and in the deepest workings the dark predominates over the light rock. There are not sufficient exposures of the coarse-grained diorites with brown hornblendes to determine its relations to the varieties with fibrous hornblendes, but it evidently preceded the porphyritic rocks. The main mass of the porphyritic diorite succeeded the granitic. Just to the south of the *Eldorado* croppings there is a distinct dike of porphyritic diorite in the granitic mass, with well-developed contact phenomena, extending about an inch from each wall of the dike. To the north of Mount Davidson the mine shafts, too, have gone down through porphyritic diorite into the granular variety. Indeed Mount Davidson, between Bullion ravine and Spanish ravine, constitutes the principal area of the granitic diorite at the surface; while both to the north and the south porphyritic varieties prevail, and nearly all the diorite to the east of the Lode is of the same character.

METAMORPHIC DIORITE.

Origin and association.—The southern portion of the district contains a large area of this rather puzzling rock. It was mentioned by Mr. King as a "compact, black, crystalline rock, which in hand specimens would unquestionably be classed as a basalt," but which can be shown to be of metamorphic origin. Professor Zirkel determined it as a peculiar basalt. The most ordinary variety is of a black or iron-gray color, and shows an irregular crystalline fracture; but certain varieties (the more feldspathic ones) are light in color, and considerably resemble Mount Davidson diorite. There is no little difficulty in determining whether this rock shall be regarded as of metamorphic origin, or as eruptive. To the west of the *Florida* mine the contact between it and the underlying metamorphic rocks appears as sharp as possible. At the *Wales Consolidated*, a mine opened on a deposit lying between this rock and the granite, there is no evidence whatever of bedding. Near the *Amazon* mine it is weathered in round boulders, precisely like those produced by the action of frost on basalt; and close to the *Volcano* mine it forms a distinct breccia. On the other hand, in some of the railroad cuts, there appear to be transitions into rocks of evidently sedimentary origin. But such appearances need very cautious treatment, for between metamorphism and decomposition, a contact might readily assume the appearance of a transition. The microscopical character of the rock offers nothing decisive as to its origin, and the point which has mainly determined me to regard it as metamorphic is its relation to the quartz-porphyry. An inspection of the map will show that it is invariably associated with the quartz-porphyry, and that if it had resulted from the metamorphism of the sedimentary strata by porphyry eruptions, subsequent erosion must have exposed it in relations almost identical with those observed. Its composition also indicates a metamorphic rather than an eruptive origin.

Character in detail.—The principal constituents are plagioclase, hornblende, and mica, often with the addition of quartz; while the subsidiary minerals are titanic iron, apatite, sphene, zircon, and in one case tourmaline. The hornblende is for the most part fibrous and bluish green. But this does not appear to have been its original color. The centers of considerable masses of hornblende appear under the microscope wholly colorless, and the association of the two varieties described in detail under slide 295 is such as to lead almost inevitably to the conclusion that the green color is secondary. In many specimens the hornblende is present in great quantities, and microlites so crowd the feldspars that their striations are almost imperceptible and their species indeterminable. To a considerable extent the hornblende is decomposed into chlorite and epidote, the latter mineral appearing in unusually fine crystals. Mica is present in smaller quantities than hornblende, and gives the interference figure of biotite. Some specimens contain augite.

In the less hornblendic varieties the feldspars are well developed, many of them with sharp, rectilinear outlines, like those in the more porphyritic diabases. The lamellæ are exceedingly attenuated; they show angles of extinction appropriate to oligoclase, and pericline twinning is occasionally visible. A few orthoclase crystals also occur. Quartz grains are numerous in the less hornblendic specimens, and do not appear to be of secondary origin. They contain numerous minute fluid inclusions, and with irregular grains of feldspar form a kind of coarse groundmass. The titanic iron is accompanied by leucoxene, which in some cases appears to pass over into titanite, though a transition cannot be demonstrated. The apatite presents nothing peculiar, and the zircon is in no way remarkable except in the frequency of its occurrence. Tourmaline was found only in one slide. Of course it suggests metamorphic origin, though the same mineral is known to occur occasionally in rocks of eruptive origin, and, as has already been mentioned, was noticed in one of the almost unquestionably eruptive diorites of this very district.

Comparatively little decomposition has been noticed in this rock, a fact which no doubt stands in intimate relation to its unusual hardness and toughness, but in some limited areas it is highly chloritic, and certain specimens would pass for propylite.

Diagnostic peculiarities.—Some varieties of this rock, especially a portion of the small patch shown on the map in square C. 7, greatly resemble Mount Davidson diorite, and indeed the difference under the microscope is chiefly in the species of feldspar. On the hills west of the *Florida*, and in some other localities, it is much like augite-andesite or basalt in appearance, but the macroscopical resemblance does not answer to any microscopical similarity. It sometimes occurs in rounded shapes such as basalt often assumes. In many cases weathered surfaces of this rock can be recognized by the crystal outlines which they exhibit. These are often polygons of a variable number of sides, and represent sections of hornblendes crystallized in remarkably short prisms and provided with terminal faces.

QUARTZ-PORPHYRY.

General character.—Quartz-porphyry covers a large area in the southwestern portion of the Washoe District, and extends for miles in the direction of Washoe Lake. It presents a rough surface varying in color from white to a yellowish or reddish gray, and is thickly set with quartz-grains the size of a mustard seed, and smaller. Mica is nearly always visible, and hornblende occasionally. Only in one small area near the granite is the quartz macroscopically suppressed, and here the rock is finer-grained than elsewhere. Underground it extends to a considerable distance farther north and east than its northern limit on the surface, and there underlies hornblende-andesite and augite-andesite.

Composition.—None of the rock is really fresh and, though an earnest search was made, not a single specimen could be found showing the constituent minerals in an undecomposed state. Those which enter most largely into the composition of the rock are feldspar, quartz, mica, hornblende, and ores of iron. As accessory minerals, titanite, apatite, and zircon were observed. The feldspars are not well defined, but occur in irregular or rounded grains. They are in part striated, but the larger portion show no trace of polysynthetic structure, and while in some slides so large a quantity of calcite is distributed through the feldspars that the striations might be supposed to be obliterated, in others the crystals are so clear that striations, if present, could not but be apparent. Many of the unstriated feldspars show cleavages, and extinguish light at angles which seem to prove their orthoclastic character. No unstriated feldspars were found to give angles of extinction, reckoned from the cleavage planes, which would refer them to either of the triclinic species. The triclinic crystals show for the most part very narrow striations, and give angles of extinction which correspond to oligoclase. The microlitic feldspars of the groundmass do not appear to be triclinic. On introducing a portion of the rock in a condition of fine powder into the well-known solution of mercuric iodide in potassic iodide, of a specific gravity of less than 2.65, a large proportion rose to the surface. This mounted in balsam appeared to consist mainly of feldspar. The portion which sank contained some feldspar and the other components of the rock. The feldspars contain inclusions of glass and also of fluid, but a portion of the latter I regard as of secondary origin.

Quartz.—The quartzes are bounded in part by straight lines and in part by curves. In some cases the imperfectly developed crystals appear to have been broken, and the fragments are now separated by narrow bands of groundmass; in other cases they contain deep sinuous bays of the same material. The quartz shows both fluid and glass inclusions, but their distribution is somewhat uneven. In some slides they are present in nearly equal numbers, while in others one or the other preponderates, or even occurs exclusively; but this is exceptional. The inclusions are not thickly set, but a glass inclusion and a fluid inclusion, with a moving bubble, can often be seen in the same field with a Hartnack No. 7 objective. Of the hornblendes, which were all black-bordered, none now remain in a fresh condition. They have been replaced by the usual products of decomposition—chlorite, epidote, quartz, and calcite. The mica, too, is in great part decomposed, but occasional scales remain, and these give the interference figure of biotite. The groundmass in every case shows fluidal and pseudospherolitic structure. In some cases a base is also present; in others it is either wanting or devitrified. When glass is present, it shows a preference for elongated sinuous forms, and often the central line is marked by aggregations of iron ore from which, as axes, black trichites sometimes spread into the surrounding isotropic substance. The iron ore is in part magnetite, while in other cases it appears to be ilmenite. Apatites of the usual colorless variety are frequent. Zircons are not uncommon, and there are occasional small patches of titanite.

Field habit.—The croppings of the quartz-porphyry are usually exceedingly rough, and the nearest approach to a structure is indicated in some localities by the separation of the rock into uneven sherdy fragments. Its appearance is almost identical all over the district, except in the small area where the quartz is macroscopically suppressed. Here it shows various brown and green colors, and sometimes a smooth fracture like a fine-grained hornblende-andesite. In this area the color and texture vary every few feet. This macroscopical difference appears to correspond to no microscopical peculiarity beyond a finer grain. As quartz-porphyry is the only quartzose rock in the district, it is readily distinguishable.

Various determinations.—As has been seen in the résumé of former memoirs, the quartz-porphyry has been variously determined by the eminent geologists who have discussed the WASHOE DISTRICT. Baron v. Richthofen very positively asserted that the circumstances of its occurrence rendered it certain that this porphyry was intermediate in age between the granitic and the volcanic rocks, and I entirely agree with him. The absolute uniformity of the rock from the *Overman* mine to the southern extremity of the mass, with the exception of a small felsitic area, utterly precludes the supposition that it is separable into different species of Tertiary and pre-Tertiary origin. The felsitic modification comes in contact only with granite and basalt, but its microscopical character is identical with that of the coarser porphyry; it strongly resembles well-known varieties of quartz-porphyry, and I can see no evidence on the ground sufficient to separate it from that species. That in the *Overman* and *Caledonia* mines and the *Forman* shaft the porphyry vertically underlies hornblende-andesite is beyond question; both optical tests and specific gravity determinations show that it is an orthoclase rock; and the character and association of the inclusions in the quartzes are precisely those which are so very common in old quartz-porphyry. Professor Zirkel determined the larger proportion of this rock as a dacite, but on reëxamining his slides I found that they corresponded in every respect to mine, and that the quartzes in each of them contained fluid inclusions with moving bubbles. The one slide which Professor Zirkel determined as rhyolite differs, in that the quartz contains glass but no fluid inclusions; in a slide of my own, however, from as nearly as possible the same locality, these conditions are reversed, the quartzes showing fluid inclusions but none of glass. I can see no difference in the amount of orthoclase present in those slides determined respectively as dacite and rhyolite. Professor Zirkel gives an analysis of this rock made by Mr. Councler, showing two per cent. of soda and three and six-tenths per cent. of potash. In discussing this composition Professor Zirkel cites a number of analyses of Transylvania dacites, but in none of these is the proportion of potash to soda so high as in the WASHOE rock.

DIABASE.

Earlier diabase.—There are two varieties of diabase in the district. The older of these forms the hanging wall of the LODE; the other has been known as "black dike." The east-country diabase varies considerably in coarseness of grain and in color. When really fresh it is always dark, and when also fine-grained it closely resembles an andesite. The coarser-grained and somewhat decomposed occurrences are often confusingly like granitoid diorite.

The rock consists of plagioclase, augite, and an iron ore, with a number of accessory and irregularly distributed minerals, quartz, hornblende, mica, and apatite. The structure is not that most usually found in diabases, being somewhat porphyritic. The augite is of the usual pale-brown tint, and occurs largely in well-developed crystals. These are often twinned according to the ordinary law.[1] The twinning attracts more attention than usual, because polysynthetic structure is common, some of the lamellæ often penetrating only part way through the crystal. The ordinary cleavages are well marked, and instances are common in which the pinacoidal cleavages as well as the prismatic ones are developed. Some slides contain only separate and well-formed crystals, while in others they occur in groups, and these are apt to be gathered about branching masses of iron ore, almost like

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[1] For a peculiar case, which might be interpreted as abnormal, see page 113.

close-growing bunches of grapes. In still other slides grains of the mineral are distributed through the groundmass.

Mineral constituents in detail.—This rock always contains porphyritical feldspars. They are long, sharply rectilinear, and without exception triclinic. They give angles of extinction proper to labradorite. The lamellæ are of moderate width, and are often combined at the same time according to all the common twinning laws. In nearly every slide they carry liquid inclusions, generally of vesicular shapes. The smaller feldspars form granitoid grains of "secondary consolidation," and with the iron ores and more or less augite, make up the groundmass. I have observed some of these smaller feldspars which gave angles of extinction indicating a different species from the larger crystals of first consolidation. The iron ore is in part magnetite, and in part ilmenite, with the characteristic cleavage-lines and products of decomposition.

Quartz grains of unquestionably primitive character are occasionally met with. These show an arrangement of particles of magnetite, etc., about their peripheries such as secondary quartzes never exhibit. Almost all of them show fluid inclusions, the smaller ones with moving bubbles. I have observed none in which the liquid appeared to be in the spheroidal state, and the bubbles do not disappear at a temperature of above 40° C.; the fluid is therefore aqueous. I have met with no salt cubes. Hornblende occurs sparingly, and is generally confined to closely-limited areas. Where it is present great care is necessary in discriminating the rock macroscopically from diorite Mica is rare, and is seen only in almost indeterminably small particles, which might even be secondary. The apatite is of the usual colorless variety. Not a single zircon was detected.

Evidences of diabasitic character.—The microstructure of this rock strongly suggests that of some lavas, and I have sometimes been puzzled to say at the first glance whether a particular slide was augite-andesite or diabase; but the resemblance is superficial. As will be seen later, somewhat granular augite-andesites occur in the district, but they are exceptional. Here as elsewhere the younger rock generally shows a microlitic groundmass, and frequently a glass base. This is the case equally on the surface, and in the *Sutro Tunnel* more than a thousand feet beneath the surface. The diabase now under discussion shows in all cases a thoroughly crystalline structure, and the groundmass is always composed of granitoid grains. The feldspars of, I believe, every slide of the augite-andesite show glass inclusions; and I have not met one fluid inclusion in that rock which appeared to me of primary origin.[1] In the diabase the occurrence of fluid inclusions and the absence of those of glass is equally universal. The augite of the augite-andesites shows no pinacoidal cleavages, and only one locality has been detected at WASHOE in which it has passed into uralite. The change even there is so exceedingly local that although a dozen slides have been ground from the same cropping, but one shows the alteration of augite into hornblende. In the diabase the passage of augite into uralite is the usual preliminary to chloritic decomposition. Finally, if there is one point of structure incapable of two interpretations, it is that the black dike is of later origin than the east and west country rocks. As will be shown, the black dike is an ordinary diabase, and the hanging wall is consequently a pre-Tertiary rock, and would necessarily be classed as a diabase were its resemblance to the volcanic series much more thorough than it really is.

Decomposition.—In decomposing, the diabase shows few peculiarities. As has already been mentioned, the augite is apt to be converted into uralite and then into chlorite. Epidote almost always forms to some extent from the chlorite, but the latter does not generally seem to pass so readily and completely into epidote as does that which results from the degeneration of hornblende. Instances occur, however, where the conversion is complete. The decomposition of the feldspars presents no peculiarity. They change slowly to quartz and calcite, and become porous and suffused with chlorite, just as in the diorites. The final result is a mass showing aggregate polarization with a few determinable grains of silica and carbonates, and particles of a whitish opaque substance, but nothing determinable as kaolin

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[1] It has been shown of late years that the evidence afforded by fluid inclusions needs to be treated with caution, for they are reported as present in all the younger rocks. No one, however, has claimed, so far as I am aware, that such inclusions are frequent in or characteristic of the Tertiary eruptives. Professor Rosenbusch, in his "Physiog. der Gesteine," does not mention a single observation of his own on fluid inclusions in augite andesites, and cites only one instance of such an occurrence noted by others.

If my inferences as to the secondary nature of certain fluid inclusions (p. 79) are correct, a deduction may need to be made from the number of fluid inclusions, to which a genetic significance can properly be attributed.

Field habit.—The commonest variety of the east-country diabase is a fine-grained blackish-green rock, the most noticeable macroscopical peculiarity of which is its tendency to develop smooth fissure planes. Sometimes these planes are parallel, and of course divide the rock into sheets. In other cases, quite as common, they form all sorts of angles with one another, and divide the rock into polyhedral fragments, almost like large crystals, or into prisms of various angles; but I failed to find any law governing the angular relations. There can be little question that the cleavages of the rock have been developed by the dynamical action which has repeatedly racked the hanging wall; but the tendency to jointing and the planes of cleavage may have been involved in the original structure of the rock, for the hammer develops only the imperfectly conchoidal and somewhat rough surfaces, which other fine-grained rocks show when fractured, and not smooth planes Possibly, however, such might result from a slow but irresistable pressure. The coarse-grained diabases show much less of this jointing, but the fracture of both presents the same appearance except in regard to scale—a granular surface with frequent larger lath-like plagioclases. In a great proportion of cases the feldspars are pellucid, even when the augite is wholly decomposed; but when the coarser rocks are so far altered that the feldspars become opaque, the rock looks very like diorite, a resemblance which is greatly increased by the comparative absence of joints. The diabase on the south side of Ophir ravine looks very like a diorite, though here the exposure is so large that the jointing is clearly visible. In many cases under ground it is little developed, not more so than is frequently the case with the diorite. In a few places, as for example the 2,700-foot level of the *Yellow Jacket*, there are limited occurrences of excessively fine-grained, closely laminated diabase resembling slate. The diorites and both the andesites show the same phenomenon.

It will be seen that the andesites behave very differently in subterranean and subaërial decomposition. The behavior of the diabase in this respect cannot be directly compared with the later rocks, because the exposure in Ophir ravine is but little affected, and that near the *Ward* is obscure and almost wholly covered with wash; but the protection of occasional masses of diabase from decomposition by accidental arrangements of fissures and clay seams can be seen very perfectly in some of the mines, as well as extensive disintegration of decomposed portions, and there can be little doubt that the behavior under erosion would be analogous. The pistachio-green so often seen in the diorites and hornblende-andesites is less common in the decomposed diabases, simply because the prevalent secondary mineral is not epidote but chlorite. The chlorite is sometimes peculiarly distributed in blackish, rounded spots on a lighter ground.

Diagnostic points.—Diabase is likely to be confounded with diorite chiefly when the feldspars have lost their transparency. The best indication macroscopically is then the lath-like feldspars, which are rare in diorite. The granular fracture, though it may be very fine-grained, is usually sufficient to separate it from augite-andesite. Hornblendic diabases in some cases greatly resemble hornblende-andesites, which are often rather granular; but hornblende is not very common or widely distributed in the diabase, and if one specimen arouses a doubt, another can generally be found near by which will set it at rest.

Younger diabase.—The "black dike" is a feature which has long been observed on the COMSTOCK. It extends horizontally more than a mile through some of the most important mines, and occurs from near the surface to the lowest levels reached. It lies upon the foot wall, and is nowhere more than a few feet in thickness. When fresh it is of dark-blue color and a granular texture, without the least tendency to a porphyritic structure. Surfaces which have been exposed only a few hours turn to a smoky brown tint, a peculiarity shared by no other rock in the district.

Under the microscope it is seen to be composed of triclinic feldspar, augite, and magnetite. The feldspars are mostly developed in lath-like shapes, and are of very uniform size. They give angles of extinction corresponding to labradorite. The augites are of the usual color, but seldom well developed, and to a large extent occupy the interstices between the feldspars. The rock is singularly free from inclusions of liquid or glass; indeed, none such have been made out with certainty. The brownish tint seems to arise from a suffusion of the minerals with brown oxide of iron, and this substance is very likely produced by the oxidation of some chloritic mineral, of which, however, little is visible under the microscope.

Diabasitic character.—As this rock is wholly different from the diabase of the east country, and is evidently younger than either wall of the Lode, the question naturally arose whether it might not be a peculiar form of augite-andesite. This supposition, however, proves untenable on closer examination. The tendency of augite-andesite is to glassy forms, and this tendency could scarcely fail to be developed to more than a usual degree, had it been injected into so narrow a fissure as that which the black dike must have filled; and any hypothesis which might be invented to account for its having crystallized much more uniformly and thoroughly than usual would seem very forced.

The black dike, moreover, thoroughly resembles diabases from other localities, and indeed represents a type of diabase which is much more widely distributed than the variety which forms the east wall of the Comstock. The rock from Orange Mountain, New Jersey, for example, possesses the same color, turns brown in the same way, has the same microscopical characteristics, and, in short, is indistinguishable from it except by the label. The analysis of black dike is conclusive evidence of its diabasitic character.

Little can be said of the weathering of this rock beyond the fact that it passes into a black clay; almost the only form in which it was observed in the upper levels. To some extent it has been confounded in the Gold Hill mines with underlying black slates, with which, however, it has exceedingly little in common except the color.

Had black dike occurred in a fresh condition on the upper levels former observers would assuredly have recognized its true character, and the east wall would never have been supposed to be of Tertiary origin.

EARLIER HORNBLENDE-ANDESITE.

General character.—The thoroughly fresh hornblende-andesites are macroscopically dark-bluish rocks, showing porphyritical crystals of hornblende. The feldspars are scarcely perceptible, except as they express themselves in the crystalline fracture, on account of their transparency. Where the hornblendes are small, the appearance is consequently somewhat basaltic.

No base has been recognized in the earlier hornblende-andesite of the

DISTRICT. The prevalent variety contains much augite; sometimes even more augite than hornblende, but no mica. There are also micaceous occurrences, and these are nearly or quite free from augite.

Hornblende.—The hornblende is always brown in the fresh rocks, occasionally with a reddish, and often with a greenish, tinge. Of course it is highly dichroitic, and the angles of extinction appear[1] in some cases to exceed 20°. The crystal form is the ordinary combination of prism and clinopinacoid; terminal faces too, though rarer than in augite, sometimes occur. The cleavages are usually developed, though in the freshest crystals they are marked by such narrow lines that under a low power they seem absent. In one case a clinopinacoidal cleavage was observed. Twins are very common. Glass inclusions occur, generally as negative crystals, and apatites are often inclosed. Very rarely indeed a slide shows a particle or fragment of hornblende inclosed in another mineral, but as a rule all the hornblende is concentrated in porphyritical crystals, and does not enter into the groundmass. I discovered only a single very small area in which the rock shows a large amount of hornblende distributed through the groundmass in minute particles; and even in this case the difference seems to be one of degree rather than of kind; for the minute hornblendes are in large part well developed and appear to be "crystals of first consolidation." The black border accompanies all the hornblendes in most of the andesites. Often it is very heavy, and sometimes so encroaches on the crystal that little or none of the mineral appears in the center. I have noticed no instances in which black-bordered hornblendes accompany crystals of the same mineral without black borders. In several cases a double black border is visible, the inner one concentric with the outer, leaving a zone of hornblende between. Such a case is described under slide 450, and shown in Fig. 17, Plate III. I venture to offer some speculations on this phenomenon elsewhere. The black border is readily soluble in chlorhydric acid, even where the slide contains ilmenite A very few slides show hornblendes without black borders. One such exception is from the *Sutro Tunnel* in a region of intense solfataric activity. Here the hornblendes are in part very fresh, while the

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[1] I say appear, because it is seldom possible to make absolutely sure that a crystal is cut exactly in either of the three principal zones, and a very small obliquity often greatly alters the angle of extinction.

remainder of the rock is not. Cases occur on the surface in which it is evident that the black border has been attacked before the hornblende, and this slide may represent such an instance.

Augite.—The augites are essentially similar to those of the augite-andesites, but it may be mentioned that in one case a pinacoidal cleavage was observed which I have never noticed in the augite rock. In a slide from an area which I have classed as hornblende-andesite, the augite also shows heavy black borders like those of the hornblende. Augite is frequently present in the groundmass in crippled crystals and irregular grains, which appear to me referable to "secondary consolidation." The proportion of augite to hornblende is always large except in the micaceous andesites, and, according to Professor Rosenbusch, this is common elsewhere; while in the augite-andesites of the WASHOE DISTRICT there must be more than one hundred times as much augite as hornblende. I have not always seen my way, however, to determining slides containing a decided excess of augite otherwise than as hornblende-andesite, for such rocks occur in areas which appear characteristically hornblendic. While in such cases, which are exceptional, the endeavor has been made to take all the circumstances into consideration, it must be confessed that where very augitic hornblende-andesites and very hornblendic augite-andesites come together, the lines of contact laid down may be somewhat inaccurate, though the error cannot be great; and as these conditions appear to prevail only along Cedar Hill Cañon it is of small importance.

The mica of the andesites gives the interference figure of biotite. It is frequently black-bordered, and the border is usually deeper than that around the accompanying hornblende.

Feldspar.—The feldspars of the hornblende-andesites are nearly without exception triclinic, and of course they can be divided into porphyritical crystals of first consolidation and microlites of second consolidation. As for the species, the porphyritical crystals are either labradorite or anorthite, and the microlites either oligoclase or labradorite. Crystals giving anorthite angles of extinction have been found in only a few cases, and in these I suspect a mixture of anorthite and labradorite, because while many crystals *seemed* so placed that had they been anorthite they must have given angles of extinction exceeding those of labradorite, only a few such sections gave above 32°, while many of the remainder gave within a degree or two of 31°. But I know of no way of absolutely proving this point. The feldspars very often show a zonal structure. A beautiful case of this kind is mentioned under slide 20. Simply twinned feldspars are rare, and most are polysynthetic, according to the albite law; pericline twinning is very common, and both of these sometimes appear in combination with Carlsbad twinning. The stripes are ordinarily fairly uniform, and of considerable width; but sometimes one or both sets are exceedingly fine, and not uncommonly they do not penetrate the crystal, so that one end shows stripes while the other does not. It need scarcely be said that in such cases the unstriped portion if favorably placed may be proved to be triclinic by its optical properties. The porphyritical feldspars are usually developed in long lath-like forms. The feldspars contain inclusions of glass in almost every slide, either as negative crystals or as rounded bodies, and these, when fresh, ordinarily carry bubbles. Inclusions of groundmass too are common, and inclosed microlites occur both of apatite and of what appears to be augite. The latter are not sharply crystallized, and are generally fresh, though occasionally accompanied by chlorite. They are light yellow, and sometimes give angles of extinction of above 30°. I have seen no fluid inclusions in such feldspars as seemed to be unaffected by decomposition.

Other minerals.—The apatites are usually colorless, but sometimes brown and dusty. They seem to be universally distributed. Zircon occurs in only one or two slides. The iron ore is for the most part magnetite, but occasionally ilmenite is present. Fig. 19, Plate III., shows an excellent ilmenite section from the highly augitic andesite in Cedar Hill Cañon, and the application of chlorhydric acid established its presence with certainty in the typical hornblende-andesite from near the *Combination* shaft.

The groundmass consists of feldspar microlites usually referable to oligoclase, magnetite, and sometimes microlites of augite Fluidal structure is common. Of course the groundmass must have crystallized in cooling, and the question is suggested why the glass inclusions were not devitrified at the same time; but it is evident that a large part of each porphyritical crystal must have formed after the glass was inclosed, leaving a residual magma of a different composition. In only one or two cases has anything like a thoroughly granular structure in the groundmass been observed. The greater part of the feldspar microlites are generally well and sharply developed. The same is true in the augite-andesites, and in cases of extreme decomposition the shape of the feldspars, large and small, is an important point of distinction between andesites and the older porphyritic rocks.

Field character.—In the most important part of the DISTRICT lying in the immediate neighborhood of the productive portion of the LODE, the hornblende-andesite is dark and fine-grained, and contains only small hornblendes, which are recognizable as such more often by their brilliant surfaces and evidences of cleavage than by their crystal form. The rock breaks easily under the hammer with a somewhat conchoidal fracture, and its luster is more or less glassy. The hornblende-andesites which occur south of Gold Hill are much more porphyritic, and the hornblendes are unusually well developed. Crystals of an inch and a half in length are common, and one decomposed crystal fully four inches long was observed. In none of the varieties are the feldspars visible when fresh except on minute examination, simply because they are transparent, and the dark color is therefore due to the bisilicates and magnetite. Columnar structure is occasionally developed all over the district, but in no great perfection.

Weathering.—Ordinarily the hornblende-andesite appears to possess little or no structure in mass, while under the action of the atmosphere it develops considerable fissility in certain directions, so that some croppings present almost the appearance of upturned beds of sedimentary rocks with parallel partings at a distance of one or two inches. That the fissile tendency does not extend to an indefinite lamination is evident from the behavior of the sherds. These do not continue to part parallel to their more extended surfaces, but are gradually rounded by the action of frost. By this agency conchoidal fragments are separated from the corners and edges of the loose blocks, and when it is considered through how short a distance the action of the frost can extend, the display of force is quite astonishing. Conchoidal chips of three or four pounds in weight are often found at a distance of two or three feet from the block on which they fit. Large masses of hornblende-andesite breccia also occur, though this form is not so common as with the augite-andesites. Of course, neither columnar structure nor fissility, both of which are probably to be regarded as results of tension from cooling, are developed in the comparatively porous breccias, for the fragments of unfused rock in breccia act like the chamotte in a fire-brick in preventing density of structure.

Decomposition.—The weathering of the hornblende-andesite seems to differ in its nature, as it takes place in direct contact with the air or under ground. Croppings of the rock which on being broken prove internally fresh, are commonly coated with a very thin, deep-red or brown scale and, to judge by fragments found in the immediate neighborhood of such croppings, the change seems to consist mainly in disintegration by frost and in peroxidation of the iron. Under ground, on the other hand, decomposition appears to extend into the body of the rock. One of the first minerals to be affected is the feldspar, which loses its transparency and becomes a dead white. This totally alters the appearance of the rock, which becomes a light-gray porphyry, instead of a dark-bluish and basaltic-looking mass. Every variation in coarseness of grain also becomes apparent. The feldspars lose their transparency when only a very minute portion of their substance (certainly less than one per cent.) is altered. The next stage of decomposition is the formation of chlorite from the bisilicates, which soon diffuses itself through the groundmass and the feldspars. The chlorite is further frequently decomposed into calcite and epidote without any special change in the appearance of the rock. All these changes tend to diminish the sharp definition of the porphyritical crystals and give the mass the look rather of an older dioritic porphyry than of a volcanic rock. It is easy to suggest plausible explanations for the different behavior of the andesite above ground and beneath the surface. The presence under ground of water holding carbonic acid in solution is perhaps sufficient to account for the formation of calcite in the feldspars, and the strong oxidizing action on the surface may well explain the direct formation of ferric oxide in the exposed rocks. When the andesites are not in the condition of breccia the subterranean decomposition is commonly accompanied by a softening or partial disintegration of the mass, though in some cases, as at the South Twin Peak, rock not brecciated preserves great consistency, possibly from an originally porous texture. The breccias remain hard and tough until every mineral has been subjected to complete alteration. There is much evidence and every analogy to show that this decomposition proceeds from external surfaces, cracks, and fissures toward the centers of blocks or masses. Very frequently where cuts have exposed altered rocks, blocks of small size may be seen, which consist of concentric shells of loose decomposed rock-substance, and still contain kernels of fresh andesite. The size of the blocks is, of course, a matter of accident, and sometimes extensive masses decompose only from their external surfaces. When this is the case erosion often acts more rapidly than decomposition and, as the decomposed rock is comparatively soft, masses of the fresh andesite are frequently left standing above the general level. The fresh rock thus exposed has the appearance of a cropping of a younger eruption penetrating and overlying an older and different one; and this appearance is heightened by the weathering of the pseudo cropping which, as already explained, results in a mass of reddish-brown fragments quite unlike the product of alteration beneath the surface. The andesite which had decomposed under ground used to be regarded as propylite, but careful examination of exposed masses of andesite such as those described, shows that a transition into the propylitic form may always be followed out at their base. As the course of the decomposition is dependent on the presence of accidental fissures and, no doubt, on the texture of the rock, the form of the residual masses of undecomposed andesite is fantastically various, sometimes resembling dikes, again assuming the shape of domes and cones.

Distinctive characteristics.—Hornblende-andesites are distinguishable from the augite-andesites when fresh by the presence of abundant porphyritic hornblende crystals and by the luster, which in the augitic rocks is resinous. From the porphyritic diorites they are distinguishable macroscopically by a lack of the granular structure, which the older rock commonly shows. In the propylitic stage of decomposition the three rocks are almost indistinguishable.

Speculation on "black border."—Some of the WASHOE andesites seem capable of throwing light on the conditions under which the black border forms about hornblende crystals. In slides from different parts of the DISTRICT two concentric belts of magnetite have been observed, separated by hornblende-substance. Much the finest instance is illustrated in Fig. 17, Plate III. There can be little doubt from direct observation on modern lavas that porphyritical crystals are formed prior to eruption, and a tolerably large and very sharply defined specimen, like that shown in the drawing, is not likely to be an exception. At some time after it ceased to grow this crystal was broken; but the external black border was formed at a still later period, for it is as heavy on the fractured surface as on the crystal faces. It is difficult to imagine a mass of melted lava in a state of agitation sufficiently violent to break crystals suspended in the fluid magma, except during an actual eruption, and it may be inferred with some probability that this was fractured in its passage to the surface. If so, the external black border was probably formed as the rock cooled after eruption. The inner belt of magnetite, on the other hand, indicates a check in the growth of the crystal, and must have been formed long before ejection. But it is impossible to suppose the temperature to vary greatly in melted rock-masses, at the depth below the surface at which it is believed that eruptions originate. The pressure upon subterranean fluid masses, however, probably varies within very wide limits, and it is well known that changes in pressure produce effects closely analogous to those caused by variations in temperature It seems on the whole, therefore, most likely that this hornblende grew to the limits of the inner black border under conditions which were uniform, or perhaps varied uniformly; that a sudden change in pressure equivalent to a diminution of temperature induced the secretion of magnetite; that the conditions for hornblende secretion were then reëstablished, and continued till the time of the eruption, when the crystal was fractured, and became surrounded by a second border during the cooling process. Other large hornblendes in the same slide also have double black borders, though less symmetrically developed, but the smaller hornblendes, though also of considerable size, and manifestly "crystals of first consolidation," show only a single external belt of magnetite, as if their formation had begun only after the temporary change in pressure. If the hypothetical history suggested is correct, it is probable that hornblende only forms under conditions of pressure which have not yet been reproduced in the attempt to crystallize the mineral artificially, and the comparative rarity of the black border about augite may indicate that this mineral is less influenced by differences of pressure. The basis of the whole speculation is, however, exceedingly slender.

Discussion of a zonal plagioclase.—Zonal structure is exceedingly common in the feldspars of nearly all the rocks of WASHOE, and not infrequently there is a nearly uniform and progressive change in the optical properties from the center of the crystal towards the periphery without demarkation into zones. Of course such a feldspar may be regarded as consisting of an indefinite number of zones, but while ordinary zonal crystals show recurrent layers these do not.

A remarkable instance of zonal structure occurs in slide 20 from the North Twin Peak. It is illustrated in Fig. 13, Plate III. This feldspar is probably a labradorite cut on a plane at right angles to the brachypinacoid. The outer edge and the interior kernel extinguish light almost simultaneously when the cleavage plane makes an angle of about 14° with the principal Nicol section. The intermediate belt, on the contrary, extinguishes at an angle of only 5°, though in the same direction as the outer and inner portions. The fine stripes are blackest at an angle of about 14°, with an opposite inclination, but they show no zonal structure extinguishing light at the same angle throughout their entire length. The persistence of these stripes throughout the crystal seems to prove its crystallographic unity, which is further confirmed by the parallelism of the zonal limits. The section also shows very well the alteration in form of the feldspar during growth, as well as the identity of the zonal inclusions with the groundmass, there being a connection through an opening on one side.

The variation in the position of the optical axes of different portions of a crystal, the effects of which are seen in zonal structure, must be due to differences in crystallographic orientation, or in tension, or in chemical composition.[1] Checks in the growth of a crystal may produce demarkations such as are shown in Fig. 17, Plate III., and described on p. 60, but so long as composition, tension, and orientation are the same, the position of the optical axes must be constant. In the feldspar under discussion the orientation of the zones cannot be different, and variations in tension would

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[1] Cf. Minéralogie Micrograph. by Fouqué & Lévy, pp. 36 and 130.

be visible in the narrow lamellæ as well as in the broad ones. The intrusive groundmass, too, is scarcely compatible with the supposition of variable tension, and the zonal structure in this case must be due to modifications in chemical composition. This may vary in two ways; there may be a substitution of isomorphous elements without disturbance of the characteristic "oxygen ratio" (atomic ratio) of the mineral species, or this ratio may be modified in the sense of Professor Tschermak's feldspar theory. Granting the accuracy, or even the approximate accuracy, of Messrs. Fouqué & Lévy's discussion of the optical properties of labradorite[1] and other feldspars, the first supposition is impossible in the present case; for if, at the position indicated by the angle of extinction of the thin lamellæ and two of the zones, this angle may vary 10°, the distinction of different species by this property is illusory. Indeed the extinctions are consistent with the supposition that the intermediate belt is oligoclase, an hypothesis, however, with which the crystallographic unity of the section is incompatible. I am therefore forced to the supposition that the intermediate belt answers to a variety of feldspar of a different oxygen ratio from labradorite, but crystallizing in this mixture in the same form.[2] The same explanation seems to me indicated in most zonally-built plagioclases, and in those which display progressive divergence of the optical axes.

AUGITE-ANDESITE.

General character.—The augite-andesites present the closest parallellism to the hornblende-andesites; the resemblance being far closer than that which exists, for example, between the diorite and the diabase. But for the fact that they clearly belong to different eruptions it would seem more appropriate to regard the two rocks as varieties rather than as independent species. In the WASHOE district the porphyritic augites are rarely macroscopically noticeable, but their effect is perceptible in a certain resinous luster. While the color of the earlier hornblende-andesite in a fresh condition is commonly

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[1] L. c., p. 253

[2] The influence of salts of analogous properties, when mixed, in modifying the resultant crystal form is well-known.

a blue-gray, not unlike "teinte neutre," the augite-andesites are generally a much deeper, somewhat brownish-blue. Certain glassy augite-andesites strongly resemble the glassy hornblende-andesites, while another variety is pinkish-gray, and bears no superficial resemblance to anything else in the DISTRICT. Some gray vesicular modifications have a basaltic look. The crystalline augite-andesites greatly predominate over the glassy ones Hornblendes occur in a majority of specimens, but in very small numbers as compared with the augites, probably not one per cent., while mica is met with only often enough to justify the assertion of its occurrence.

Augite.—The augite is of precisely the same character as that of the hornblende-andesites. Its color is always a more or less brownish-yellow, which varies somewhat in shade but not in character, and is very like that of bamboo. I have not observed a single case of pinacoidal cleavage, while there is a decided tendency to the suppression of one of the prismatic cleavages. In some specimens the proportion of augite is small, and the crystals are then very well developed. In other cases they are very numerous and occur in groups in which, owing apparently to interference, the crystallographic outlines are imperfectly developed. They frequently contain glass inclusions, which sometimes assume the form of negative crystals, and sometimes spheroidal shapes; but embedded microlites of other minerals are rare. Besides the porphyritical crystals, the augite often appears to form a portion of the groundmass, and microlites of it are common in the feldspars. In one rock, which has been classified as a hornblende-andesite, an augite was noted piercing an ilmenite. These facts point to a very wide range of time for the crystallization of the augite, which would seem to have been among the first, and among the last, minerals to assume a crystalline form. This is a strong contrast to the occurrence of hornblende, but in conformity with the results of experiment, for, as is well known, augite has been artificially reproduced under a variety of conditions; whereas, so far as I am aware, the efforts to reproduce hornblende have hitherto proved unsuccessful. The augites very exceptionally show a trace of the black border, so commonly accompanying hornblende.

Other minerals.—The hornblende is precisely similar to that of the hornblende-andesites. It usually occurs in minute crystals, with heavy black borders; but in one very glassy rock it lacks this accompaniment. The feldspars are also entirely similar to those in the preceding rock. Anorthite has been identified in a few slides among the larger crystals, but in most cases the maximum angles of extinction correspond to labradorite. The microlitic feldspars appear generally to be oligoclase. The iron ore is commonly magnetite, but in a few cases characteristic ilmenite sections have been observed. Apatite is invariably present, very frequently as brown or dusty crystals. There is no inconsistency between the presence of the brown apatite and the colorless variety, which often occur in profusion in the same slide; but the brown crystals seem rarely to assume the acicular form which so generally prevails among colorless apatites. I have not observed a single zircon, nor anything which can be set down with certainty as titanite. The groundmass of the augite-andesites is usually microlitic, though in one or two cases granular structure has been noted. It is very frequently the case that the microlites of feldspar are excessively minute, and with lower objectives the groundmass then gives the impression of felt. This is an appearance which the hornblende-andesites seldom present. The microlites are often so arranged as to produce the effect called fluidal structure.

Field character.—The ordinary variety of augite-andesite in a fresh condition is dark blue, or brownish-blue, in color, resinous in luster, and has a rough fracture. The comparatively fine-grained varieties often show the lighter colors and smoother fractures common in hornblende-andesites, and when the rock is at the same time somewhat hornblendic it is readily confounded with hornblende-andesite. Sometimes, when the feldspars are unusually developed and the fracture is excessively rough, the rock might be mistaken for trachyte; but the absence of mica, the rarity of the hornblendes, and the predominance of triclinic feldspars are generally sufficient to distinguish it. In a few instances the augite-andesites are very granular and coarse-grained, and when slightly decomposed do not greatly differ from some diorites in appearance, but the likeness is superficial. An imperfect columnar structure is occasionally met with, but is not characteristic of the rock. Breccia is exceedingly common, and is sometimes tufaceous.

Decomposition and weathering.—As is the case with the hornblende-andesites, when the rock is directly exposed to the action of the atmosphere the process of decomposition is very different from that which it undergoes when buried beneath the surface. Croppings of the fresh rock rarely exhibit the tendency to divide into parallel plates so characteristic of the other andesite. The want of homogeneity in structure displays itself in a different but very interesting manner. Under the action of the weather it frequently becomes apparent that large masses of augite-andesite are composed of thin beds of various character. Some of these yield to weathering much more rapidly than others, and the exposed face becomes indented with closely set parallel grooves, such as are often observed in finely laminated sedimentary rocks. There is, however, no perceptible tendency to the development of cracks in the directions indicated by these grooves. The most natural explanation of this structure would seem to be that they represent rapidly succeeding flows of the melted rock, but it is hard to see in that case why differences of tension do not lead to the development of fissures. Other masses show an analogous but different behavior in the development of grooves of sinuous form, which cross each other at considerable angles, and give the surface somewhat the appearance of an irregular pavement. If this structure were found only upon opposite surfaces of blocks, it might be interpreted as an expression of a tendency to separate into columns; but when it occurs at all, it is found equally on all the faces exposed. It appears to me that solidification must have set in from numerous centers distributed through the rock, giving it a coarse pseudo-spherolitic structure, and that the grooves must represent a slight difference in chemical composition in that portion of the lava which was the last to solidify. Whatever may be the cause of the appearance, it is highly characteristic of the rock in this DISTRICT. A good example appears in the foreground of the frontispiece.

When fresh augite-andesite is exposed to the air, it soon becomes coated with a yellowish-white product of decomposition. This is gradually converted into a bright reddish-brown substance, no doubt largely ferric oxide, the surface at the same time growing rough. In many cases this color is succeeded later by a pitchy black. The rate of change is by no means slow, and in some of the railroad cuts, made a dozen years since, decomposition has penetrated the rock for about a quarter of an inch. There is reason to suppose that after the rock has turned black the rate of change is greatly decreased. While the changes in direct contact with the air are markedly different from those which take place in hornblende-andesite, the process of decomposition under ground seems to be identical in the two rocks; nor are the products of decomposition distinguishable after the propylitic stage has been reached. As is the case with the hornblende-andesites, too, solid augite-andesite disintegrates, while brecciated masses retain their consistency, and are consequently exposed as bold croppings by the erosion of adjoining disintegrated rocks. I do not know of any cases of unbrecciated augite-andesite retaining its consistency in spite of considerable decomposition, as the hornblende-andesite of the South Twin Peak has done.

LATER HORNBLENDE-ANDESITE.

General character.—This rock, most of which has hitherto been regarded as trachyte, varies greatly in appearance in different parts of the field. The more trachytic varieties, such as those of the quarries a couple of thousand feet northeast of *Sutro* shaft No. III, are purplish or reddish soft rocks, loose in structure, and thickly studded with large feldspar crystals, hornblendes, and flakes of mica. Near the *Utah* mine the color is gray, and the texture firmer and finer-grained, while further north the rock is dense, black, and glassy. It also occurs largely as tufa.

Fe-Mg silicates.—All the younger hornblende-andesite contains mica, though in some cases the amount of this mineral in comparison with the bisilicates is small. Hornblende, too, is always present, and augite generally forms a subordinate constituent. The feldspars are of course triclinic, and no determinable sanidin has been detected. Much of the rock is thoroughly crystalline excepting inclusions, but the extent of the occurrences showing a glassy base is considerable. The hornblende is entirely similar to that of the older andesite, but there seems to be a relation between the physical structure of the rock and the development of black border. In the coarser, more trachytic-looking masses, the black border of both hornblende and mica almost wholly replaces the original mineral, as may be seen to some extent in Fig. 32, Plate V. In the dense glassy rocks, on the other hand, the border is narrow, or altogether wanting. The mica seems to be biotite in most cases, but in two or three localities cleavage scales give an unmistakably biaxial interference figure. It is as uniformly surrounded by a border of magnetite as the hornblende. The augite presents no peculiarities in structure. The amount of this mineral is commonly inversely as the quantity of mica. Magnetite is remarkable only for its abundance, and nothing which could be pronounced titanic iron was noticed. Apatites are rarer than in the older volcanic rocks.

Feldspars.—Almost all the large porphyritic feldspars show abundant striations, even under the lens, and few large crystals appear to lack them under the microscope. Many feldspars which do not show polysynthetic structure under an objective of low magnifying power, show striæ under higher powers. Many of the feldspars show zonal structure comparable with that discussed on page 61 and illustrated in Fig. 13, Plate III. The large feldspars are manifestly crystals of first consolidation, while the groundmass is in great part made up of microlitic feldspars. While the large crystals commonly give angles of extinction indicating labradorite, the microlites appear to be chiefly oligoclase. There are also among the larger feldspars a comparatively small number of Carlsbad twins, and simple crystals which might be regarded as sanidin if no further test were applied; but none such which were cut in the determinable zones, gave angles of extinction appropriate to orthoclase. As some of the possible sanidins were not so oriented as to make optical determinations practicable, I submitted a specimen of the most trachytic-looking rock in the district to Dr. George W. Hawes,[1] curator of the National Museum, for separation by Thoulet's method. The specimen sent was from a quarry 2,000 feet east of the Occidental mill, E 5, and was in all respects identical with that described by Professor Zirkel under slide 283. The following details are taken from Dr. Hawes' report on this rock:

Feldspars determined by Thoulet's method.—The specimen was pulverized to such an extent that it would pass through a sieve containing three meshes to the millimeter; and from this mass of grains the dust that would not settle was separated by elutriation. As the special object in view was to determine

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[1] While this report was going through the press Dr. Hawes died (June 22), leaving a vacancy in the ranks of American geologists which it will be hard to fill, as well as a deep personal regret in the hearts of all who knew him, however slightly.

the species of feldspar, the mass of grains was first placed in a solution of the double iodide of potassium and mercury, which possessed a specific gravity of 2.95. A portion of the substance immediately fell to the bottom. When examined with the microscope this was found to consist of hornblende, augite, mica, and iron oxide. The specific gravity of the fluid was then diminished to 2.85, when a small portion settled out. The precipitate was found under the microscope to consist of composite grains including portions of one of the previously mentioned minerals. At the specific gravity 2.75 only a few grains of the same character fell down, and these were more largely feldspathic.

On reducing the fluid to 2.70, a large amount of clear white grains fell from the fluid. At 2.68 another large portion was precipitated, and these precipitates when examined under the microscope proved to be composed entirely of grains of feldspar. On reducing the specific gravity to 2.67 very little fell down, and this was of a red color, and consisted mostly of grains containing clear feldspar, together with portions of the groundmass. Subsequent reductions of the specific gravity caused the remaining substances to fall to the bottom in successive portions, and when the fluid had reached the specific gravity of 2.61, only a very small amount of material floated. This examined under the microscope was found to consist entirely of groundmass. There appeared to be no portion of the glassy feldspar crystals in any of the substances which had a specific gravity below 2.65. As the amount of rock which will float at any specific gravity which approaches that of orthoclase is very small, it would seem that under no circumstances could this feldspar be considered as a preponderating species, and that, if present at all, it must be in very small amount.

Mr. F. P. Dewey, at Dr Hawes' request, analyzed the feldspar which fell when the specific gravity of the solution was 2.70 and found its oxygen ratio 1:2.89:7.95. This I find would correspond to a mixture of 39 per cent. labradorite and 61 per cent. oligoclase, supposing these the only feldspars present. He also analyzed the portion which fell at a specific gravity of 2.68 and found the oxygen ratio 1:2.96:8.69, corresponding to 12 per cent. labradorite and 88 per cent. of oligoclase. The entire feldspar analyzed was 31 per cent. of the rock, or 8 per cent. labradorite and 23 per cent. oligoclase, on the supposition of a mere mixture of species. It appears to me more probable, however, from the character of the zonal plagioclases, that many of the feldspars are not chemically referable to either species.

The results of the application of Thoulet's method agree excellently with those of the microscopical examination, and together render it impossible to classify this rock otherwise than as a hornblende-andesite, in spite of a macroscopical appearance exceedingly like ordinary varieties of trachyte, and very dissimilar to common andesite.

Remarkable glass inclusion in feldspar.—The feldspars contain glass inclusions in all the slides of this rock, but these are most abundant to the north of the *Utah.* In the quarry close to the hoisting works of that mine some of these inclusions are of a peculiar character, forming negative feldspar crystals of a more or less perfect shape. These were mentioned by Professor Zirkel with admiration. No such fine example occurs in my slides as in that described by him, and in his slide number 284 there is but one which can have furnished his description. This is illustrated in Fig. 14, Plate III. It is not a sanidin, however, but probably a labradorite crystal.

Groundmass.—The groundmass of the more trachytic varieties is entirely crystalline, though never granular like some of the older hornblende-andesites; its texture is also very loose and open, a fact which often influences the course of decomposition. To the north of the *Utah* patches of glass similar to that which is included in the feldspars of the same locality are distributed through the groundmass, and on the ridge running east by south from the Geiger Grade toll-house, D. 1, as well as at the point where the Grade cuts the younger hornblende-andesite area, the glass prevails to such an extent that the rock approaches an obsidian in character. Its pitchy black color is due merely to the bisilicates and magnetite, the glass and feldspar being transparent.

Field character.—The more trachytic varieties near Shaft III. of the *Sutro Tunnel*, and on the southwesterly spur of Mount Rose, are red or purple, and highly porphyritic, very soft and rough rocks, quite incapable of being confounded with any other occurrence in the district. They do not exhibit regular partings or columnar structure. Mount Rose and Mount Emma are largely composed of tufa and tufaceous breccia. The tufa is not macroscopically distinguishable from other tufas, such as that of augite-andesite, but inclosed masses commonly indicate its character. The exposure represented in Plate VII. is made up of coarse porphyries and tufa, and the engraving shows a species of bedding in the rock, no doubt due to variations in eruption. Gray, tolerably firm varieties, about as coarse as ordinary granular diorite, occur at the Sugar Loaf, F. 3, and near the *Utah*. At the latter point columnar structure is very finely developed. Mount Abbie, C. 2, is intermediate between the firm gray and the soft, highly porphyritic modifications, and the black glassy occurrences require no further description. None of these bear much resemblance to the prevalent varieties of earlier hornblende-andesite, but there is a considerable area to the northeast of Mount Emma, and just outside of the map, where the resemblance is almost perfect. This area seems to be strictly continuous with the more typical one, however, and transitions occur. Lithologically the presence of more or less mica seems characteristic.

The weathering of this rock is commonly confined to the separation of ferric oxide, not merely on the surface, but often for considerable distance into the mass, where the latter is of an open texture. In the neighborhood of the *Sierra Nevada* mine, however, chloritic degeneration of the bisilicates is perceptible.

Distinctive characteristics.—No essential property distinguishes the younger from the older hornblende-andesite, but in the WASHOE DISTRICT it forms a variety of andesite readily distinguishable in most cases by its loose structure, and the presence of mica. The glassy modification is more likely to be confounded with augite-andesite, but the luster is not resinous, as in the augitic rocks. The distinction is hardest to draw in the wild cañons east of Mount Kate, a region wholly unlikely ever to have any importance.

BASALT.

Basalt plays a very small part in the geology of the district, but the rock is a thoroughly characteristic representative of the species. It is dark and compact, with many visible crystals of dark amber-colored olivine.

Microscopical character.—The basalt is a thoroughly crystalline mixture of olivine, augite, labradorite, and magnetite, showing no glass excepting as inclusions in the augites. The olivine occurs in part as fairly well developed crystals, with hexagonal and octagonal sections, and occasional perceptible cleavages. It is almost colorless, but shows the faintest possible tinge of yellow. The decomposition amounts only to a slight discoloration along some of the edges and cracks. Augite is present, in part in crystals as large as the olivine, and in part in minute grains forming a portion of the groundmass. The feldspar is crystallized for the most part in lath-like forms, and is often twinned according to the Carlsbad law, but in one or two cases both albitic and periclinic twinning are visible. The determinable crystals seem all to belong to labradorite. The magnetite is in no way remarkable.

Field character.—The larger part of the basalt occurs in the form of ridges with horizontal summits, giving the impression of tables, though they are really very narrow. At the base of these ridges are numerous bowlders which, under the action of frost, have assumed rounded forms. Besides the areas visible on the map, there is a single bluff-like cropping near McClellan Peak, where the bowlders have assumed an almost perfectly spherical shape. It is hard, and rings like cast iron under the hammer, but is rather brittle and chips readily. There is no considerable quantity of decomposed basalt to be seen.

This rock cannot be confounded with any other in the district, for it all carries visible olivine, a mineral not met with in any other WASHOE rock. The elevation laid down as Basalt Hill is augite-andesite, and the rock described by Professor Zirkel as an unusual basalt[1] is both macroscopically and microscopically the same as that here considered as metamorphic diorite.

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[1] Expl. of the 40th Par., Vol. VI., slide 528.

SECTION 2. (Chapter III.)

THE DECOMPOSITION OF THE ROCKS.

Such facts as have been established with reference to the decomposition of the WASHOE rocks are necessarily mentioned in connection with the lithological description of each species. The subject, however, is one of such great importance in the geology of the DISTRICT that it appears advisable to consider the observations bearing upon it as a whole, and in some detail.

Area of extreme decomposition.—While few absolutely fresh rocks occur in the region surveyed, decomposition so great as to oppose a serious obstacle to lithological determinations is confined to a smaller area. In the nature of things this area is incapable of precise definition, but it is shown as nearly as may be in its relation to the COMSTOCK and the *Occidental lode* by the accompanying sketch map, page 73. From this it appears that precisely the area which is of the most importance in a discussion of the vein-geology is that profoundly decomposed.

Effects of decomposition on various rocks the same.—While the physical character of the different rocks has to some extent modified the physical results of decomposition, the chemical and mineralogical changes and the degree of alteration observed in the rocks of the decomposed area seems almost wholly independent of their age or species. Granular diorites, porphyritic diorites, the two diabases, earlier hornblende-andesite, and augite-andesite appear to have been subjected to the same influences, with the same results. Quartz-porphyry and younger hornblende-andesite come within the limits of the chief area of decomposition only to a slight extent, either above or below ground, but to that extent they show the same effects, as does also the metamorphic-diorite in limited spots more or less nearly related to the focus of action. Only basalt and granite have escaped with mere traces of decomposition, while the quartz-porphyry as a whole appears to have been subjected to decomposing influences not shared by the other rocks in the same degree. It is difficult to avoid the conclusion that the period of intense chemical action cannot antedate the eruption of later hornblende-andesite, and probably succeeded it.

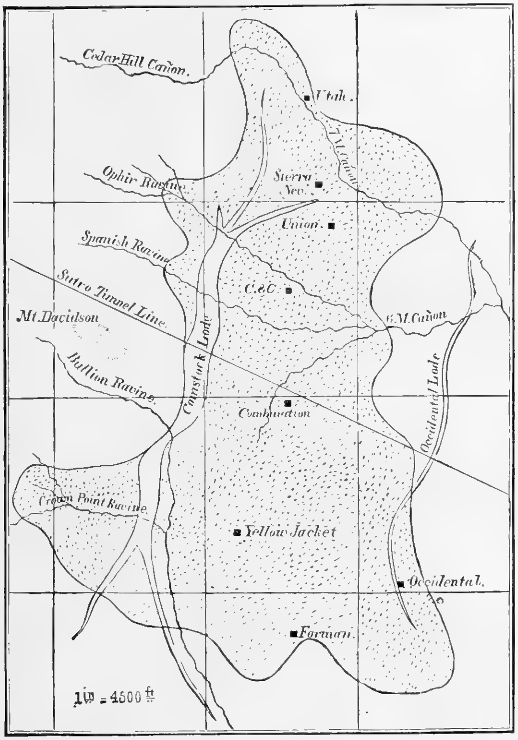

FIG. 1.—Area of extreme decomposition.

Not only have the same minerals in the various rocks undergone identical processes of alteration, but similar groups of minerals have yielded almost identical results. Hornblende, augite, and mica have given place to the same ultimate products, though in slightly different proportions, and the degeneration of each of the various feldspar species has taken the same course.

Hornblende.—Hornblende in the diorites is met with, both brown and green The brown variety is usually quite fresh, while the green exhibits a tendency to a general degeneration throughout its whole mass. In one instance, at least, it has been shown that the brown solid hornblende of a semi-porphyritic diorite is altered into the green fibrous modification, and in other cases there is strong reason to suspect a like change. Similarly, it has been shown that the hornblende of the metamorphic diorite was in all probability once colorless, and that it is now in part converted into a green modification of a fibrous texture. The result in both cases is very similar to uralite. It is by no means asserted that all the green fibrous hornblende of the diorites in WASHOE is an alteration-product of other varieties, though this seems possible, but there is evidence enough to warrant calling the attention of lithologists to the question how far green fibrous hornblende is to be considered the original form of the mineral. Professor Rosenbüsch mentions this change in connection with the proterobases of Lusatia. In the younger rocks I have not succeeded in detecting a similar change. The hornblendes of the WASHOE andesites are either full brown, reddish brown, or greenish brown in color. The tint of those last mentioned it is somewhat difficult to describe, and consultation has shown that the definition proposed depends considerably on the susceptibility of different eyes. To some they appear green with a tinge of brown, while to others the green admixture is scarcely perceptible; but all agree that the color is very different from the grass-green or bluish-green of the fibrous diorite hornblendes.

Alteration of hornblende to chlorite.—The fibrous dioritic hornblende, some of the brown variety in the porphyritic diorites, and all the hornblendes of the younger rocks, appear to pass directly into chlorite. The attack seems to take place from external surfaces and cracks. If the cleavages of the crystal are well opened, each cleavage prism is attacked, and the result in longitudinal section is a quasi-fibrated mass of rods of hornblende separated by chlorite, and in cross-section a group of isolated rhombs or irregular patches of the unaltered mineral embedded in chlorite, which often retains the outlines of the original crystal in great perfection. Figs. 1, 2, and 3, Plate II., are exact representations of such cases. The chlorite, with only one or two exceptions, has the same characters described elsewhere.[1] The WASHOE chlorite evinces a considerable solubility, which can be traced in many series of slides, notably in those from the *McKibben Tunnel.* In the early stages the pseudomorphs after hornblende are very fine; later the form of the hornblendes is obscured, and irregular patches of chlorite appear in the groundmass; at last this mineral appears diffused through the rock, settling in bands round apatites, magnetites, or other solid minerals, and penetrating partially decomposed feldspars. Frequently too it occupies microscopic veins traversing the slide. One such observation would perhaps be open to great question, but scores of similar cases occur in the numerous slides examined.

Augite and mica.—Both augite and mica exhibit the same tendency to pass into chlorite as hornblende, and neither the process nor the result commonly differs in any way from that just described. A preliminary change of augite to uralite is, however, not uncommon in the diabases, and in a single slide of augite-andesite the same alteration appears, though several other thin sections from the same cropping show nothing of it. On the whole augite seems to be somewhat more disposed to decomposition than hornblende, and cases are numerous in which the hornblendes of a rock retain their freshness, when the augites are completely altered; but in some instances the augites have resisted longer than the hornblendes. Mica, on the other hand, certainly yields somewhat less readily than the bisilicates, to which it is so closely allied, though it is often wholly changed to chlorite.

Formation of pyrite.—In very numerous cases pyrite has been observed in relations indicating that it is formed directly from hornblende and augite, apparently at the same time as chlorite. The two products do not seem to me dependent upon one another, for chlorite occurs where no pyrite is found, and the process of conversion to chlorite is not visibly modified by the simultaneous growth of pyrite. The indications are, therefore, that the two processes are wholly independent of and not inconsistent with each other.

Epidote formed from chlorite.—Epidote is usually considered as a direct result of the decomposition of the bisilicates, but in WASHOE such a transformation, if it occurs, must be exceptional, for it was not recognized in a single

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[1] See pp. 84, 211, etc.

instance, though the paragenesis of the products of decomposition was a subject of special inquiry. On the other hand, the formation of epidote at the expense of chlorite is proved beyond a doubt. The development of epidote usually begins near the centers of patches of chlorite, sending out faggot-like masses of crystals in all directions, and ultimately, under certain conditions, occupying the whole space. In certain stages this process can be admirably observed, long prismatic needles of epidote extending into the chlorite and cutting the minute fibers of the latter at all sorts of angles. This is peculiarly well seen in Figs. 6 and 7, Plate II. Sometimes the chlorite-fibers, at the periphery of hornblende pseudomorphs, exhibit a special arrangement, lying strictly parallel to one another and perpendicularly to the crystal face. These fibers are often nearly of the same length, and thus form a belt or zone. Such a belt must be denser than a spherolitic mass, and not infrequently appears to offer a greater resistance to the formation of epidote. This is in accordance with the chemical conditions, for the transformation cannot take place without the access of solutions. Complete pseudomorphs of epidote after hornblende may result from this process under favorable conditions, and such an one occurring in a slide from the *McKibben Tunnel* is shown in Fig. 9, Plate II. From a study of a series of slides from the same locality it is evident that this pseudomorph is the last stage of the process illustrated by Figs. 6 and 7, Plate II., and not a case of direct conversion. Epidote is also constantly found developing in patches of chlorite, which occur in the groundmass of the rocks, where they have apparently been deposited but not formed; and microscopic veins of chlorite are common in which various proportions of the mass are changed to epidote.

Feldspar does not decompose to epidote.—When the feldspars become porous, as they do so soon as decomposition has commenced, they are subject to infiltration by chlorite, and the chlorite so deposited is converted into epidote under the same conditions as in other portions of the rock. One distinguished lithologist has attributed the supposed, but confessedly mysterious, alteration of feldspar into epidote, to the presence of plentiful hornblende-needles embedded in the feldspar. In the section of this chapter dealing with propylite it is shown that this determination is erroneous, the supposed hornblende particles in the slide upon which the suggestion is founded being in fact chlorite; but that the epidote is to be attributed to the alteration of these foreign particles, and not to a transformation of the feldspar substance, seems to me certain. The grounds for this view, which has not hitherto been entertained, are as follows: There is no question that chlorite arises from the decomposition of the bisilicates, and that it may become diffused through the groundmass is equally certain. Many slides from WASHOE show the feldspars in a very fresh state, while the bisilicates are wholly chloritized. In such cases the chlorite cannot be due to feldspar decomposition, but its diffusion through the groundmass is nevertheless common. Carious feldspars appear to be impregnated with chlorite as a rule when the neighboring bisilicates are undergoing chloritic decomposition, but not otherwise; and epidote is found developing in chloritic masses inclosed in feldspar when, and only when, the same process is going on in chlorite patches not so inclosed, the origin of which is distinctly referable to hornblende, augite, or mica. Many cases of the formation of epidote have been observed in chlorite inclosed in feldspar, as convincing as the instances of the transformation of chlorite arising from the bisilicates which are illustrated on Plate II., though none so beautiful; but in no instance in the WASHOE DISTRICT has epidote been seen sending its twig-like crystals into feldspathic masses.

Other alteration-products of chlorite.—Chlorite also degenerates into quartz, calcite, and limonite, and this change is sometimes to be observed in the same slide which shows its alteration to epidote. In this case, also, the dense belt of chlorite which occasionally forms at the surface of a crystal of hornblende, seems to offer considerable resistance to attack. An instance is illustrated in Fig. 10, Plate II. Sometimes this change seems to be referable to a distinct period in the decomposition of the rock, as in the case shown in Fig. 3, Plate II., and described under slide 464.

Character of the chloritic mineral.—The chlorite arising from the bisilicates and mica shows the same optical properties, and the conversion of chlorite into epidote is frequent from whichever primary mineral it may be derived. There seems, however, a somewhat smaller tendency for the chlorite arising from augite to change to epidote, than is displayed by that formed from hornblende and mica; but the difference in this respect is not great or uniform.

Insolubility of epidote.—Epidote is usually classed as an insoluble mineral, and the evidence to the contrary in the WASHOE DISTRICT is slight. Epidote, it is true, frequently crystallizes in vugs, but since chlorite certainly possesses some degree of solubility, their growth might be accounted for by supposing them to form in a solution of the mineral from which they are derived. There seems, however, to be a relation between the size of epidote masses and of the crystalline grains of which they are composed, which is most easily accounted for by supposing the mineral to be somewhat soluble. In very small patches epidote is frequently so fine-grained as to reflect almost all the light, and under low powers appears opaque. In larger masses, formed apparently under similar conditions, the epidote often shows crystalline grains of considerable size, and transmits light readily. In a few cases among the diabases epidote appears to be replaced by opaque mixtures of iron oxide and other substances, but no certain instance of this sort was made out, and there is usually no indication of any tendency to decompose.

Decomposition of feldspars.—The study of the process of decomposition which the feldspars of the WASHOE rocks undergo is much less satisfactory. They have offered a far greater resistance than the bisilicates, and no great continuous area exists in which they are not sufficiently fresh to be readily determinable. Incipient decomposition is marked by the appearance of specks of calcite, readily recognizable in polarized light. At a later stage quartz grains make their appearance, accompanied by particles of a white opaque substance, of a nature unknown to me. In the last stages of decomposition nothing further than these three substances is recognizable. Kaolin, according to Mr. H. Fischer, is an isotropic substance, accompanied in the slides he studied by polarizing grains and scales.[1] Nacrite is crystalline and consists of an aggregate of six-sided scales of fibrous texture, each composed of six triangular sectors. Nothing corresponding to the description of either was observed in any of the slides, a fact which seems to prove that kaolinization, if it has taken place at all, is a very subordinate phenomenon. The analyses of the "clays," too, show that they are not concentrations of kaolin washed out of the surrounding rocks, but represent so much rock crushed and degenerated in place. The water contents of some of them is

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[1] Rosenbusch: Phys. der Min. u. Gesteine, Vol. I., p. 374.

such as to preclude the idea that even this material contains any notable quantity of kaolin.

Secondary liquid inclusions.—The behavior of the particles of calcite which first form in the feldspars is of some little importance, for these on leaching out give rise to secondary liquid inclusions, as will be explained under slide 210.[1] Such inclusions are met in all the decomposed andesites and appear to be frequent also among the other rocks. If proper regard is paid to the condition of the feldspars and to the shape of the inclusion, there is little difficulty in discriminating between secondary and primitive liquid inclusions, but a neglect of these precautions might readily lead to incorrect diagnoses.

Magnetite appears in certain cases to be converted into a yellowish-white opaque substance, accompanied by polarizing grains, much resembling calcite. The black border of hornblendes is sometimes wholly removed in this manner, and the appearance of the rock considerably modified. The phenomena suggest a conversion to a mixture of carbonate of iron and limonite.

Decomposition of rock-masses.—The course taken by the decomposition of masses of rock depends largely on their physical character, and is sufficiently discussed in connection with the general description of each rock. Only porous masses suffer decomposition uniformly throughout, and these are apt to retain their coherence. Blocks of dense rocks are attacked from their surfaces and, as in all processes involving solution or substitution, the corners and edges yield more rapidly than the flat faces, so that the fresh kernel tends to assume a spheroidal shape. The altered portion of the dense rocks frequently disintegrates.

Condition of the quartz-porphyry.—The quartz-porphyry throughout the DISTRICT and far beyond its limits is so much decomposed that not a single fresh hornblende has anywhere been found in it. Except where increased by special causes, such as propinquity to the LODE, the degree of alteration is also very uniform. As it overlies very fresh granite and metamorphic diorite and is overlain by fresh andesites, special causes must be sought to account for its exceptional degeneration. None such have occurred to me except its phys-

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[1] Page 119.

ical structure. The porphyry is, and seems always to have been, very porous, and has permitted a more rapid percolation of surface waters than the other rocks. This is not improbably ascribable to the difference in the coëfficient of expansion of the quartz grains, and the other mineralogical constituents.

The chemical aspects of the decomposition of the WASHOE rocks will be discussed in a separate chapter.

SECTION 3. (Chapter III.)

PROPYLITE.

Historical statement.—The term propylite, as is well known, was introduced into lithology by Baron F. v. Richthofen, mainly in consequence of observations made in the Carpathians and in the States of California and Nevada. In his memoir on "The Natural System of Volcanic Rocks"[1] greater prominence is given to the WASHOE occurrence than to any other. From his description of the rock the following statement of its characteristics is taken almost verbatim. Propylite is always porphyritic, and no prominent property distinguishes it from porphyritic diorite. The feldspars are oligoclase and the hornblendes ordinarily dark-green and fibrous. The groundmass is usually green and appears to owe its color to the profuse dissemination of small particles of fibrous hornblende. It also presents a peculiar and recognizable, though hardly describable, appearance or habitus. It is extraordinarily rich in mineral veins, both in Europe and in America. Geologically it is the earliest of the Tertiary volcanic rocks. Mr. Clarence King[2] accepted Baron v. Richthofen's determination of propylite in the WASHOE DISTRICT (a region which he visited in company with that geologist), though with some limitations and additions. Outside of this DISTRICT the geologists of the Exploration of the Fortieth Parallel found only a few obscure localities of the rock. In 1876 Prof. F. Zirkel[3] confirmed the independence of propylite as the result of a microscopical examination of the collections of the Exploration of the Fortieth Parallel. In 1880 Capt. C. E. Dutton[4] announced the presence of considerable areas of propylite in Utah.

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[1] Mem. Cal. Acad. of Sciences, Vol. I., Part II.

[2] Exploration of the Fortieth Parallel, Vol. III.

[3] Ibid., Vol. VI.

[4] The High Plateaus of Utah.

Failure of the search for propylite.—WASHOE presenting the typical American occurrence of propylite, a study of the rock necessarily formed a prominent feature in the re-examination of the DISTRICT; for while the structure and vein formation of the COMSTOCK are the objects of first importance and interest in WASHOE, the first step toward their elucidation was manifestly to clear up the lithological obscurities as far as possible. Since Baron v. Richthofen and Mr. King examined the DISTRICT, the exposures of rock have been greatly increased. Not only have the mines on the LODE been deepened by a couple of thousand feet, but innumerable roads, quarries, prospect-holes, and the like, have exposed more than the mere weathered surface in thousands of spots. It soon became apparent that the area of andesite, which to Baron v. Richthofen seemed inconsiderable and to Mr. King quite subordinate to that of the propylite, had been underrated. Fresh andesites were found exposed by cuts in many localities which had been laid down as propylite; and since the latter was supposed to underlie the former, the upper portions of these exposures furnished a safe study of decomposed andesites, the results of which could be applied elsewhere. It was found that even where a high degree of decomposition and a thoroughly propylitic character prevailed, reasonably fresh rocks could be discovered by diligent search, either as masses protected by some accidental arrangement of fissures, or as nodules at the centers of concentrically weathered blocks; and to the east of the LODE, wherever fresh rocks were discovered among the propylites, they always proved andesitic. Where andesite dikes or overflows had been recognized, and had been supposed to succeed propylite, careful examination and excavation showed that the change was through a transition, not by a contact. In short, the propylite area to the east of the LODE was reduced almost foot by foot, until it disappeared altogether. The propylite from the head of Ophir ravine, one of the type-localities, had a slightly different character from the eastern rock, yet the difference was not greater than seemed possible within the limits of a rock-species. Fortunately there are many long tunnels penetrating the hills in the neighborhood; and an examination, undertaken to establish contacts between propylite and diorite, resulted in a study of transitions between typical diorite-porphyries and decomposed porphyritic forms of the same rock. At last even in the huge "propylite" croppings of Ophir Ravine the industrious use of the sledge revealed surfaces which were unmistakably dioritic, and so propylite disappeared from the surface. Under ground it early became evident that the east country rock was different from that upon the surface; but a long time elapsed before an accidentally protected mass was discovered, which was fresh enough to serve as a basis for determination. It proved to be diabase. Later, other localities of fresh diabase were found, but while in a new district broad inferences might soon have been drawn as to the character of the hanging wall, this was impossible in the face of previous determinations. If a rock answering to the definition of propylite existed, it was necessary to determine its precise area and occurrence; and if there were no such rock it was indispensable to prove that the whole area was occupied by others. The state of decomposition of the underground rocks is so advanced, that in not more than three out of a hundred of the specimens, all selected with the utmost care, is there a fresh augite or hornblende, and perhaps half of the 185 miles of underground workings are accessible. The task was therefore a laborious one. The lithological examination became a protracted study of decomposition-products, and resulted in proving that propylite did not exist below the surface any more than upon it.

Propylitic habitus.—The most striking macroscopical points of distinction between the rocks in the WASHOE DISTRICT which have been determined as propylite,[1] and the better established Tertiary and ante-Tertiary rocks, are a greenish color which often tinges the feldspars as well as the groundmass, impellucid feldspars, and a certain blending of the mineral ingredients which helps to deprive the rock of those characteristics by which we are accustomed to recognize fresh specimens as belonging to the older or to the younger series. These appearances seem to me to constitute its "characteristic habitus."

Fallacious nature of the distinguishing characteristics.—Baron von Richthofen believed that the macroscopical character of the rock was due to green, fibrous hornblende, and the diffusion of this mineral in fibrous particles through the mass of the rock. This view was confirmed by Professor Zirkel, who

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[1] See page 88.

founds the greater part of his diagnostic points of difference between propylite and andesite upon the color and structure of the hornblende, and its distribution in the rock. What has been taken for green fibrous hornblende, however, in a great majority of the propylite slides of the collection of the Exploration of the Fortieth Parallel proves to be not hornblende, but chlorite. This mineral, which is probably the rhipidolite of G. Rose, is, like hornblende, green, fibrous, and strongly dichroitic, but it occurs largely in spherolitic and felt-like masses, extinguishes light when either of the principal sections of the polarizing apparatus is parallel to the fibers; and, when the Nicols are crossed, usually shows only dark-bluish tints, very different from those commonly transmitted by hornblende. In one of the slides, indeed, there is abundant green fibrous hornblende, but the rock is a granular diorite from Mount Davidson, while in the section from Storm Cañon, Fish Creek Mountains, there is both chlorite and hornblende, but the latter is certainly uralite.

It has been shown in the preceding section of this chapter that chlorite, which is a decomposition-product of hornblende, augite, or mica, is frequently diffused through the groundmass and any feldspars which may have become porous through decomposition. This fact, combined with the mistake of chlorite for hornblende, explains the distinctions based upon the greenish hue of the propylitic rocks, upon the color and structure of the masses mistaken for hornblende, and upon the distribution of supposed particles of that mineral through groundmass and feldspars. Seemingly conclusive proof has also been offered elsewhere that epidote in the WASHOE DISTRICT is not an immediate product of the decomposition of hornblende, but of chlorite; which explains its absence in the comparatively fresh rocks recognized as andesitic.

In one limited area of hornblende-andesite, not represented among the slides of the Fortieth Parallel, minute spiculæ of hornblende occur, distributed through the groundmass; but they are brown, each microlite is solid, and they are not grouped in crystal-like aggregates. In almost all cases the andesitic hornblendes when fresh are black-bordered; but while the magnetite usually resists decomposition longer than the hornblende substance, it sometimes yields first. The hornblendes of the diorite-porphyries, though otherwise very similar to those of the andesites, seldom show even a trace of the black border. Barring two or three exceedingly local exceptions, a division of the hornblende rocks of the DISTRICT into those showing black-bordered crystals, and those which do not contain them, would be equivalent to a separation into andesites and diorites. The assertion that propylite is characterized by the presence of hornblendes without black borders is founded on the determination of chlorite as hornblende.

Much of the chlorite mistaken for hornblende is due to the decomposition of augite, but though fine pseudomorphs of this description occur in the slides of the Fortieth Parallel collection, the significance of their outlines appears to have been overlooked. Some of these slides are from typical, though somewhat altered, augite-andesites. Augite also occurs in the dioritic porphyries of WASHOE.

Glass inclusions, in some cases partially devitrified, seem to occur in nearly all the propylitic rocks of volcanic origin, while they are of course absent from the dioritic rocks, included among the propylites. The WASHOE andesites are somewhat unusually crystalline, and if those which have been regarded as propylite ever contained any isotropic base, of which there is no evidence from analogy, it is now devitrified.

Quartz occurs to a considerable extent among the granular diorites, as an original constituent. One specimen of hornblende-andesite, from an area not represented in the collection of the Exploration of the Fortieth Parallel, however, contains a few minute quartz grains of indubitably primitive character, and these carry fluid inclusions. Occasional fluid inclusions have of late years been found in all volcanic rocks, and they do not consequently form a conclusive point of difference unless they are widely distributed and are present in great abundance. In some of the rocks determined by Professor Zirkel as quartz-propylite, the quartz appears to me to be secondary. It occurs in groups of grains of different orientation, and is indistinctly separated from the surrounding mass. Secondary quartz, of course, frequently contains liquid inclusions.

Value of habitus in rock-determinations.—The methods employed to identify the propylites of WASHOE with other rocks were by no means confined to mere mineralogical examinations under the microscope. It is but a few years since the only resources of the lithologist were a study of variations and transitions, and a keen perception of the habitus characteristic of rock-species, aided only by the feeble help of a lens and an occasional chemical analysis; and how much can be accomplished in this way is evident from the fact that the chief features of lithological classification are still much what they were before the introduction of the microscope. Nor are the methods of the older lithologists antiquated; on the contrary, the proper use of the microscope greatly increases their applicability and efficiency. The microscope enables lithologists of the present day to give greater precision to their ideas of macroscopical habitus, and to distinguish in most cases between essential and non-essential characteristics, and, with this advantage, they should become even keener field observers than their predecessors. Indeed the relations of lithological varieties, and of the causes on which they are dependent, can be successfully studied only in the field. In the present investigation slides were ground and examined from day to day as the exigencies of the field-work seemed to demand. The microscopical and macroscopical appearances were also diligently compared (for grinding slides without machinery was a serious addition to the labor of days spent in the saddle or under ground); and it became possible at length to recognize at a glance a unity of origin in specimens of very diverse appearance and to detect lithological differences in spite of advanced decomposition and great apparent similarity. It proved possible to make the proper allowance for decomposition and to infer the original habitus when veiled by another of secondary origin, as well as to identify the precise character of the change.

Typical propylite localities.—The three most important propylite localities mentioned by Professor Zirkel in the WASHOE region are the head of Ophir Ravine, Crown Point Ravine, and Gold Hill Peak. The last is represented in the map accompanying the present report, as the southern Twin Peak (C. 4).

Head of Ophir Ravine.—The upper portion of Ophir Ravine presents a very great variety of diorite-porphyries, which are not related as separate flows or sheets, but pass over into one another as if the whole heterogeneous mass had cooled at once. The character of the rock changes every few feet, and the same varieties recur in spots. Among them are some so granular as to be nearly indistinguishable from Mount Davidson rock, while others are dark fine-grained porphyries closely resembling andesites. The latter, however, can be shown from slides to be dioritic, while the granular varieties are as like the Mount Davidson rock microscopically as they appear to the naked eye. A portion of these rocks is altered, but the transitions from the fresh to the decomposed state can be studied more satisfactorily in the *McKibben Tunnel*, because, in the ravine, decomposition is most prevalent in the bluffs near the andesite, which is also somewhat altered. There is no evidence of any contact between these bluffs and the unquestionable dioritic masses adjoining them, and in spots where the rock is comparatively fresh, its character seems unmistakably the same; but when the effect of decomposition on the tunnel porphyries is considered in reference to the ravine rocks, it becomes clear that the bluffs can be only altered forms of the adjacent varieties of diorite.

Crown Point Ravine.—One flank of Crown Point Ravine shows tolerably fresh hornblende-andesites, the other excellent fresh augite-andesite. Near the drainage the rock is largely a highly decomposed breccia, in part bleached to whiteness, but the area occupied by propylitic rocks is very small and could only represent an exposure by erosion. As is common in breccias, the decomposition is not uniform. The matrix is so altered that its coherence is a matter of surprise, and many of the included fragments are tinged with epidote. Some, however, from superior density or accidental protection are less affected, and a few large unfissured blocks are tolerably fresh at some distance within their surfaces. Wherever the inclosed masses are fairly fresh they look like andesites, and under the microscope there proves to be no distinction, when the course of chloritic decomposition known from other occurrences is allowed for.

South Twin Peak ("Gold Hill Peak").—The South Twin Peak looks more like the younger gray hornblende-andesite of the Utah quarry than the more usual varieties of the earlier eruption, while the northern peak is for the most part normal; but it also shows occasional small patches resembling its southern neighbor, and there seems a gradual transition from one to the other. Fresher specimens from the South Peak show abundant lustrous, seemingly black, hornblendes with perfect cleavage, and these under the microscope prove to be deep brown black-bordered crystals. There is no green hornblende and there are glass inclusions. In short, there is no assignable reason for separating this rock from the andesites. There are many other localities in the DISTRICT where the propylitic rocks are quite as puzzling as in the three described, but it is sufficient to state that they were studied with equal care and with similar results.

Conclusions reached.—Field observations, aided by microscopical examination, show that the mineralogical composition and the structure of the propylites of the WASHOE DISTRICT in their original state were identical with those of certain fresh rocks found in the same region, namely, granular diorite, dioritic porphyry, diabase, hornblende-andesite, and augite-andesite. The great and misleading similarity of the propylites to one another is due not to original constitution, nor to their geological relations, but to the identity of the decomposition processes to which they have all been subjected. The failure to detect the lithological relations of these rocks arose principally from a confusion between green hornblende and the green and dichroitic, but uniaxial, minerals grouped under the term chlorite; but a neglect to give due weight to evidences of pseudomorphism, partial devitrification and other phenomena of decomposition, materially aided in obscuring the true nature of the supposed rock-species.

Causes of error.—It appears to me by no means superfluous to consider how so keen an observer as Baron v. Richthofen came to regard propylite in the WASHOE DISTRICT as an independent rock-species, and as a volcanic of Tertiary age; and while I have no authority for my suggestions, I offer the following explanation.[1] Baron v. Richthofen regarded Mount Davidson as syenite and the visible plagioclases as accessory. The rock does indeed more nearly resemble ordinary syenite in its general appearance than ordinary diorite, and the error was never detected until Professor Zirkel examined it microscopically. In the porphyritic diorites v. Richthofen saw a plagioclase rock, but the triclinic character of the feldspars in the porphyry aroused no known doubt in his mind as to those of the mass of Mount Davidson. Porphyritic syenites are very rare, while the relation of the

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[1] It would be superfluous to remind geologists that in 1865 the science of microscopical lithology was undeveloped.

diorite-porphyries of WASHOE to the granitoid diorite is peculiar. Any but a very thorough inspection would lead to the belief that the porphyries are younger than the granular diorite. v. Richthofen had reason to suppose that Mount Davidson was post-Jurassic, and the plagioclase porphyries were therefore in his eyes younger than that period, and older than the andesites which cap the range. As I have endeavored to show, the dioritic porphyries, when in a certain stage of decomposition, are scarcely distinguishable from the thoroughly crystalline andesites, when the latter are also somewhat decomposed. These v. Richthofen found at considerable distances from his "syenite," and so associated with Tertiary rocks as to prove them members of that series. Tertiary leaves were also discovered in similar rock at no great distance. These wackenitic andesites, too, stood in such a relation to the fresher rocks that they appeared to precede them, and the chain of proof seemed complete of a pre-andesitic Tertiary rock. The extension of the propylite to the mines was natural and easy.

If propylite were older than andesite, where should we look for it but in depth? And if there was no distinct lithological reason assignable for pronouncing the underground rock, mostly in the last stages of decomposition, identical with that on the surface, there was next to no reason, macroscopically speaking, for supposing it different. This mistake having once been committed, I do not believe it could ever have been corrected in opposition to even a far less weighty authority than Baron v. Richthofen, had not fresher rocks been opened up by the extensive lower workings, and had the microscope not been sought as an auxiliary. That an association between propylites and mineral veins should have been observed is natural, for in mineralized districts we expect general decomposition.

Propylites from other districts.—By the courtesy of the geologists of the Fortieth Parallel Survey, I have been permitted to examine the specimens and slides from all the localities laid down in their publications as propylite. Captain Dutton, too, has kindly furnished me with specimens and slides from his propylite localities in Utah. Rocks which are indeterminable in the field are very apt to give uncertain evidence under the microscope, and as all propylites are decomposed, I do not feel absolute confidence in my determinations of the propylites occurring outside of the district which forms the subject of this paper. Nevertheless, I have given my notes upon them in the section containing the "Detailed description of slides." There appear to be fairly good grounds for the determinations there suggested, and the specimens seem to offer no evidence even approximately sufficient for the establishment of a new rock-species.

No propylite yet found in the United States.—The term propylite might be retained to express a certain macroscopical appearance and certain chemical changes, just as we still speak of serpentine without denying its secondary character. But a better name, and an older one, already exists for this very thing, for the terms greenstone and greenstone-trachyte designate rocks in every way similar. Considered as its originator intended it, as a pre-andesitic Tertiary rock, I feel no hesitation in asserting that nothing answering to its definition has as yet been proved to exist in the United States.[1]

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[1] **European propylites.**—The investigation of American propylites described in this report was carried out entirely without reference to the opinion of European lithologists regarding the Transylvanian rocks. American geologists who have not followed the subject closely may be interested to learn, however, that the tendency of opinion in Europe is strongly against the independence of this rock-species. Dr. C. Doelter upholds it in a paper "Ueber das Vorkommen des Propylits in Siebenbürgen. Verhandl. der k. k. Geolog. Reichsanstalt," 1875, p. 27. In reviewing this paper in the "Neues Jahrbuch für Mineralogie," etc., 1879, p. 648, Professor Rosenbusch incidentally considers Baron v. Richthofen's description and Professor Zirkel's views, and states his own conclusions as follows (translated):

"The reviewer, in common with all other investigators, willingly recognizes the peculiar greenstone habitus of the so-called propylites; their Tertiary age, which in many cases must be further and more sharply determined, being assumed. Since similar changes in habitus occur in many other series of rocks, however, he does not feel himself compelled to accord propylite an independent position, but rather to regard it as a mere pathological variety of quartzose or quartzless hornblende-andesites, or of the augite-andesites, as the case may be."

Professor vom Rath has published a paper in the "Sitzungsberichte der Neiderrheinischen Gesellschaft in Bonn," vol. 35, 1878, p. 26, in which he expresses a very positive opinion that the so-called propylite of Schemnitz is diabase, and has no relation to the andesites of the neighborhood. He asserts that this diabase has a very different look macroscopically and microscopically from andesites, but it is to be regretted that he does not give the differences in sufficient detail to enable readers to judge for themselves. Prof. J. Szabó has read a paper before the Hungarian Geological Society, which is reported in the Verhandlungen der k. k. Geolog. Reichsanstalt, 1879, Literaturnotizen, p. 17. In this paper Professor Szabó maintains that various eruptive rocks and even sedimentaries have been altered to what is called greenstone by solfataric action at Schemnitz, and he concludes with the following statement (translated): "There is no greenstone-trachyte formation proper in a geological sense; there has never been an independent propylite eruption." I infer that the conditions in Schemnitz are substantially similar to those in WASHOE.

SECTION 4. (Chapter III.)

DETAILED DESCRIPTION OF SLIDES.

Reasons for this section.—In view of the considerable alterations proposed in the classification of the WASHOE rocks, it appears proper to submit detailed descriptions of a sufficient number of slides to enable lithologists to judge whether the methods employed in the determinations are correct and the grounds upon which distinctions have been drawn sufficient. Nearly but not quite all the statements made in the foregoing sections of this chapter concerning the microscopical character of the rocks may be substantiated from these slides. It was considered that further descriptions were needless and would be burdensome.

Determination of feldspar.—The feldspars have been determined optically according to the rules laid down by Messrs. Fouqué and Levy.[1] This method is very tedious, and is, properly speaking, applicable only to the determination of the most basic feldspar present; but by applying it to a great number of cases the microscopist is able to satisfy himself of the prevailing feldspars as well, and in this respect it appears to me more satisfactory than the determination of isolated feldspar fragments by their specific gravity. In two cases M. Thoulet's method has been employed. Professor Szabó's method has not been attempted.[2]

An explanation of the method of reference to the slides by a system of coördinates in millimeters, referred to the upper left-hand corner of the glass, will be found in the description of the lithological illustrations, page 145.

GRANITE.

Slide 460. Close to *Red Jacket* mine.

Typical granite.—This is a moderately fine-grained gray micaceous granite. The slide shows besides orthoclase, quartz, and mica, a few plagioclases,

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[1] Mineralogie Micrographique, 1879. So far as I know this method was first suggested by Prof. R. Pumpelly, Proc. Amer. Acad., Vol. XIII., p. 258.

[2] Tests by this method, subsequently made, are described on p. 405, *et seq.*

magnetite, and some accessory minerals. The structure is typically granitoid, none of the principal minerals showing either perfect crystalline outlines or microlitic development. The orthoclase is for the most part transparent, and in many cases shows good cleavages, which are usually parallel to the extinctions. The plagioclases show very narrow stripes and no angles of extinction exceeding those of oligoclase. The quartz contains abundant liquid inclusions, many with moving bubbles. The mica shows the interference figure of biotite, and is of course brown and highly dichroitic. A portion of the biotite appears "bleached" to a lighter brown, and other fragments are converted into chlorite. A few particles of epidote are visible, forming from the chlorite. The iron ore is evidently magnetite, occurring mostly in quadrangular forms, and being accompanied by hematite. There is also a considerable amount of titanite, which in some cases takes the form of perfect rhombs, with an angle of somewhat less than 140°. It shows the cleavages, the rough surface, high refraction, and dull colors between crossed Nicols, appropriate to sphene. There are many minute zircons, and some ordinary apatites. The slide contains two patches of a somewhat highly refracting, nearly colorless, slightly yellowish, mineral, one of which seems to be of an imperfect hexagonal outline, and the other nearly square. They show a rippled surface, such as is often seen on augite. They remain dark between crossed Nicols, and give no interference figure. The mineral shows cracks, some of which are irregular; others seem referable to an imperfect rhombohedral cleavage All these properties suggest sodalite. This mineral, however, has been noticed, I believe, among the older massive rocks only in syenite,[1] and in combination with elæolite and zircon. As zircon is plentiful in this slide, I carefully looked for elæolite. If present at all it must be in granitoid crystals, which might be mistaken for orthoclase. Many such are cut nearly at right angles to an optical axis, but I failed to find one such which gave the interference figure of a uniaxial mineral.

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[1] As the name is now usually understood. In Dana's Mineralogy the quartzless mica-orthoclase rocks are still termed granite.

GRANULAR DIORITE.

Slide 213. Bullion Ravine, at Water Company's flume.

Typical diorite with green fibrous hornblende.—This is the typical diorite of Mount Davidson. Macroscopically, it is gray in color and granitic in structure. The slide shows that it is composed of a mass of crystalline grains, filling the whole space and without the most distant approach to a porphyritic structure. It contains triclinic feldspar, fibrous hornblende, quartz, magnetite, a few fragments of mica, and a number of accessory minerals. The hornblende is present only in fibrous crystalline masses and patches, which seem to have crystallized after the feldspar. Many of the masses of hornblende are cut at right angles to the main axis, and show excellent cleavages at the characteristic angles. It is strongly dichroitic, giving tints varying from buff to sea-green It polarizes with great brilliancy, showing the whole range of prismatic colors. The angles of extinction observed reached 20°. In parts of the slide the hornblende is decomposed, the products being chlorite, epidote, quartz, and calcite. The disposition of the original mineral is so irregular that the process of decomposition cannot be studied to advantage.

The feldspars seem to be without exception polysynthetic plagioclases. The twin striations are irregular in width, but very continuous and sharply defined. The angles of extinction of the twins, which extinguish light at equal inclinations to the plane of the Nicols, are large. Very many such were observed to exceed 20°, and one or two reach 29°. The feldspar is therefore in the main labradorite, and I saw no indications of the presence of any other feldspar species. There are no untwinned feldspars or feldspathic microlites. Besides the twins following the law of albite, there are many instances of additional periclinic twinning. In several crystals there is well-developed zonal structure. The feldspars are for the most part very free from inclusions of any kind, and are clear and transparent.

Many grains of quartz are present, but I observed no crystal faces. The quartzes are full of fluid inclusions, some of them dihexahedral. One of these is so large that the movement of the bubble can be clearly seen with a magnifying power of 60 diameters. The bubbles of these inclusions do not disappear upon heating the slide to 40° C. on Vogelsang's table, and are therefore probably aqueous.

There is a considerable quantity of magnetite in this slide, characterized by its square outlines and opacity. I observed no titanic iron. A few crystals of apatite appear under the microscope, rather fewer than is usual in the rocks of the DISTRICT. They are colorless, and contain no determinable inclusions. There are many minute zircons recognizable by their high refraction, brilliant polarization, and by their crystal form (the eight-sided prism, terminated by the fundamental pyramid). One or two fragments of mica appear in the slide—*e. g.*, at 21–21. There are also a number of irregular fragments of a mineral which can scarcely be anything but titanite. It shows an uneven surface, brown color, perceptible dichroism, and high refractive index. In polarized light it is only feebly chromatic. Plate IV., Fig. 25, shows a characteristic portion of this slide.

Slide 413. *Union Shaft*, 2,625 feet from surface.

Dark diorite with some brown hornblende.—Macroscopically this is a very dark rock, highly charged with scales of hornblende. It reminds one of freshly fractured "No. 1" pig iron. Under the microscope it is seen to be composed essentially of triclinic feldspar and hornblende, both minerals having consolidated nearly at the same time. A few grains of quartz, and an insignificant amount of colorless apatite, complete the list of components.

The hornblende is in part of a brown tint, very slightly tinged with green; in part it is of a light and vivid blue-green color. Many of the hornblende crystals show both colors; the green variety occurring along the edges and cleavages, and sometimes leaving only small irregular patches of the brown mineral surrounded by the green. The structure of the two varieties is distinctly different. The brown mineral shows excellent cleavages, but no tendency to fibration. In the green portions of the same individuals the hornblende seems to be composed of minute fibers, but the tesselated appearance of the cross-sections is nearly obliterated. In fact all the appearances are such as accompany a distinct alteration in mineral character. The brown hornblende is as usual very strongly dichroitic; the green is less so. On the other hand, the green mineral polarizes in colors of the utmost brilliancy, like those of the preceding slide.

The hornblendes contain a vast number of included microlites of a black, wholly opaque mineral, crystallizing in needles and long pointed scales, which can scarcely be anything but ilmenite or hematite. These microlites are arranged in certain planes of the hornblende crystals, viz: perpendicular to, and parallel to the base. In sections nearly parallel to the vertical axis no further regularity is perceptible, but cross-sections show that they are also parallel to the prismatic faces and to the clinopinacoid The distances from these faces are wholly irregular, and the effect is therefore merely that the microlites form with one another angles of nearly 60°. It is noteworthy that just the faces most usually found in microscopic hornblendes are the ones emphasized by the position of these minute bodies. The same microlites also occur in the feldspars, in which, too, their distribution seems to be governed in part by some crystallographic law, but what one is not evident from this slide. These microlites are, for the most part, entirely unaltered in the brown hornblende, while in the green they are replaced in part by very fine transparent yellowish crystalline grains. In some places the black and the transparent inclusions are continuous with one another, and everywhere the disposition of the latter is precisely that of the former. In fact a narrow inspection does not leave a doubt that the opaque microlites are decomposed into a transparent mineral. The minute size of the grains found does not permit of absolute determination; but the product of decomposition is doubly refracting, possesses a high index of refraction, is slightly dichroitic, and seems to polarize in rather feeble colors. The only familiar minerals which it recalls are titanite and epidote, and the probabilities are that it is sphene.

In one portion of the slide is a mass of a nearly colorless substance, slightly tinged with green, which seems to be totally isotropic. Under crossed Nicols it remains absolutely dark, and when the quartz plate is introduced, and the Nicols are adjusted to the *teinte sensible*, no change whatever in the shade is perceptible on revolving the slide This is one of the substances grouped under the term "chloritic constituents," but it does not appear to be certainly identical with the ordinary product of the decomposition of hornblende. Embedded in it are numerous small grains and microlites, which extinguish light at a large angle to the plane of the Nicols. They are arranged at angles of about 60°, and it appears to me that the object must be supposed to be a decomposed hornblende, filled with microlites of the mineral which results from the decomposition of the black microlites. This opinion is strengthened by the occurrence of a number of intermediate stages, as they seem to be, between fresh hornblende and the last mentioned chloritic mass. As the black microlites alter, the hornblendes become in some cases grayish and less and less pellucid, not apparently from want of transparency on the part of the minerals, but through irregular refraction of light.

The feldspar is undoubtedly for the most part labradorite, many of the finely twinned crystals showing angles of extinction of nearly 30° on each side of the twinning plane. I see no evidence of the presence of any other feldspar. There are a few grains of quartz, which contain some liquid inclusions. The apatites are few in number, colorless, and in no way remarkable. I detected no other minerals in the slide.

Slide 81. *Utah,* 1,950.

Gray diorite with brown hornblende.—This is the freshest diorite in the collection, the feldspar being as transparent as it ordinarily is in andesite. Unfortunately the slide is not thin. The principal difference between this and slide 413 is that the majority of the hornblendes are brown, many of them without a tinge of green.

Slide 361. *Savage* 1,300. North drift, about 310 feet in.

Micaceous granular diorite.—In this rock, which is not a porphyrite, but granular, the hornblende has been almost wholly replaced by biotite, which is of the usual structure, and gives an interference figure nearly like that of a uniaxial mineral. The slide contains much quartz and many beautifully sharp zircons. In other respects it is similar to slide 213.

Slide 291. *Chollar* 1,700; 1,425 feet west of *Combination* shaft.

Diorite containing tourmaline, etc.—This is a diorite of the granular crystalline type, but of a very quartzose variety. The quartzes contain innumerable fluid inclusions, many of them of unusually large size. Some are dihexahedral in shape; the bubbles of the smaller ones are active, and some contain excellent salt cubes. The proportion of salt to water seems to be very high; for on heating the slide to about 70° C., the only effect produced was to round the edges of the cubes. The bubbles did not grow perceptibly smaller at this temperature.

The slide is further remarkable for containing what appears to be tourmaline. One small patch dichroizes between black and clear brown. The mineral exhibits scarcely any structure, but there are traces of what appear to be cleavage cracks parallel to the direction of extinction. No distinct interference figure could be obtained. The lack of structure and the absolute extinction of the ordinary ray seem to separate this substance from hornblende; to mica it bears no resemblance.

PORPHYRITIC DIORITE.

Slide 421. Center of Cedar Hill Ridge.

Fresh porphyry.—The mass of porphyrite forming Cedar Hill is very uneven in composition, and, for the most part, greatly decomposed. Near the highest portion, however, is a small quantity of a comparatively fine-grained variety, which, from one of the accidents so common in regions of decomposition, has escaped nearly unaltered. Macroscopically it is a dark, leaden-gray rock, rather fine in texture, and exhibiting porphyritical crystals of feldspar and hornblende. Under the microscope it is seen that these minerals are separated out in a groundmass of tolerably fresh feldspar microlites, and magnetite, to which the dark color of the rock is due. Numerous colorless apatites form the only other prominent mineral ingredient. The hornblendes are almost wholly undecomposed. They are of a slightly greenish-brown color and fairly well-crystallized. Most of this mineral occurs in crystals of large size, but there are a few minute crystals and crystalline fragments interspersed through the groundmass. The hornblende is dense, though in many cases the cleavages are well developed, and one crystal even contains fluid inclusions (10–24½). There is no tendency to zonal structure in this slide, but several of the hornblendes are twinned according to the ordinary law. Decomposition has set in to a slight extent; and in one or two cases the degeneration into chlorite may be observed starting from the cleavage fissures of the parent mineral. Where the masses of chlorite have reached any considerable size, particles of epidote have developed near their centers. In a large proportion of the hornblendes occur inclusions of the same kind mentioned under slide 413. A group of these microlites is shown in Fig. 21, Plate III. Their disposition is the same as in slide 413, but this section contains nothing which throws light on their nature.

There are numerous good-sized but rounded plagioclases in this slide. Those which show an approximately equal angle of extinction on each side of the twinning plane, give angles of extinction which, in some cases, considerably exceed 20°; no untwinned microlites were observed, and the feldspar is probably labradorite. The feldspars contain a few fluid inclusions of apparently primitive character, and are pierced by numerous apatite needles. One or two fragments of hornblende are inclosed in feldspars, but for the most part the feldspars are wholly free from that mineral.

The groundmass consists mainly of feldspar microlites and granules, and traces of fluidal structure are perceptible. An abundance of magnetite is recognizable as such from its crystal form; and associated with and penetrating it are many colorless apatites. The slide also contains one poorly developed zircon. There is further a small amount of chlorite and epidote. Most of the former is concentrated in an excellent vein.

Except in the matter of inclusions, this rock bears a strong resemblance to an andesite; its groundmass, however, is less microlitic and the porphyritic feldspars have not the sharp development almost invariably observable in andesites. Its occurrence as a mass little more than a foot cube, embedded in porphyritic diorites of an ordinary variety, forbids the supposition that it is a volcanic rock. A portion of the slide is shown in Fig. 26, Plate IV.

Slide 278. Ophir Ravine, south side.

A second fresh porphyry.—This rock strongly resembles 421 in most respects, but the hornblendes are noteworthy. They are unusually solid, often showing scarcely a trace of cleavage. Indications of zonal structure are visible; *i. e.*, the exterior layer of the mineral exhibits a somewhat different texture from the remaining mass. The polarization of these hornblendes is remarkably brilliant, quite equalling that of ordinary augite. Many of the crystals are twinned, one of them (14–23) being polysynthetic. A crystal of considerable size is divided into halves of identical orientation by a narrow layer of the mineral in a reversed position.

In one part of the slide (13–27) are some minute scales of epidote which appear to represent the clinopinacoid, limited by the base, the orthopinacoid, and the positive hemidome. The direction of extinction is sensibly perpendicular to the orthopinacoid. The same form of epidote is found in other slides, *e. g.*, in 371 at 17½–19.

Slide 252. *Sierra Nevada*, 1450. North drift 289 feet north.

Partially decomposed dioritic porphyry.—This is a grayish-green granitic-looking rock, with brilliant hornblendes, and only a slight apparent tendency to porphyritic structure. Under the microscope, however, it is seen to belong among the porphyritic diorites. The feldspars are almost opaque, and it is with some difficulty that they can be made out to be triclinic. The groundmass was evidently granular when fresh. There appears to have been a little mica, now converted to chlorite and epidote. The hornblendes are unusually interesting because present in all stages of decomposition. The fresher ones are bright brown, without black borders, and solid except for the well-marked cleavages. Other crystals seem to have undergone a species of fibration in the direction of the cleavages. This fibration is accompanied by the presence of decomposition products, and each small elongated cleavage prism seems coated with secondary minerals. Other hornblendes are partially converted into chlorite, and a fine example is illustrated in Plate II., Fig. 1. Still others have passed completely into epidote. In some of the partially decomposed hornblende crystals there are small crystals of pyrite.

Slide 194. *McKibben Tunnel*, 480 feet from entrance.

Decomposed dioritic porphyry.—In hand specimens this rock is greenish-gray, and somewhat porphyritic. Under the microscope it is seen to be greatly decomposed, but not in such a manner as to obscure its original constitution. When fresh it consisted essentially of well-developed crystals of triclinic feldspar and hornblende, disposed porphyritically in a groundmass mainly composed of feldspathic grains. A little mica, a small amount of black ore (probably magnetite), and numerous colorless crystals of apatite, were subordinate mineral ingredients.

No undecomposed hornblende now remains. It has been replaced by chloritic material, epidote, quartz, and calcspar, but in such a way as to leave the larger portion of the hornblende crystal outlines undisturbed. All, or nearly all, the hornblendes seem to have been crystals of considerable size and sharp definition, and there is nothing to indicate that they possessed a fibrous structure. Some of the hornblende crystal outlines are completely filled with the chlorite. This substance sometimes shows an excessively fine, fibrous, imperfectly spherolitic structure. In other cases the fibers near the peripheries of former hornblendes are arranged at right angles to the crystal face. These fibers are of nearly equal length, and they form a zone just within the crystal section. The chlorite is grass-green, and very slightly dichroitic, varying between more and less yellowish green shades. Between crossed Nicols it behaves almost like an isotropic substance and shows, besides black, only dark purple tints. The chlorite is not confined to the hornblende sections, but is diffused through the rock in veins and patches. It also occurs in narrow borders about magnetite and apatite, as if these minerals had mechanically obstructed its movements.

The epidote occurs in a similar way both without and within the hornblende sections, which it sometimes wholly and sometimes only partly fills. It is noteworthy that this mineral when it occurs in small patches is usually finely granular, and that within certain limits, the larger the area, the coarser the grain. When, as is often the case, the occurrences are wedge-shaped, the granulation grows coarser from the point to the base. This seems to indicate a more or less continuous recrystallization of the mineral.

The relations of the chlorite and epidote in this slide are extremely interesting, for it affords abundant proof that the epidote has formed at the expense of the chlorite. This is well illustrated in Figs. 6 and 7, Plate II., especially in Fig. 7, where the growth of the epidote into the chlorite is accurately and clearly shown. It is very noticeable that, as has already been mentioned, the chlorite at the edges of the hornblende sections frequently remains undecomposed longer than the interior mass. The behavior of this peculiarly arranged chlorite seems to indicate a greater density, and consequently a greater resistance to decomposition, than is possessed by that with spherolitic structure. In a majority of cases the decomposition of chlorite into epidote begins toward the center of the section, but there are many exceptions. It is probable that the veins and patches of epidote not connected with the hornblende sections have also been formed from chlorite, for the latter appears to be the more soluble mineral. There is evidence too, from other slides of the same rock, that, as decomposition proceeds, the chlorite is replaced to an increasing extent by epidote, etc. The chlorite in this rock also decomposes into quartz, calcite, and limonite. Whether epidote, too, undergoes the same decomposition is uncertain. Forming, as it does, masses of irregular granules and imperfect prisms, it would be difficult to show that it had been encroached upon in any given case by quartz and calcite, and had not formed simultaneously with them.

There is no augite in this rock, but a little (5–23) mica, which, like the hornblende, has been converted into chlorite and epidote. The feldspars still show twin striations, but are considerably decomposed, and under high powers the mass is seen to be porous or even spongy. Particles of chlorite, epidote, quartz, and calcite are disseminated through the feldspars. In some of the freshest portions fluid inclusions may be detected. The apatites are all colorless, and sharply crystallized. Fig. 18, Plate III., shows a curious case, in which an intrusive bay of groundmass has reduced an apatite section to the form of a horseshoe. There is a considerable amount of pyrite in this rock (which occurs near ore), but only a trifling amount of magnetite. The groundmass shows gray, semi-opaque markings, not dissimilar to stippling. This appearance is caused in part by particles of calcite, etc., but close examination shows that it is largely due to the spongy structure mentioned above.

Slide 197. *McKibben Tunnel*, 488 feet from entrance.

Decomposed dioritic porphyry.—This slide is from the same body of porphyrite as 194, which it greatly resembles. Fig. 10, Plate III., from this slide, shows a mass of chlorite bounded by the outlines of a former hornblende. A portion of this chlorite has been converted into a mixture of quartz and calcite, accompanied by limonite. This pseudomorph seems to prove that the survival of a border of chlorite at the outer edge of the hornblende section accompanies the decomposition of chlorite into quartz, etc., as well as the change into epidote.

Slide 199. *McKibben Tunnel*, 488 feet from entrance.

This slide, from the same specimen as 197, contains a fine hornblende section completely changed into epidote. In this case the formation of epidote appears to have started from points near the edge. It is shown in Fig. 9, Plate III.

Slide 281. Head of Ophir Ravine.

Decomposed diorite-porphyry.—This rock strongly resembles that from the *McKibben Tunnel* both macroscopically and microscopically. It forms very extensive croppings, different portions of which vary greatly in degree of decomposition and appearance. Where most decomposed it is reduced to an almost uniform dull green color, but in the freshest portions it is granular, greenish gray in tint, displays its feldspars and altered hornblendes in marked contrast, and, in short, betrays its dioritic character. Under the microscope this slide shows the original constituents to have been feldspar, well crystallized hornblende, some augite, magnetic iron, and apatite.

The hornblende has been completely decomposed, and comparatively little chlorite remains within the hornblende sections, which are mainly filled with epidote. A definite geometrical relation is noticeable here, as in slide 194, between the outlines of the hornblendes and the progress of the decomposition. Many of the outlines of hornblende sections are occupied towards the center by a mass of epidote, between which and the periphery is a band mainly filled by quartz. Either, then, the chlorite has been decomposed from the center into epidote, and simultaneously from the exterior into quartz; or the epidote, after replacing the chlorite, has been decomposed from the periphery of the hornblende section. The former supposition is altogether the more probable. A portion of the epidote does not show the usual crystalline structure, but forms a mass of small grains or scales, of which so many are superimposed upon one another in the thickness of the section, as to present perfect aggregate polarization; indeed it is difficult to detect a difference between these masses in polarized light and natural light. The change of the edges of the hornblendes to quartz has been accompanied by the separation of minute particles of a whitish opaque material of unknown character, and further by the formation of black opaque particles which can hardly be anything else than hematite or magnetite. These particles are arranged in lines parallel to the crystal edges, and now surround many of the interior masses of epidote with a black border. This is interesting as evidence that the black border of decomposing hornblendes is sometimes a secondary formation.

The slide contains a number of augites, some of them in very well defined octagonal cross-sections. The presence of this mineral associated in diorites with hornblende which was in all probability dense, is unusual and interesting Like the hornblende, the augite has been completely converted into chlorite, but the change from chlorite to epidote has begun in only one or two cases. The augite is sometimes also surrounded with a black border. Some of the apatites are dark brown and strongly dichroitic. In all except a single case the outer edge is much more deeply colored than the center, but in one instance this order is reversed. Many ordinary colorless apatites are also present. The feldspars are triclinic; little more, however, can be said of them, for they are much decomposed, and filled with products of decomposition. The same is true of the groundmass, in which secondary quartz and calcite, veins and patches of chlorite, and grains of epidote greatly obscure the original structure, but it is still apparent that it was granular and not microlitic.

Slide 233. Head of Ophir Ravine.

This slide is from the same locality and the same cropping as 281, but from another specimen. In addition to the principal features of that slide, it shows unmistakable mica sections, which have undergone precisely the same changes as the hornblende and augite described under 194 and 281. As would naturally be supposed, the change to epidote begins along cleavage lines. The change is illustrated in Fig. 8, Plate II.

Slides 482, 485, 486. East-and-west dike, just south of *Eldorado* croppings.

Dike of diorite-porphyry.—At this point a dike of porphyritic diorite about six feet wide cuts the granular mass of Mount Davidson. Towards the center the rock is fine-grained but evidently crystalline, with small porphyritic crystals of feldspar and hornblende. For about an inch from the edge the rock is very dark and crypto-crystalline. The contact with the granular diorite is an absolutely sharp mathematical line, and the adhesion is very strong. Under the microscope the gray including rock is precisely such as is described under slide 213. The adjacent dark rock is manifestly the same as 421. It is very andesitic in appearance, showing a microlitic groundmass, with excellent flow structure, and solid brown hornblendes without black borders. It also contains a few green fibrous hornblendes, and a good deal of augite. Even within the limits of the slide, however, it is apparent that the structure of the groundmass is more granular as the distance from the contact increases. In slide 486, from the center of the dike, almost the whole of the hornblende is fibrous, the structure is granular, and the impression is simply that of an ordinary granular diorite with a few porphyritical crystals of feldspar. But a few of the hornblendes are partly brown and solid, and these portions pass into and are surrounded by green fibrous hornblende of the same crystallographic orientation.

MICACEOUS DIORITE-PORPHYRY.

Slide 101. 1,000 feet northeast of *Silver Hill* mine.

Typical example.—This is a gray-green porphyry, in which crystals of feldspar of a very uniform size, about half as large as a grain of wheat, and smaller crystals of mica and hornblende, are evenly distributed in a crypto-crystalline groundmass. Under the microscope apatite, titanic iron, and zircon also make their appearance.

The mica is in part decomposed into quartz and epidote. One scale, 18–28, happens to be so exactly in the plane of the slide as to show no trace of dichroism. This scale gives an almost absolutely constant interference cross, and is optically negative. It is therefore biotite. The hornblendes, which are much less numerous than the micas, are wholly decomposed to chlorite and epidote.

The large feldspars are all striated. Several of them are cut in the zone at right angles to $\infty P \breve{\infty}$ and show lamellæ extinguishing at equal angles on each side of the twinning plane. These angles correspond to labradorite. One feldspar, which shows both albitic and periclinic twinning, gives angles of extinction which differ by 75° in two successive lamellæ, but the angle on one side of the twinning plane is 8° larger than that on the other. The crystal is cut in the zone $\infty P \bar{\infty}$ and $\infty P \breve{\infty}$, and of this zone so little is known that the crystal cannot be pronounced anorthite. One of the feldspars contains a fluid inclusion with an active bubble. The grains of feldspar in the groundmass are not well preserved, but almost all those in which the angle of extinction is determinable transmit least light when the twinning plane is parallel to the plane of the Nicols. It seems probable, therefore, that they are oligoclase.

The groundmass is composed chiefly of partially decomposed feldspar microlites and much secondary quartz, with some calcite. There is a considerable amount of titanic iron in characteristic forms, accompanied by much leucoxene. This decomposition product has the familiar want of structure close to the undecomposed ilmenite, but the edges of the patches show a granular crystalline arrangement, as if the smaller particles gradually united into comparatively large ones. The same appearance is often visible in epidote. There are further many colorless apatites, and an unusual quantity of zircons, which draw attention by their relief, and the brilliant colors which they exhibit between crossed Nicols.

Slide 172. *Sutro Tunnel*, 20,424 to 20,434 feet from entrance.

This is a mica-diorite entirely similar to slide 101, except that it contains large quartzes, in which are sinuous bays of groundmass. These quartzes contain fluid inclusions with active bubbles.

METAMORPHIC DIORITE.

Slide 295. *Amazon* dump.

Typical basaltic variety.—This rock is of a very dark iron-gray color, and is full of bright scaly particles of bisilicates. It is intensely hard and tough. Under the microscope it is seen to be composed chiefly of hornblende and feldspar, but the former is present in great excess, and the feldspar is so full of hornblendic microlites as scarcely to be recognizable. Mica, chlorite, and epidote are also present in considerable quantities.

The hornblende is of two varieties, green and colorless. The colorless hornblende is wholly undecomposed, shows capitally marked prismatic and clinopinacoidal cleavages. It absorbs light very faintly, but polarizes in brilliant green and purple colors, like augite. Sections parallel to the vertical axis show angles of extinction reaching 27°. The green hornblende shows an equally high angle of extinction. It dichroizes strongly between a bright, very slightly brownish, yellow and a dark grass-green. It is often fibrous, and is frequently accompanied by decomposition products. The two species of hornblende stand in the closest relations to one another. In all cases the colorless variety is surrounded by the green; in cross-sections the white modification appears in polygonal spots in the green; in the longitudinal sections in irregular stripes. Where they occur together in this way the optical orientation of the two is in all cases identical. In fact, the relations are just such as would result from an alteration of the white into green hornblende, and taking into consideration the fact that the green variety alone appears to suffer decomposition into any other mineral, I cannot avoid the conclusion that the case is really one of alteration. The association of colorless and green hornblende is illustrated in Figs. 11 and 12, Plate II. All the microlites of hornblende, which are present in great quantities, are green. These microlites are so numerous in the feldspars that the striations are only just perceptible, and the species cannot be satisfactorily determined; indeed, hornblende microlites form the greater part of the rock.

A considerable quantity of fibrous chlorite occurs between the microlites of green hornblende; it is strongly dichroitic, and extinguishes light parallel to the fibers. There is also much epidote present in comparatively large crystalline masses. The dichroism, high colors of polarization, and the angles of extinction referred to the cleavages, leave no doubt as to the mineral species. A few quartz grains are scattered through the mass. The slide contains many minute scales of brown mica, but no well-developed crystals. Its quantity is insignificant as compared with that of the hornblende.

The iron ore is very characteristic ilmenite, occurring in groups of particles which look as if they had been produced by chopping a larger mass, and is accompanied by a little leucoxene.

Slide 429. 3,000 feet southeast of Basalt Hill.

Granitoid variety.—This is a pinkish-gray rock of granitoid structure, with many lath-like feldspars, and a somewhat waxy look. In fact, its general appearance resembles that of many diabases, but close inspection with the unaided eye discloses small crystals of hornblende and mica. Under the microscope quartz grains and some subsidiary minerals are added to the list.

The hornblende is for the most part green and fibrous, a few patches showing a tendency to brown shades. It is all partially decomposed, and is far inferior to the feldspar in quantity, and has evidently crystallized later. Only a few flakes of mica are visible. The feldspar is for the most part polysynthetic, and the lamellæ are excessively thin. The angles of extinction of the sections cut at right angles to the twinning plane indicate oligoclase as the species. There are no microlites of feldspar so developed as to justify inferences concerning the species. A large part of the interstices between the crystals are filled with quartz grains, which are evidently not of secondary origin. They contain exceedingly minute fluid inclusions.

There is a large amount of titanic iron in this slide, recognizable by its cleavages and accompanying leucoxene. This latter mineral is intimately associated with sphene, and indeed possibly passes over into it. Sphene also occurs in patches independently of decomposed ilmenite. Though determinable crystals are not visible, the characteristically irregular shape of the masses both as to outline and surface, the high refraction, the feebly chromatic tints between crossed Nicols, and in one or two instances the cleavage, make the diagnosis fairly certain. Besides the ilmenite there appears to be a certain quantity of magnetite, which is not improbably titaniferous, for while the crystal forms are referable to the cube there is no accompanying limonite. Finally, there are numerous well-crystallized zircons and a few ordinary apatites.

Slide 293. 700 feet southwest of Devil's Gate.

Intermediate variety.—This rock is intermediate in character between slides 295 and 429. It is crowded with green hornblende microlites, but not to such an extent as to conceal the feldspar, which shows the angles of extinction proper to oligoclase. It also contains much quartz and ilmenite, as well as many apatites and zircons.

This slide is chiefly remarkable for the presence of tourmaline. It occurs in grains and in imperfect prisms. These extinguish light parallel to their principal axis. They are very highly dichroitic, showing a clear brown color when parallel to the main axis of the polarizer, and an almost absolute black at right angles to this direction.

QUARTZ-PORPHYRY.

Slide 354. 1,000 feet south of *Lawson's Tunnel.*

Typical variety.—Macroscopically this rock shows a purplish-gray groundmass in which are separated out porphyritically feldspar, mica, and quartz. Under the microscope a few hornblendes, apatite, and iron ores also make their appearance.

The feldspars, which in this slide are fairly fresh, occur for the most part in irregular grains, rendering it difficult or impossible in many cases to determine the crystallographic orientation. The larger part of the feldspars are unstriated, and of these many are certainly orthoclase, as determined by the angles of extinction referred to the cleavages. I was unable to find any unstriated feldspars which, tested in the same manner, gave angles appropriate to either of the triclinic feldspars. There is also a considerable amount of plagioclase present, which seems from the character of the banding and the angles of extinction to be oligoclase. There is certainly less plagioclase than unstriated feldspar. The feldspars contain fluid inclusions.

The quartz is present for the most part in macroscopical grains, which are bounded in part by crystalline outlines and in part by curved lines. One large mass appears to have been broken, and a narrow line of groundmass separates the parted edges. In many cases deep sinuous bays of groundmass penetrate the quartz, and patches of groundmass are sometimes surrounded by it. A considerable number of inclusions are sparsely scattered through the quartz. Of these the fluid inclusions are somewhat in excess of the glass. The glass inclusions, which all show bubbles, are rather large, and often penetrate the slide, so as to extinguish light between crossed Nicols. The glass is colorless; its shape is often dihexahedral. The fluid inclusions are smaller but very characteristic, many of them having exceedingly active bubbles. None of them appear to be carbonic acid. Although there are comparatively few inclusions in these quartzes, they are so distributed that both kinds are often in the field of a Hartnack No. 7 objective at once.

The hornblendes are entirely decomposed to chlorite. They have a black border, which does not appear to me to have resulted from weathering of the hornblende substance. The mica too is entirely decomposed.

There is no large quantity of iron ore, and its character is somewhat indefinite. It is present in irregular forms, but there are no sections with the characteristic cleavages of ilmenite; neither is there any ferric oxide accompanying the mineral. The groundmass shows traces of fluidal structure, and in places is pseudo-spherolitic. There is no base, but as the groundmass is impregnated with decomposition products, calcite, quartz, and minute grains of epidote, it is probable that any glass that may have been present would be devitrified. There are a few poor zircons and colorless apatites in the slide. The rock is shown as it appears under the microscope in Fig. 27, Plate IV.

Slide 304. 1,000 feet south by west of railroad tunnel above *Red Jacket.*

A second example.—This rock is not distinguishable macroscopically from that last described (slide 354). Microscopically it is also very similar. The relations of the feldspars are the same. A horizontal plate of mica shows the interference figure of biotite. The quartzes contain good-sized inclusions of glass and some exceedingly minute ones which appear to be liquid. The groundmass shows a highly fluidal structure. The effect is produced by elongated aggregations of iron ore, embedded in nearly colorless material. This colorless substance appears to be absolutely isotropic in some places, in others it shows pseudo-spherolitic structure, but for the most part it exhibits aggregate polarization as if it were a devitrified substance. In many places it is full of black microlites, which seem to radiate from particles of iron ore.

Slide 353. 1,700 feet south-southeast of the *Amazon.*

A third example.—This rock and slide are entirely similar to the preceding; the fluidal structure is less marked than in 304, but the pseudo-spherolitic structure is well developed. The feldspar is mostly orthoclase, and the quartzes with bays of groundmass, etc., contain some glass inclusions, and a very few liquid ones.

Slide 351. *Overman* 1142, 200 feet north of *Caledonia* shaft.

Specimens tested by Thoulet's method.—A gray rock entirely similar to those already described. Under the microscope it is seen to be somewhat more altered, the feldspars being clouded with calcite. Hornblende and mica occur, and the groundmass shows the same fluidal and pseudo-spherolitic structure. The quartzes contain more inclusions both of fluid and glass than those of the surface rocks. One of them is of a very unusual character. It is a glass inclusion in a glass inclusion, the inner one bearing a bubble. The inner glass may differ slightly in composition, or may have solidified at a different pressure. This cannot be a case of a cut bubble filled with balsam and air, for if the instrument be focused on either surface of the quartz, the inclosure and bubble are out of focus. The inclusion is shown in Fig. 24, Plate III.

To test the nature of the feldspars in this rock a fragment was pulverized and separated in a solution of mercuric iodide in potassic iodide of a specific gravity of 2.65. A large portion of the rock rose to the surface, and, on being mounted in balsam, proved to be groundmass and feldspar. Hornblende and mica, most of the quartz, some feldspars and decomposition-products sank.

Slide 461. West end of railroad tunnel above *Red Jacket*.

Felsitic variety.—This is a greenish gray, fine-grained, rhyolitic-looking rock. Under the microscope, too, it differs in general appearance from the ordinary quartz-porphyries of the District. In detail, however, it is found to correspond with them. The quartzes, of which there are but few, and those minute, carry numerous fluid inclusions, many of them with active bubbles. One of the quartzes also carries a comparatively large glass inclusion with a cut bubble, the hemispherical space being of course filled with balsam. The groundmass shows traces of fluidal structure, and is pseudo-spherolitic in places. The feldspars are badly clouded, but a few are plagioclase, and the remainder appear to be orthoclase. Hornblende, mica, titanite, and ilmenite are present. In short, the rock appears to be merely a felsitic variety of the ordinary quartz-porphyry.

Collection of the Exploration of the Fortieth Parallel. Slides 265 and 266.

40th Parallel slides.—Professor Zirkel's description of these slides excellently represents the phenomena, with one or two exceptions. While many of the feldspars are clouded with decomposition products, others are nearly free from extraneous matter. Most of these are unstriated and appear to give the angles of extinction of orthoclase. The quartzes of both slides contain fluid inclusions with moving bubbles, though they are neither very frequent nor of large size. In slide 266 there are good glass inclusions in quartz, penetrating the section and remaining dark between crossed Nicols. The thin sections and specimens correspond entirely with those described in this paper as quartz-porphyry.

Collection of the Exploration of the Fortieth Parallel. Slide 333.

40th Parallel slide.—This slide is very graphically described by Professor Zirkel. It happens to be a very small one, and shows only two or three minute quartzes, in which I have detected no inclusions. The specimen from which it was taken, however, presents quartzes in abundance. The structure and mineralogical composition of this slide appear to me identical with that of the rocks of the DISTRICT described by Professor Zirkel as dacite and by me as quartz-porphyries. The properties of the triclinic and orthotomic feldspars are the same, the hornblende and mica are of the same character and of the same degree of decomposition, and the groundmass is indistinguishable. Professor Zirkel draws special attention to the fluid inclusions in the feldspars of this slide.

EARLIER DIABASE.

Slide 349. *Sutro Tunnel*, north branch, 50 feet south of *Ophir*.

Typical example.—This is a gray rock, which might readily be mistaken at first glance for a diorite. On close inspection, however, a certain waxy luster, characteristic of augitic rocks, is perceptible, as well as numerous lath-like feldspars from $1^{mm.}$ to $2^{mm.}$ long. Under the microscope it is plain that the rock consists of triclinic feldspar, augite, and an iron ore.

The larger feldspars are well developed; the smaller ones are granitoid in structure, and appear to have occupied the interstices between the larger crystals. The larger feldspars show polysynthetic twinning, according to the albite law, the lamellæ being of moderate thickness. In addition, many of the individuals show pericline twinning, and in some cases polysynthetic individuals are united as Carlsbad twins. The angles of extinction are all within the limits appropriate to labradorite, and some of the macropinacoidal sections recognizable by the shape, and by the angles of the two species of twin lamellæ, give almost exactly the theoretical maximum angle of extinction on each side of the twinning plane. Very few of the small feldspars forming a sort of groundmass show crystalline outlines; but almost all are twinned, and many of them give angles of extinction indicating labradorite. In fact, I was unable to find any evidence of the existence of any other feldspar. There are a few fluid inclusions in the feldspars.

A considerable portion of the augite is fresh. It is of the ordinary pale brownish-yellow, only just perceptibly dichroitic, and in general exhibits excellent cleavages. Some well-defined octagonal cross-sections show not only the prismatic cleavages, but both the pinacoidal ones. A large part of the augites are twinned, and many of them show polysynthetic structure. In one case in another slide, from the same region, I counted thirteen lamellæ. In many cases, as is so frequent in feldspars, the lamellæ do not extend entirely through the crystal. An excellent instance is represented in Plate III., Fig. 15. In this slide (and many similar cases have been found in others from the *Sutro Tunnel*) there occurs a long, somewhat ill-defined section of augite, showing a single cleavage parallel to the longer axis and extinguishing at an angle of 38°, yet showing planes of twinning which cut the direction of cleavage at an angle of 32°. At first sight this gives the impression of a pinacoidal section, and a twin with a hitherto unobserved face of composition. In reality it is a section at a considerable angle to the principal axis, and cutting a prismatic face nearly parallel to the edge 0 P, ∞ P. The second system of cleavages does not appear in this instance, because it cuts the section at a very low angle. Such sections must occur in all augite rocks, but attract attention here on account of the prominence of the twinning.[1]

A portion of the augite is converted into uralite. This product is strongly dichroitic, light greenish-yellow in color, and of course fibrous in texture. The crystallographic orientation is often the same over considerable areas, and these show the angles of extinction characteristic of hornblende. In some cross-sections, too, an excessively fine cleavage at an angle of about 125° can be made out with high powers. The conversion into uralite seems to have proceeded with little regularity, sometimes attacking the augite from the outside, and sometimes along cleavages and fractures. The direction of the fibers of uralite is not in general that of the augite cleavage, but usually not very far from it.

The uralite is further often converted into chlorite of a darker green color and equal dichroism. The fibers of this product extinguish parallel

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[1] When there is reason to suppose that a section showing an oblique trace of a twinning plane cuts one of the prism faces lying next to the clinopinacoid parallel to the edge between this face and the base, the approximate position of the section can readily be inferred; for if the prism angle were 90°, the tangent of the angle at which the trace of the twinning plane cuts the longitudinal striations, would be equal to the sine of the angle at which the section cuts the main axis of the crystal. As the angle of ∞ P is only 87½ degrees, the observed and the calculated angle will be too large, but the error will reach a maximum of 2½ degrees only in sections at right angles to the main axis.

to their direction, and polarize for the most part in dark bluish tints. In many cases the uralite seems to be attacked from innumerable points, and the chlorite then shows a spherolitic structure. There are a few grains of epidote in this slide, associated in a somewhat indefinite manner with the uralite and the chlorite.

The iron ore seems to be ilmenite. It occurs in the characteristic forms of that mineral, and is accompanied by a very little leucöxene. There are also a very few apatites, a little quartz, which is probably secondary, and one or two particles of sphene.

Slide 18. *Sutro Tunnel.* Hanging wall of LODE at *Savage* connection.

Fresh diabase used for experiments.—This in hand specimens is a very black rock, with less waxy luster than most diabases show, but with the usual lath-like feldspars. The feldspar does not differ from that in slide 349, and measurements of the angles of extinction show it to be labradorite. It contains some fluid inclusions. Most of the augite is fresh, and some crystals show zonal structure; a few are converted into uralite and chlorite. The groundmass of the rock contains many microlites of augite. There are a few flakes of a brown, highly dichroitic mineral in this slide, which show none of the structure of hornblende, and seem to be biotite. Its quantity is insignificant. The iron ore is at least in part ilmenite.

This is the freshest diabase known to exist in the DISTRICT, and as such was selected for the experiments on kaolinization. Assays and a chemical analysis of it will be given at the end of the chapter. Its appearance under the microscope is illustrated in Plate IV., Fig. 28.

Slide 53. *Sutro Tunnel,* 19,200 feet from entrance.

Quartzose diabase.—Macroscopically this rock entirely resembles that represented by slide 18. The slide is one of the few containing quartzes which are unquestionably primitive. In this case the arrangement of the microlites of iron ore round their edges, and the inclusions of groundmass, put their character beyond question. These quartzes are remarkably full of fluid inclusions; the smaller ones with spontaneous bubbles, which do not decrease in size when the slide is heated to above 40° C. The rock contains comparatively little fresh augite.

Slide 346. *Sutro Tunnel*, **south branch, 3,960 feet from fork.**

Hornblendic diabase.—Macroscopically this rock looks much like those already described, except that it contains a considerable number of clearly recognizable hornblendes. Three or four of these occur in the thin section. They are bright brown in color, and decomposition has scarcely set in. Far more numerous are the augite sections, which, though wholly decomposed to uralite and chlorite, retain their characteristic outline. In some of these the conversion of chlorite into epidote may be traced. The relations of the porphyritical crystals to the groundmass in this slide are precisely those met with in the ordinary diabases of the DISTRICT.

Slide 396. *Yellow Jacket* **shaft, 2,299 feet from surface.**

Diabase containing epidote.—This is a greenish-gray granular rock, somewhat unusual in color for WASHOE diabase. In most cases in this DISTRICT grains of epidote may be observed under the microscope, developed in the chlorite formed by the decomposition of the augite; but this change seems to cease almost as soon as begun. In the more decomposed rocks the chlorite is seen passing into calcite and quartz, while the epidote grains are replaced by an opaque substance, which is probably iron oxide. In this slide, however, it is plain that augite has passed into uralite, this into chlorite, and that a great part of the chlorite has been converted into epidote. All the stages can be observed here, as in the *McKibben Tunnel* diorite, and, as in that rock, the crystals of epidote are seen eating their way into the chlorite.

Slide 134. *Sierra Nevada*, **1,450, north drift, 217 feet north of shaft.**

Diabase containing diallage.—Macroscopically this is a dark, fine-grained rock, which looks more like some of the dark diorites than it does like diabase. Under the microscope it is seen to be composed of rather uniform grains of plagioclase, diallage, and hornblende.

The plagioclase is broad-banded, contains fluid inclusions, and gives the angles of extinction of labradorite. The hornblende is bright brown. The diallage, which is much in excess of the hornblende, is dark gray and feebly diaphanous. In general it is disposed in irregular patches between the feldspars, but there are a few sections with the augite outline, and showing close partings in a pinacoidal direction. It transmits light too feebly to permit of exact determinations of angles of extinction, but angles of about 30° were noted.

The occurrence of the rock is purely local, and I regard it as a mere modification of the diabasitic rocks, and as not sufficiently independent to be classified as gabbro.

YOUNGER DIABASE.

Slide 466. *Chollar*, 1,900 foot level; 40 feet east of incline.

The only variety.—This is a bluish-black fine-grained rock, without a trace of porphyritic structure. Under the microscope it seems to be composed of plagioclase, augite, and magnetite. The feldspars present lath-like forms of nearly equal size; they give angles of extinction corresponding to labradorite, and show no distinguishable inclusions besides augite microlites. The augite is mostly granular, and with the magnetite fills the interstices between the feldspars. It is somewhat dichroitic.

The slide is considerably obscured by clouds of a smoky brownish substance, which possesses no visible structure and no dichroism, but shows aggregate polarization. It is the formation of this substance which turns fresh fractures of the black dike from the bluish color known by draughtsmen as "neutral tint" to a smoky brown after a few hours' exposure. There is but one variety of the black dike, and it is almost impossible to distinguish slides of this rock from different parts of the Lode. A characteristic field of this slide is shown in Fig. 29, Plate V. A specimen of the diabase from Orange, N. J., showed a tendency to the same alteration in color after a few days' exposure, and a slide from it exhibits the same peculiarities.

EARLIER HORNBLENDE-ANDESITES.

Slide 309. Edge of plateau, northwest of Ophir Hill.

Typical rock.—This is a porphyritic rock, in which crystals of feldspar and hornblende are separated out in a bluish-gray groundmass. Under the microscope a large amount of augite and some apatite and iron ore make their appearance.

The feldspars appear to be, without exception, triclinic. The large crystals give labradorite angles, while the microlites appear to be for the most part referable to oligoclase. The large feldspars in these andesites very commonly show both albite and periclinic twinnings, and polysynthetic individuals are frequently combined as Carlsbad twins. The feldspars, which strangely enough, considering the fresh condition of the bisilicates, are largely converted into calcite and quartz, contain some glass inclusions.

Hornblende is present only in large masses of somewhat irregular outline, surrounded by a deep black border. The substance of the hornblende is for the most part quite fresh, and of a deep greenish-brown. It contains minute opaque inclosures, which are probably of the same nature as those described under slide 421. The augites are very numerous, but small. The percentage of the two silicates cannot differ greatly, but the hornblendes give the character to the rock. The augites are very perceptibly dichroitic, and are often crystallographically well developed. Many of them are twinned and some are decomposed to fibrous chlorite, which polarizes in dark bluish colors. There is much of this mineral in the slide which has evidently been transported, and has settled in patches in which there is a strong tendency to spherolitic arrangement. The patches of chlorite are accompanied by quartz, which usually occupies the periphery. In some cases particles of epidote may be seen in the chlorite.

The groundmass is made up of microlites of oligoclase, with a considerable amount of augite, magnetite, and apatite. The last is almost all of a deep brown color, and in consequence markedly dichroitic. There is scarcely a trace of fluidal structure in this slide.

Slide 228. Knoll northwest of *Combination* shaft.

A second typical specimen.—This is a purplish-gray rock, and in that respect peculiar. Under the microscope it is very similar to that last described. It shows a decided fluidal structure, but no glass base. The feldspars contain good glass inclusions. Some of the hornblendes are twinned. In spite of its purplish color this hornblende-andesite is microscopically typical of the WASHOE occurrences, and is illustrated in Fig. 30, Plate V.

Slide 229. From the same locality as 228.

Specimen containing ilmenite.—This contains an augite which shows excellent pinacoidal as well as prismatic cleavage. It also contains a few patches of a finely granular mineral, which shows very feeble tints between crossed Nicols, and might be taken for sphene. It is in reality epidote, which often behaves in this way when finely divided.

The hornblendes in this slide are, as a rule, less decomposed than the augites. Indeed, the hornblendes in the WASHOE andesites frequently, though by no means always, resist decomposition better than the augites, perhaps on account of the heavy black border. Much of the chlorite formed from the augite has further decomposed into calcite and quartz. One pseudomorph of chlorite after augite has been attacked from within by epidote, and from without by calcite.

To test the nature of the iron ore in this rock the cover of the slide was removed, and the balsam well washed off with alcohol. Careful drawings were made with the camera of certain portions of the slide, which were then treated with strong chlorhydric acid. A drop of acid was placed upon the area to be tested and the slide warmed over a lamp for several minutes. The acid was then washed off with water, and the operation repeated five times. After each treatment the slide was inspected, and the result showed that while the black border and certain grains of iron ore were completely soluble, others were only coated with a white film, and remained undissolved. The etching also brought out faint straight lines on the undissolved grains, at an angle of approximately 60°, which seems to complete the proof that the mineral is ilmenite. I find myself unable to distinguish under the microscope the difference in tint between magnetic and titanic iron, which is so perceptible in the streak.

Slide 208. North Twin Peak.

Partially decomposed hornblende-andesite.—A dark, bluish, fresh-looking andesite, but in reality much more decomposed than those just described. The feldspars contain glass inclusions, but no fluid ones were observed. They are but slightly decomposed, showing a little calcite and a few porous streaks and spots. They contain many yellow, rounded microlites, some of which extinguish light at an angle of above 30°, and are probably augite. The rest of the augite is decomposed to chlorite, of which there are excellent pseudomorphs. The hornblende, too, is decomposed. With a low power it seems as if the space within the heavy black border were filled with calcite, quartz, and magnetite; but a No. 7 objective shows that the apparently opaque particles are in reality minute grains of a strongly refracting mineral, no doubt epidote. Epidote in determinable grains also occurs in the chlorite masses. There is considerable magnetite in this slide, as well as many colorless apatites and one or two zircons. The groundmass shows well marked fluidal structure, but no glass base.

This is the rock described by Professor Zirkel as from the first hill north of Gold Hill Peak, and analyzed by Dr. Kormann.

Slide 209. Quarry 1,000 feet west of *Yellow Jacket* east shaft.

Considerably decomposed hornblende-andesite.—A gray-green porphyritic rock, immediately overlying and passing into ordinary bluish hornblende-andesite. Under the microscope it appears that the bisilicates are wholly decomposed, the hornblendes being traceable only by the black borders now filled with quartz, calcite, and oxides. A few pseudomorphs of chlorite after augite remain. The feldspars also are considerably attacked, and contain secondary fluid inclusions.

Slide 210. 500 feet north of North Twin Peak.

Much decomposed specimen.—This specimen is from the same mass of rock as that represented by slide 209, and resembles it, except in the fact that the feldspars have lost their transparency. Under the microscope it is also plain that it is the same rock in a more advanced stage of decomposition. The feldspars are in part filled with specks of calcite; in part the calcite appears to have been removed by solution, and in some instances the cavities thus formed seem to have been filled with liquid, accompanied by a bubble; or in other words the feldspars contain *secondary* liquid inclusions.

Secondary fluid inclusions.—I base the opinion that these inclusions are secondary on the following grounds: They do not occur in the fresh hornblende-andesite from the same locality, or in unattacked feldspars in decomposed andesites. They are accompanied by particles of calcite, and by cavities which entirely resemble them in outline and general character. While primitive fluid inclusions are either negative crystals, or more or less distorted vesicles, and are bounded by smooth curves of greater or less complexity, these inclusions, as a rule, show irregular edges composed of broken lines. It is of course necessary that these inclusions should at some time have had a connection with the minute water channels of the rock mass through capillary fissures, but it by no means follows that these would appear even under high powers if open, and nothing is more probable than that they should often be closed by decomposition products. I have but rarely observed an active bubble in inclusions of this class.

Similar inclusions have been observed in the decomposed andesites of other localities in the DISTRICT, and in the same relations to the decomposition of the feldspars. While in typical instances it appears to me easy to discriminate between primary and secondary liquid inclusions in feldspars, cases may arise in which a confusion is possible. There is no reason why such inclusions should not occur in the older rocks as well as in the andesites, and indeed they appear to me to do so, especially in the quartz-porphyries. I have not alluded to them in describing slides of the older rocks, because they are there accompanied by primitive inclusions, and it seemed best to mention the subject in connection with a rock in which primitive fluid inclusions are very exceptional. I have borne the matter in mind, however, and have not used the presence of fluid inclusions as a diagnostic point, except where their primitive character appeared certain. A secondary inclusion from slide 210 is shown in Fig. 22, Plate III.[1]

Slide 311. 1,200 feet northwest of Geiger Grade Toll House.

Specimen showing disseminating hornblende.—This is a light bluish-gray, ordinary-looking andesite, with rather a large number of visible hornblendes. Under the microscope it is remarkable from the fact that, besides the hornblendes which are apparent to the unaided eye, it contains a vast number of spiculæ of the same mineral disseminated through the groundmass. In the thin sec-

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[1] Mr. C. W. Cross, in his Studien über Bretonische Gesteine, Vienna, Hölder, has called attention to secondary fluid inclusions of a different origin and character.

tion these hornblendes are of a light yellowish-brown color, and are not accompanied by black borders. Very many of the hornblendes are twinned, and a few show zonal structure. The hornblende is strongly dichroitic and gives angles of extinction reaching 20°. The augites are few in number and minute; indeed, at first sight, there seems to be no augite at all.

The feldspars are all triclinic, but are considerably decomposed, and it is not easy to determine their angles of extinction with accuracy. Most of the large crystals, however, give angles which fall within the limits of labradorite, while the microlites seem to be oligoclase; but one crystal showing the two ordinary striations gives angles of almost exactly 37°. This then must be anorthite. It is impossible to say that the other large crystals are not so, but the probabilities are that others would have been found exceeding the limits of labradorite had such been the case. In one of the large feldspars fluid inclusions of the kind called secondary were observed, and one of these contained a slowly moving bubble. Some of the feldspars also contain partially devitrified glass inclusions.

The slide shows two or three small grains of quartz which, from the arrangement of the particles of the surrounding groundmass, appear to be primary. They contain liquid inclusions with moving bubbles. This is the only case in which primitive fluid inclusions have been detected in the WASHOE andesites. The opacite is, for the most part at all events, magnetite. A very perfect hexagonal crystal may be a section of a dodecahedron. The apatite is colorless and without peculiarities. The groundmass polarizes throughout, though in places only very feebly. If it ever contained any base, the glass is now nearly or quite devitrified.

Slide 464. 1,200 feet northwest of Geiger Grade Toll House.

Coarse-grained trachytic-looking hornblende-andesite.—This slide is from the same cropping as 311, and beyond the possibility of a doubt the same rock, but it differs greatly in appearance, being coarse-grained, gray, and more like an ordinary trachyte than a common andesite in habitus. Under the microscope it is manifestly the same rock, though with a modification of structure, for the groundmass is granular instead of microlitic. There are a few grains of quartz which carry fluid inclusions. Slide 311 contains remarkably few augites, while in this I was unable to find a single one, in which respect it and slide 375 form the only exceptions among the earlier andesites of the District. The hornblende is of the same color and general character as that in slide 311, but the crystals are fewer in number and larger in size. The decomposition of the hornblende in this specimen is peculiar and interesting. The first change appears to have been to chlorite masses, of which a few are still surrounded by fresh hornblende. Some spots of this chlorite contain bunches of epidote, evidently formed from it, but much of the chlorite has been converted into, or has given place to, quartz. Decomposition has set in along cracks or cleavages of the hornblende crystals, producing little veins of chlorite, and the substitution of quartz for chlorite has subsequently taken place from the hornblende walls of the veinlet towards the central line, but has sometimes left a narrow seam of chlorite along the middle of the vein. This is shown in Fig. 3, Plate II. A question might be raised as to whether the quartz had not first partially filled the veins, the chlorite representing a subsequent infiltration; but the thoroughly fresh condition of the hornblende walls seems to forbid such a supposition. In some of the smaller crystals a fresh kernel of hornblende is seen surrounded by a zone of quartz, and this again by a narrow border of epidote. Taking the appearance just described into account, it appears to me probable that these hornblendes were in process of conversion into chlorite from the edges, and that an alteration to epidote had begun on the periphery, when the silicifying action set in, leaving the hornblende and the epidote unaffected. The hornblendes carry small bubble-bearing glass inclusions. The slide also contains much decomposed mica. That mineral has been replaced by chlorite and this, again, is full of patches of epidote, evidently parasitic on the chlorite. A portion of this chlorite, as well as that derived from hornblende, appears to have been converted into quartz. The feldspars are much decomposed, but are evidently triclinic.

Slide 454. Cedar Hill Cañon, 1,500 feet due west of Water Tunnel.

Highly augitic variety.—This is a dark bluish rock, which shows a considerable number of macroscopical hornblendes. Under the microscope the augite is seen to predominate over the hornblende, but as it occurs in a typical hornblende-andesite area, has a microlitic groundmass, and shows considerable hornblende, I have regarded the excess of augite as local. The slide is remarkable for the fact that much of the strongly dichroitic augite is surrounded by a black border quite as broad as that which ordinarily occurs about andesitic hornblendes, though not so broad as that accompanying the hornblendes in this specimen. This slide contains unquestionable ilmenite with rhomboidal cleavage marked by translucent lines. One of these is shown in Fig. 19, Plate III. One of the masses of ilmenite incloses a twin augite crystal, just as the same mineral so commonly includes apatite. The apatites are mostly deep brown and dusty.

Slide 450. 1,000 feet east of station at junction of Silver City Railroad.

Specimen showing hornblende with double black border.—This rock is only exposed by the railroad cut for a few yards, and undoubtedly underlies the adjoining augite-andesite. It is dark purplish gray, and contains a very large amount of visible hornblende. The slide is chiefly remarkable for the light which it throws on the character of the black border. The hornblendes are developed with unusual symmetry, but many of the crystals have been broken, and all the fragments are surrounded by black borders. In one case a beautifully fresh, highly dichroitic, dark brown hornblende fragment shows not only a black border but a parallel band of magnetite at some distance from the edge—a zonal structure marked by an interior black belt. This crystal is shown in Fig. 17, Plate III. Other of the large hornblendes in the slide show the same phenomenon, though imperfectly; but the small crystals have but a single border.[1]

The specimen contains considerable augite, and the groundmass shows fluidal structure, as well as the peculiar felt-like texture so common in augite-andesites. It is possibly not a hornblende-andesite, in spite of the great predominance of hornblende, but an augite-andesite with a local segregation of hornblende. No other hornblende-andesite occurs for a long distance, and a glance at the map will show the improbability of any considerable amount of that rock being entirely covered by the limited areas of augite-andesite.

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[1] For some speculations on this occurrence see page 59.

Slide 375. Outcrop at junction of Sutro and Quarry roads.

Micaceous hornblende-andesite.—This is a somewhat trachytic-looking rock, with very white feldspars embedded in a rough gray groundmass. Mica is also visible, though not prominent. Under the microscope it is plainly only a micaceous variety of the surrounding hornblende-andesite. The feldspar is wholly triclinic, and the large crystals give the angles of extinction of labradorite. They are much decomposed, but contain recognizable glass inclusions. There are also numerous secondary fluid inclusions. The mica is decomposed, largely to chlorite and epidote. There are also hornblendes, or rather their outlines. Much of the groundmass is devoid of microlites, shows a feeble aggregate polarization, and is probably a partially devitrified glass. I could find nothing which could be interpreted as augite.

Slide 326. *Sutro Tunnel*, 17,100 feet from entrance.

Specimen showing stages of decomposition.—This is a greenish-gray rock, with porphyritical crystals of feldspar and hornblende. It also shows some pyrites, and has evidently undergone considerable decomposition. Under the microscope the slide shows much brown hornblende, some augite, triclinic feldspars, and an andesitic groundmass. The hornblendes are peculiarly interesting because they exhibit the process of decomposition in all its stages. The hornblende is brown, much of it is twinned, and none of it shows black borders. The first step in the degeneration is the formation of chlorite, which, of course, largely follows the cleavages. In some cases narrow, even bands penetrate a crystal nearly from one end to the other like twin lamellæ, while in other instances irregular patches of chlorite occur in the hornblende. In some such patches, and still better in others which are distributed through the groundmass, and may or may not represent former crystals of hornblende, the formation of epidote may be followed; its prismatic microlites are to be seen invading the chlorite, just as in the *McKibben Tunnel* diorites. Other patches of chlorite are in process of conversion into, or substitution by, calcite. Where this change goes on in a partially decomposed crystal of hornblende, the central portion of the area is generally occupied by the fresh mineral and chlorite; whereas the calcite, sometimes accompanied by a little quartz, occupies the border of the pseudomorph. When the substitution of calcite for chlorite begins, the conversion of hornblende into chlorite seems to cease, and this slide shows many bright, fresh fragments of hornblende embedded in calcite. There is no indication that the hornblende tends to pass directly into calcite. Were such a process going on, we should find denticles of calcite penetrating the hornblende. Neither do I see any reason to suppose that the epidote in this slide passes into calcite; it appears rather to give place to clouds of dark-colored opaque matter, which may be oxides or earthy silicates. In this and the other slides of andesite which contain hornblende free of black borders, I see no indication that magnetite, or anything resembling magnetite, results from the decomposition of hornblende. In the black-bordered hornblendes I have often suspected such a change, but I see no way of proving that the particles in question may not have formed a part of the original border. A hornblende in process of decomposition is shown in Fig. 2, Plate II., from this slide. A portion of the augites are also partially converted into chlorite, and in the pseudomorphs epidote is certainly developed parasitically. The large feldspars are triclinic, and give angles of extinction answering to labradorite. In one of them a bubble-bearing and only partially devitrified glass inclusion was observed. The microlitic groundmass contains some magnetite, pyrite, and ordinary apatite

Slide 116. Crown Point Ravine.

Propylitic variety.—This is a very black, fine-grained rock, which, however, proves, under the microscope, to derive its color from an unusual amount of magnetite in the groundmass. The hornblendes are altered to chlorite and epidote, and only a few sections have retained characteristic outlines. It is evident that the chlorite preceded the epidote, and in some cases the encroachment of the latter can be very well observed. A portion of the chlorite has been replaced by quartz and calcite.

As I shall have occasion to refer to slides of the Fortieth Parallel Survey collection from Crown Point Ravine, and from the South Twin Peak, it would be an unnecessary repetition to say more of my own sections from these localities than that there is no notable difference between them and those described by Professor Zirkel.

AUGITE-ANDESITE.

Slide 122. Peak south of Crown Point Ravine, marked 7075.

Typical variety.—This is a black, rather fine-grained, apparently crystalline rock, with a somewhat pitchy luster. Under the microscope it is seen to be composed of augite and triclinic feldspar, with apatite and magnetite as accessory constituents. The feldspar is sharply angular, but there is no special tendency in the larger crystals to elongation. The large crystals give very high angles of extinction, many of them exceeding the labradorite limits, and they must all therefore be regarded as anorthite. Among the elongated microlites I noticed many which gave too high an angle for oligoclase, but none which exceeded the labradorite limits. The feldspars contain partially devitrified glass inclusions and augite microlites. The greater part of the augite is fresh. It is very light brown in color and slightly dichroitic. It is not specially well crystallized, and shapeless masses are more abundant than perfect sections. There is a decided tendency to the development of only one of the prismatic cleavages, and I found no trace of pinacoidal cleavage. There are numerous bubble-bearing glass inclusions. Many of the augites are converted in whole or in part into chlorite, of the same properties mentioned so often in previous descriptions. There is a single bright brown hornblende of small size heavily bordered. The apatite is in part colorless and in part brown. The magnetite shows no peculiarities. The groundmass is microlitic and in parts shows a felted structure.

Slide 137. Bench 400 feet southeast of intersection of Crown Point Ravine and Water Company's flume.

The same slightly decomposed.—This is macroscopically and microscopically the same rock as the preceding, being merely somewhat more decomposed. The feldspars contain secondary fluid inclusions; the augite is wholly converted into chlorite, which for the most part retains the augitic forms; and epidote, quartz, and calcite are developing from the chlorite.

Slide 416. First peak above Ophir Grade, south of Crown Point Ravine.

Variety with augitic groundmass.—This is a gray porphyritic rock, with none of the resinous look which augite rocks usually possess; and though it shows no hornblende, it might readily be mistaken for a hornblende-andesite. Under the microscope the slide shows little or no hornblende, but an unusual amount of augite, which is present, not only as porphyritical crystals, but as microlites in the groundmass in nearly the same quantity as the feldspar. A majority of the augites are fresh, but many are decomposed to chlorite, which in its turn is largely changed to epidote. The latter may be seen eating its way into the chlorite, as it has been described in the diorites and hornblende-andesites. Only a single patch of chlorite suggests hornblende, and there is none of that mineral in a fresh condition. The feldspars contain devitrified glass and secondary fluid inclusions. They are much dimmed by the presence of chlorite and calcite.

Slide 315. *Sutro Tunnel*, 1,400 feet from entrance.

Variety with felt-like groundmass.—This is a dark, resinous-looking rock, with some large greenish feldspars. The slide shows many fresh augites well crystallized, somewhat dichroitic, and with a tendency to develop only one cleavage. Others have undergone a somewhat peculiar decomposition, the product of which seems to be chlorite, very heavily charged with hydrated ferric oxide. There are few augite microlites in the groundmass, but many in the feldspars. The feldspars are well developed, and a very few only give angles of extinction answering to anorthite, in spite of the fact that a considerable number show periclinic twinning, and seem to be cut nearly in orthopinacoidal section. A good many such give almost exactly the theoretical maximum angle of extinction of labradorite, and I incline to the belief, for which there is no substantial proof, that they really belong to that species, and that consequently both of the more basic feldspars are present. There is much magnetite and many dark apatites. The groundmass is a felt-like aggregation of tiny microlites, between which there is certainly a small amount of glass.

Slide 481. Between summit of Mount Kate and Occidental Grade, near point 5639.

Glassy variety.—This is a gray glassy-looking rock, unlike the ordinary augite-andesite. The slide, however, shows it to be decidedly of that species, and to consist essentially of augite and triclinic feldspar, embedded in a true colorless glass. A few small hornblendes and some magnetite are the subsidiary minerals. The feldspars show little tendency to elongation; they appear to be all triclinic, and the maximum angles of extinction obtained correspond to labradorite. The augites are not very sharply crystallized, are largely massed in bunches, and are more than ordinarily dichroitic. There are a few hornblendes which are bright brown in color, and, like those in the glassy hornblende-andesite of the DISTRICT, without black borders. The glass which forms a large part of this rock is colorless, and shows in places perlitic cracks. Many microlites and trichites are distributed through it, some of them transparent and very likely feldspathic; others opaque. Some of the trichites show a beaded structure. Embedded in the glass are many curious spots of rounded shape, which are yellowish-white by reflected light and feebly transmit yellow rays. In polarized light they are seen to be wholly or partly crystalline; they are not sufficiently diaphanous to say which. They are evidently irregularly radial in structure, and in some favorable instances give a broad ill-defined cross between crossed Nicols. The pseudo-spherolitic structure is further marked by more or less curved opaque trichites which, starting from the center, preserve an approximately radial direction, branching like twigs at short intervals. One of these masses is shown in Fig. 20, Plate III.

Slide 125. Above the Ophir grade, due west of *Belcher* hoisting-works.

Granitoid variety.—This is a bluish-gray granular rock, looking almost like an older crystalline species. Under the microscope, however, it reveals itself as merely an unusually coarse-grained augite-andesite. The ground-mass is granular. A portion of the augites are fresh, the remainder converted into chlorite.

Slide 465. Crown Point Ravine; on flume, near drainage.

Specimen showing stages of decomposition.—Macroscopically a bluish-gray, compact, and rather granular rock, without macroscopically visible bisilicates.

The slide affords an unusually fine opportunity of studying the decomposition of augite-andesite. It happens to contain a large proportion of augites in octagonal sections, the outlines of which have been but little disturbed by the formation of decomposition-products. Some of the augites are almost unattacked, and show thoroughly characteristic cleavages, extinctions, etc. Others are partially converted to chlorite, and yet others are wholly replaced by the uniaxial, dichroitic, green mineral. Some of the pseudomorphs are partially converted into epidote, the characteristic prismatic sprouts of which may be seen penetrating the chlorite. A fine example is illustrated in Fig. 5, Plate II. In some other cases the degeneration to epidote and to calcite is going on in the same chloritic pseudomorph. There were originally one or two small hornblendes in this slide, now wholly converted into epidote. The feldspars seem to be labradorite. Crown Point Ravine is the best of all the "propylite" localities, and the specimen is an excellent representative of the rocks which have received this name. A portion of the slide is very faithfully illustrated in Fig. 31, Plate V.

Slide 428. 500 feet southeast of *Sutro Tunnel* air-shaft.

Specimen with peculiar augites.—This is a black rock with an uneven fracture, and a luster both vitreous and resinous Under the microscope it is seen to be a fine augite-andesite with more augite than usual, and no hornblende. The augite is of the common color and slightly dichroitic. One crystal shows the uncommon phenomenon of multiple twinning, in which the surface of composition of a portion of the lamellæ is decidedly irregular. This augite is illustrated in Fig. 16, Plate III. The large feldspars give angles of extinction corresponding to labradorite; the microlites correspond to oligoclase, and many of them show a tendency to fibration at the ends. The large feldspars contain inclusions of glass and microlites of augite. There are a few brown apatites and some colorless ones in the slide. The groundmass has the well-known felted appearance in some portions and shows fluidal arrangement in others. It contains a considerable amount of isotropic glass.

Slide 31. *Sutro Tunnel*, 10,055 feet from entrance.

Specimen with unusual chlorite pseudomorph.—This is an ordinary augite-andesite in a somewhat decomposed condition, which most likely carried a little glass when fresh. Among the many pseudomorphs of chlorite after augite which it contains, one is especially beautiful, and is illustrated in Fig. 4, Plate II. Decomposition has evidently started from the cross-fractures, and also from the centers of the fragments isolated by the cracks, but these two varieties of decomposition have proceeded somewhat differently. The chlorite around the exterior of the crystal, and along the cracks, betrays structure only by a very slight dichroism; between crossed Nicols it is not perceptibly luminous. The chlorite which has developed from the centers of the fragments is brownish-green, radially fibrous, strongly dichroitic, and polarizes in dull-brownish colors.

LATER HORNBLENDE-ANDESITE.

Slides 472 and 473. Quarry 2,000 feet northeast of *Sutro Tunnel* Shaft III.

Trachytic-looking variety.—This is a very coarse-grained soft rock, with large porphyritical feldspars and visible mica and hornblende. Its groundmass is purplish-gray. This rock is that commonly employed on the COMSTOCK for engine foundations and the like.

Under the microscope it is seen to consist of plagioclase, hornblende, mica, and magnetite, with a few Carlsbad twins and apparently simple crystals which might be sanidin. Some of these last show minute stripes under close examination, and others can be shown to be plagioclase by their angles of extinction. The highest angles of extinction of the properly oriented feldspars indicate labradorite; but many of the larger crystals show a strongly marked zonal structure. Inferences as to their composition have been drawn on page 68. The feldspathic microlites appear to be oligoclase. The mica is brown and intensely dichroitic. Cleavage-scales give an hyperbolic interference figure, which could not for a moment be confounded with a cross, and it is either a biotite in which the angles of extinction are uncommonly large or another species The hornblendes are brown and well crystallized, and are all black-bordered; but while some have comparatively narrow borders, others are almost wholly converted to magnetite, leaving only a particle of the fresh mineral near the center. The same remark applies to the mica. Some of the hornblende crystals, too, are decomposed, while the majority are perfectly fresh. This is probably due to the structure of the rock, which must admit liquid currents more easily on certain lines than on others. The groundmass is thoroughly crystalline and microlitic, and consists of feldspar microlites and magnetite. This is the most important of the so-called trachytes of the DISTRICT, and was therefore selected for illustration. Plate V., Fig. 32, shows a characteristic field.

Slide 474. Quarry 2,000 feet east of Occidental Mill.

A similar rock.—This is a reddish porphyry similar, except in color, to that described under slide 472, and also used for building purposes. Under the microscope it is remarkable for its intensely dichroitic hornblende, which shows an extremely light yellowish-brown tint, when parallel to the long section of the analyzer, and a bright red-brown when at right angles to this position. The slide also contains considerable poorly crystallized augite. The mica gives the same decidedly biaxial interference figure as that in slide 472. The feldspars also are similar to those in that slide. This is the rock separated by Dr. Hawes by Thoulet's method, and found to contain no sanidin.

Slide 230. Quarry above *Utah* mine.

More compact, gray rock.—A bluish-gray rock of manifestly loose texture, showing both mica and hornblende. Under the microscope plagioclase, magnetite, and some brown glass are also visible. The feldspars are beautifully fresh. Extremely few lack stripes, and these are not in determinable zones. Several of the larger feldspars show nearly square sections and pericline as well as albite twinning. These give angles of extinction of about 30° on each side of the albitic twinning plane. The small elongated feldspars also give labradorite angles in many cases, and I see no reason to suspect any considerable quantity of any other feldspar. The feldspars contain great numbers of colorless glass inclusions, most of them entirely fresh, as well as patches of the brown glass and of groundmass with glass. A few of the smaller feldspars seem to consist of negative crystals of brown glass surrounded by thin shells of feldspar. The hornblende is in part perfectly fresh, and so solid that the cleavages are almost imperceptible with low powers. The color of the hornblendes is various, and seems to depend largely on their position. Some crystals are nearly pure brown; others a slightly brownish-green, or of intermediate tints. A few are decomposed to calcite, quartz, and epidote. A part of the crystals show no black borders, and others only a very narrow line of magnetite. The mica is fresh biotite, giving the characteristic interference figure, and like the hornblende shows a few glass inclusions. It has a narrow black border. The groundmass is composed of feldspar microlites and brown glass. In parts of the slide the arrangement of the microlites seems wholly without order, while in others fluidal structure is well developed.

Slide 462. 2,000 feet northwest of Geiger Grade Toll House.

Black, glassy variety.—This is a pitchy-black rock, with a glassy luster, showing some large hornblendes, but resembling certain augite-andesites in appearance more than any hornblende-andesite of the DISTRICT. Under the microscope the reason of this unusual appearance is plain, for it contains a large amount of glass base, which is not the case with any other WASHOE rock of this species examined. Nearly all the feldspars seem to be labradorite, only the minutest untwinned microlites giving angles of extinction proper to oligoclase. A few sections give angles of extinction which might be referred to anorthite, but I failed to find any such in which extinction took place at equal angles to the trace of the twinning plane, and suppose the crystals to be labradorites cut in one of the uninvestigated zones. Many of the feldspars at first sight appear to be simple crystals, but show on closer examination a few exceedingly minute striæ. The feldspars contain a very unusual abundance of glass inclusions, a large proportion of which have polygonal outlines parallel to the sides of the feldspar section. They also contain inclusions of the base, many of which assume fantastic forms, some looking like ripple-marks, and others arranged as if the base had penetrated perpendicularly into the feldspar and spread between its zones. The process must have been just the reverse, and the appearance is no doubt due to an ineffectual effort of the feldspathic material to free itself from the adhesive glass during crystallization. Some of these inclusions are shown in Fig. 23, Plate III. Zonal structure is beautifully developed in many of these feldspars.

The hornblendes are of a somewhat dull yellowish-green color and very solid. They are especially remarkable from the fact that scarcely any of them show even a trace of a black border. There is a large quantity of augite of exceptionally pale color. It is faintly dichroitic and crystallized in unusually long needles. The sections and angles of extinction leave no doubt as to its nature. There is a single excellent biotite in the slide. Many colorless apatites and a considerable quantity of magnetite are present. The base shows a felt-like structure which appears to be due to the presence of minute opaque microlites.

Slide 470. Mount Abbie.

Gray coarse-grained variety.—This is a coarse gray porous rock, strongly resembling a hornblende-trachyte in appearance. Under the microscope, however, it is plain that nearly or quite all the feldspars are triclinic, and they give labradorite angles of extinction. Many of the smaller labradorites are simple individuals. The hornblende and augite are such as are common in the hornblende-andesites, but the hornblendes show only very narrow black borders. There are about twice as many hornblendes as augites. The groundmass is microlitic, and no base is visible.

Slide 467. 1,000 feet north-northwest of Flowery Peak.

Porphyry with dark groundmass.—This is a coarse-grained rock in which large crystals of feldspar are separated out in a dark, rather compact groundmass. Mica as well as feldspar is visible. Most of the feldspar crystals show twin striations, but there are some Carlsbad twins and simple crystals, none of which, however, are probably orthoclastic. Many of the larger crystals, which are well developed, show zonal structure. The maximum angles of extinction correspond to labradorite. The feldspathic microlites are shorter and broader than is usual, and a few are possibly sanidin, but the great majority are certainly triclinic. I noticed no inclusions in the feldspars beyond apatite. Hornblende and mica are almost wholly represented by patches of magnetite which are evidently exaggerated black borders. Some of these patches are pseudomorphs after hornblende, but mica plainly predominated. Of this enough is left to determine that its color was brown. The slide contains a single grain of quartz, which is evidently primary. The groundmass is thoroughly crystalline and microlitic. It contains much magnetite, and shows fluidal structure in places.

Slide 476. Divide between Mount Rose and Mount Emma.

Light-gray porous variety.—A light-gray rock with a large amount of visible mica and hornblende. The feldspar is largely in simple crystals, few, if any, of which, however, are orthoclastic. The microlites are developed with unusual sharpness. The feldspars contain bubble-bearing glass inclusions and patches of groundmass. Hornblende is much more abundant in this slide than mica, and is remarkable for the fact that it shows scarcely a trace of black border. Much of it occurs as minute brown spiculæ disseminated through the groundmass. The mica is present in well-developed crystals, and cleavage scales show the ordinary sensibly uniaxial interference figure of biotite. The iron ore is magnetite, and it and the feldspar microlites of the groundmass seem to be imbedded in a colorless glass.

BASALT.

Slide 457. Basalt mesa, just west of Silver City.

Only variety.—This is a dark ordinary basalt, with numerous visible fresh amber-colored olivines. Under the microscope it is seen to be a crystalline mixture of olivine, augite, feldspar, and magnetite. The olivine is nearly colorless in the section, but has a faint yellowish tinge. It occurs for the most part in grains showing only one or two crystalline faces or none at all. A few of the larger crystals have good hexagonal or octagonal outlines. Besides irregular cracks, there are occasional indications of imperfect cleavage. The olivine is wholly undichroitic and polarizes brilliantly. As inclusions it contains crystals of magnetite and a few particles of augite. It shows only occasional traces of decomposition. The augite is of the common brown color, but of a rather deeper tint than usual. Some of the crystals are as large as the olivines, but while there are many small augites there seem to be no microscopic olivines. The augites are better crystallized than the olivine, and often show characteristic sections and cleavages. They are decidedly dichroitic. The augites carry a few bubble-bearing inclusions, which seem to be glass. The feldspars are small, lath-like, and often simply twinned. In a very few cases both periclinic and albite twinning are visible. The angles of extinction are those of labradorite. I could detect no orthoclase. The groundmass consists of feldspar, augite, and magnetite in cubes, and contains no perceptible base. Slide 458 from 1,250 feet southeast of Roux's Ranch is identical with the above, and with the slide described in the Exploration of the Fortieth Parallel, Vol. VI., as 528. The slide and specimen described in that memoir as 529 is the same rock which is here regarded as a metamorphic diorite.

PROPYLITES OF THE FORTIETH PARALLEL SURVEY COLLECTION.

Fortieth Parallel propylites.—I have been kindly allowed free use of the collections of the Geological Exploration of the Fortieth Parallel, and reproduce in the following pages my notes on the specimens and slides described in Vol. VI. of the publications of that survey as propylites (212 to 225) and as quartz-propylites (226 to 232). While I do not feel myself competent to decide definitively the species of those rocks which I have not had an opportunity of studying in the field, my opinion of each slide is indicated, in order to convey a more complete impression of its appearance.

Exploration of the Fortieth Parallel. Slide No. 212, specimen No. 22,682, Crown Point Ravine, Washoe.

This is a smooth, fine-grained rock, somewhat resembling a limestone in texture. Its color is pistachio green. Seen under the microscope, it is evidently much decomposed; indeed, the slide shows little besides epidote and secondary quartz. Even the magnetite has almost wholly disappeared, and the residual products are grouped within no outlines from which the nature of the original bisilicates might be inferred. Many very small feldspars are still fresh enough to make out with certainty that they are triclinic.

Exploration of the Fortieth Parallel. Slide No. 213, specimen No. 22,684, Crown Point Ravine, Washoe.

A somewhat more granular rock than the preceding, but of the same color. The slide shows that it is slightly less decomposed. In a few cases feldspars can be detected with striations not entirely obliterated, and with rectilinear outlines, such as are ordinarily met with in andesites. Several brown apatites are visible. The patches of decomposition products show outlines here and there which are suggestive of hornblende and augite. Besides quartz and epidote, this slide contains some calcite. I regard this and the preceding rock as entirely indeterminable from the specimens and slides, but from a study of their associations on the spot I believe them to be hornblende-andesites.

Exploration of the Fortieth Parallel. Slide No. 214, specimen No. 22,686. Crown Point Ravine, Washoe.

A gray coarse-grained rock, the feldspars of which are opaque, giving it a superficial resemblance to pre-Tertiary rocks. Under the microscope a glance shows it to be augitic. The slide contains several sections of the undecomposed mineral with characteristic octagonal outlines and appropriate angles and cleavages, as well as some longitudinal sections, giving angles of extinction running up to above 30°. The color of this augite is the common brownish-yellow, not unlike the tint of bamboo. Much of the augite has been decomposed to chlorite of fibrous structure, which shows dark bluish tints between crossed Nicols, aggregate and sometimes spherolitic polarization, and extinction when the microlites are parallel to the principal sections of the Nicols. That the chlorite is a derivative of the augite is clear, for in some cases augites are only in part converted into chlorite, and in others the pseudomorphs are perfect, even retaining traces of the cross-fractures of the augite prisms. I found but one mass of decomposition products that might with any probability be referred to hornblende. The feldspars are triclinic, and some of the large crystals show labradorite angles of extinction. Apatite and magnetite are also present. The groundmass contains no glass, but seemed to me to show traces of a felt-like structure, much obscured, however, by particles of chlorite and epidote. This rock is an augite-andesite, and one characteristic of the DISTRICT, but is partially decomposed.

Exploration of the Fortieth Parallel. Slide No. 215, specimen No. 22,689. Crown Point Ravine, Washoe.

A very dark, somewhat basaltic-looking rock. The slide resembles that last described, containing, however, only pseudomorphs of chlorite after augite, and none of the fresh mineral. The chlorite and the mineral from which it was derived were carefully identified in the manner indicated in the last paragraph. There is no fresh hornblende, but a few very minute oval rings of magnetite grains probably represent the black borders of former hornblendes. The feldspars, which are not distinguishable from ordinary andesitic plagioclases, contain spots which look like devitrified glass-inclusions. This, too, is augite-andesite.

Exploration of the Fortieth Parallel. Slide No. 216, specimen No. 22,690, from Crown Point Ravine, Washoe.

This rock is much decomposed, and neither augite nor hornblende are present in a fresh state, but the slide contains many black borders, which retain the characteristic outlines of hornblende, though they now surround only calcite, quartz, and a few residual grains of epidote. There is also one good pseudomorph of chlorite after augite. From my acquaintance with the rocks of the DISTRICT I have no hesitation in pronouncing this a hornblende-andesite.

Exploration of the Fortieth Parallel. Slide No. 217. Gold Hill Peak, Washoe.

There is no specimen in the collection corresponding to this slide or to the locality, which is represented on the map accompanying this paper by the southern "Twin Peak". My own specimens are coarse greenish-gray rocks of somewhat open texture. The feldspars are not thoroughly transparent in consequence of incipient decomposition. The fresher portions of the mass show brilliant hornblendes. The slide contains some fresh brown hornblendes with black borders, and some black borders from which the bisilicate has disappeared. A portion of the hornblende exhibits the intermediate color between green and brown, which is seen in so many brown hornblende rocks; but I failed to find green hornblende, fibrous hornblende, or hornblende without a black border. There are a few excellent augites and many capital pseudomorphs of chlorite after augite. This chlorite shows the usual structure, dichroism, extinction parallel to the fibers, etc. The feldspars are triclinic, the large ones seemingly labradorite, and they appear to contain devitrified glass inclusions. There are many brown and dusty apatites. The groundmass has the microlitic structure of hornblende-andesites, nor can I see any reason for separating this rock from that species.

Exploration of the Fortieth Parallel. Slides Nos. 218 and 219, specimen No. 22,694. Ophir Ravine, Washoe.

These slides I have sufficiently discussed in describing my own thin sections from the same locality. I have there considered the rock as a diorite-porphyry.

Exploration of the Fortieth Parallel. Slide No. 220, specimen No. 22,588. Hill east of Steamboat Valley, Virginia Range.

This is a brown rock which looks like an impure limonite. Under the microscope nothing is visible excepting ferric hydrate and a little secondary quartz.

Exploration of the Fortieth Parallel. Slide No. 221, specimen No. 22,574. Sheep Corral Cañon, Virginia Range.

This is a light greenish, granular rock, evidently composed of feldspar and hornblende. The slide shows that the hornblende is wholly decomposed. The crystals of this mineral appear to have had black borders, which are now in part replaced by higher oxides. When fresh it contained great numbers of small augites, which are now converted into the ordinary chlorite. The same product of decomposition is also disseminated through the groundmass, and is accompanied by quartz and calcite. The feldspar is fresh and striated, and the general character under the microscope is that of an andesite. I can see no reason for calling it anything but hornblende-andesite.

Professor Wiedemann analyzed this rock and found 64.62 per cent. silica. In discussing this analysis the fact should not be overlooked that a relative increase in the quantity of silicic acid commonly accompanies decomposition.

Exploration of the Fortieth Parallel. Slide No. 221^a, specimen No. 21,950. Between the Truckee and Montezuma Ranges.

The specimen strongly resembles those from the head of Ophir Ravine, Washoe. It is highly decomposed, but the bisilicates appear to have been hornblende. The feldspars have not the sharp outlines usual in andesites, and the *toute ensemble* is that of a porphyritic diorite.

Exploration of the Fortieth Parallel. Slide No. 222, specimen No. 21,542. Storm Cañon, Fish Creek Mountains.

This is a rather coarse-grained greenish rock, in which lath-like feldspars show prominently in a finer groundmass. The slide contains an abundance of augites, some of which show pinacoidal cleavages as well as the prismatic ones. The cleavages are very heavily marked. A portion of the augite has been converted into grayish-green uralite, distinctly retaining the crystal form of augite. Where it is favorably oriented it gives angles of extinction of about 15°. The greater part of the augite has degenerated into chlorite, with the usual structure and optical properties. The slide further contains much fresh mica, some of the scales of which are horizontally placed, and give the biotite interference figure. There is also a very little brown and intensely dichroitic hornblende, but I could find none of this mineral which was green, except the uralite. The larger plagioclases are well developed in lath-like crystals, but are nearly opaque in consequence of the presence of decomposition products. The iron ore occurs in irregular masses, but its nature is uncertain. The groundmass is granular, not composed of well-developed microlites, but thoroughly crystalline. It contains much epidote and chlorite.

Exploration of the Fortieth Parallel. Slide No. 223, specimen No. 21,545. Storm Cañon, Fish Creek Mountains.

This is the same rock as the last, but in a different stage of decomposition. The green hornblende shows in numerous cases the crystal outlines of augite, and in my opinion is exclusively uralite. The plagioclases are fresher than in the other slide and contain rounded fluid inclusions of small size. While it may be somewhat rash to decide upon the age of this rock from these two specimens and slides, all the diagnostic points appear to me to indicate diabase rather than augite-andesite as the proper determination.

Exploration of the Fortieth Parallel. Slide No. 224, specimen No. 21,259. Foothills north of Tuscarora, Cortez Range.

This is a green porphyry, with impellucid feldspars and brilliant hornblendes. I am almost inclined to doubt that this can be the slide described in the "Microscopical petrography;" but the dark brown hornblendes tally precisely with the figure and the description, the slide corresponds to the specimen, as does the latter with the locality, and no other slide labeled "propylite" bears any considerable resemblance to the text and the illustration. The slide contains a large number of unusually symmetrical brown hornblende sections, with broad black borders. One or two of these exhibit clinopinacoidal cleavage as well as the usual prismatic one. Many of the hornblendes are altered into chlorite, still retaining the black border and crystal outlines. This chlorite shows the usual aggregate polarization in some places and spherolitic structure in others, and extinguishes light parallel to the direction of the principal Nicol sections. There are also many fresh augites with characteristic sections, cleavages, and optical properties, and pseudomorphs of chlorite after augite. As usual in decomposed rocks, the groundmass contains irregular patches of chlorite, the properties of which are identical with those of that in pseudomorphic forms. I could find nothing whatever corresponding to the green hornblendes described by Professor Zirkel, and figured as without black borders, and as showing hornblendic cleavages and outlines. The feldspars and groundmass are like those usually found in partially decomposed hornblende-andesite, and as such I have no hesitation in regarding the rock.

Exploration of the Fortieth Parallel. Slide No. 225, specimen No. 21,314. Wagon Cañon, Cortez Range.

This is a reddish rock, with well-developed porphyritic, impellucid feldspars, visible mica, and greenish black patches, which are possibly hornblendes. Under the microscope the rock is seen to be greatly decomposed. The slide contains fresh mica, numerous pseudomorphs of chlorite after augite, and a number of patches of chlorite, which seem referable with some probability to hornblendic forms. The feldspars are triclinic and very closely striated. None of the angles of extinction which I observed exceeded the oligoclase limits. The slide contains very little epidote, but the feldspars and groundmass are clouded with calcite and limonite. While no satisfactory determination can be made of this specimen, it seems to answer best to a micaceous hornblende-andesite.

Exploration of the Fortieth Parallel. Slide No. 226, specimen No. 21,604. Hills east of Golconda Station.

Macroscopically this rock is of a greenish-gray color tinged with yellow, and shows porphyritical crystals of mica, hornblende, and impellucid feldspars. Under the microscope it is apparent that the feldspars are rendered almost opaque by excessively fine grains of what is seemingly calcite. Some of them are triclinic, others appear to me to be orthoclase, but which are in the majority it is impossible to say. The rock contains quartz in which there are numerous fluid inclusions, some of them containing carbonic acid. The quartz also carries unquestionable glass inclusions of good size, in which devitrification has proceeded only so far that between crossed Nicols one or two bright points appear on the jet-black ground of the isotropic substance. One of these is accompanied by the short cracks in the quartz, which have often been observed, and which so beautifully illustrate the elasticity of silica. One of the numerous apatites, too, contains a glass inclusion hung like a drop on an inclosed microlite which is probably also apatite. The hornblende, and even the mica are wholly replaced by decomposition products, largely oxides of iron. I could detect no trace of augite. The groundmass contains some particles of epidote and chlorite. It is nearly impossible to determine a rock so thoroughly decomposed without a study of its occurrence. If the feldspar is triclinic it must be a dacite, for the glass precludes the supposition that it is a diorite. The absence of augite and of well-developed feldspar microlites, the appearance of the orthoclase-like larger feldspars, the abundance of fluid inclusions, and the general air of the rock, seem to put dacite almost out of the question. Similar arguments hold against its determination as rhyolite, and but for the presence of carbonic acid in the inclusions, which is, at all events, very rare in quartz-porphyry, I should class it as a member of that group.

Exploration of the Fortieth Parallel. Slide No. 227, specimen No. 21,500. West Gate, Augusta Mountains.

Macroscopically a gray, granular rock. Under the microscope it bears a strong resemblance to the preceding. The feldspars are almost opaque, the hornblende and mica are wholly decomposed. The groundmass contains some epidote and much chlorite, magnetite, and zircon. More than one of the quartzes carry besides fluid inclusions, typical, fresh, colorless glass inclusions which contain bubbles and are of sufficient size to remain black between crossed Nicols. I noticed an apatite with good prismatic cleavages. This rock seems to me an old quartz-porphyry.

Exploration of the Fortieth Parallel. Slides Nos. 228 and 229, specimen No. 21,308. Cortez Peak, Cortez Range.

I entirely assent to Professor Zirkel's description of these slides. The rock appears to me both macroscopically and microscopically to resemble a porphyritic diorite in all respects. Slide 230 is a highly micaceous variety of the same rock.

Exploration of the Fortieth Parallel. Slide No. 231, specimen No. 22,717. Cross-spur below graveyard, Virginia City.

Macroscopically this is a greenish-gray, andesitic-looking rock, with impellucid feldspars and brilliant hornblendes. Under the microscope the slide shows a considerable number of hornblendes and some augites. The hornblende is of the greenish-brown tint common among the andesites, but brown enters very largely into the color. It is not fibrous, but decomposition into chlorite has set in along the cleavages, and, in the longitudinal sections, the cleavage prisms separated by chlorite might possibly be taken for coarse fibers. It is a peculiarity of this rock that the iron ore has been attacked more energetically than the bisilicates. Many of the smallest grains of the ore, which is probably magnetite, may be seen throughout the slide, converted into a slightly diaphanous, whitish substance, which in so far resembles leucoxene; but between crossed Nicols it looks more like calcite, and it strikes me as possibly iron carbonate. The quartz is indistinctly separated from the groundmass, and seems to me secondary. The feldspars and the groundmass have the usual characters of WASHOE hornblende-andesites

Exploration of the Fortieth Parallel. Slide No. 232.

By some mistake this slide was labeled as from Berkshire Cañon, whereas the check-list of the survey, no less than the correspondence of the slide and specimen, show that it should have been numbered 155, and that the rock is the typical diorite of Mount Davidson, in WASHOE. The descriptions of this rock and of the Mount Davidson diorite, like the slides, agree.

PROPYLITES OF THE GEOGRAPHICAL AND GEOLOGICAL SURVEY OF THE ROCKY MOUNTAIN REGION.

Utah propylites.—Captain Dutton has also kindly furnished me with specimens and slides of the propylites mentioned by him in his memoir on "The High Plateaus of Southern Utah."

Geology of the High Plateaus of Utah. Slide and specimen No. 226. Base of Mount Dutton, Sevier Plateau.

Macroscopically a greenish, granular rock, in which lath-like feldspars are separated out in a groundmass of a somewhat waxy luster. Under the microscope it is seen that the rock is greatly decomposed, but also that in a fresh state it consisted of plagioclase and augite, with an iron ore, quartz, and apatite as subordinate constituents. A few of the augites are fresh, and are in every way characteristic, but most of them have been converted into chlorite, and the slide contains a large number of excellent pseudomorphs of this character. The chlorite appears to be precisely the same as that to which reference has been made so often in the foregoing pages. It is fibrous, extinguishes light parallel to the long axis of the microlites, dichroizes strongly, and gives an aggregate polarization or a spherolitic cross, according to the arrangement of the microlites. In places epidote may be seen forming at the expense of the chlorite. At least a part of the quartz is primitive. It contains fluid inclusions, gas-pores, and possibly also glass-inclusions. The larger feldspars are well developed, very closely striated, and appear to give angles of extinction of about 18° 30′ in orthopinacoidal section. The smaller feldspars are granitoid rather than microlitic in their development, and so much obscured by decomposition-products as to make it uncertain whether they also are referable to oligoclase. The iron ore is probably titanic, and is accompanied by both leucoxene and ferric oxide. The slide contains much apatite, a large part of it in unusually long microlites, and a little sphene. The rock appears to me to be a decomposed diabase.

Geology of the High Plateaus of Utah. Slide and specimen No. 274. Gate of Munroe, Sevier Plateau.

The general character of this rock, both macroscopically and microscopically, is almost identical with that last described, but the bisilicates have been entirely decomposed, and the chlorite is much disseminated; there is a strong probability, however, that the original mineral was augite. The feldspar best answers in its optical characters to labradorite. It contains fluid inclusions. The apatites are extraordinarily large and abundant, and, strange to say, contain numerous fluid inclusions.

DESCRIPTION OF ILLUSTRATIONS.

In order that any object in a thin section, to which special reference is made, may be readily found again by one studying the collection, thus saving the time and patience of the student and leaving no room for doubt as to the exact spot under discussion, the following method of determining the locality of such an object has been employed and is recommended for general use: Mark on the stage of the microscope two radii at right angles and graduate them in millimeters, beginning from the center of the stage, numbering them as in the figure Place the glass bearing the rock section

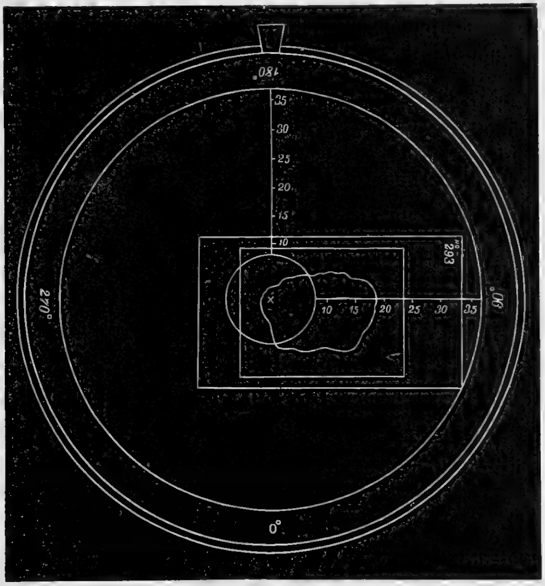

FIG. 2.—Orientation of Slides.

on the stage, so that when the spot to be located is under the cross-wires the upper left-hand corner of the object glass shall be within the quadrant between the radii, and the sides of the object glass shall be parallel to the same, as represented in the figure. The distances, then, of the spot in question from the sides crossing the radii are read from the scales, and represent the rectangular coördinates of that spot referred to the upper left-hand corner of the object glass as an origin, and are recorded thus: $293^{11.33}$; the number of the thin section being given, and the coördinates being placed after it, with the vertical coördinate preceding the horizontal. The process of finding any spot the coördinates of which are given in this manner needs no further explanation.

PLATE II.

FIG. 1. Slide $252^{9.21}$. Brown hornblende passing into chlorite. The small stippled white mass at the right of the cut is secondary quartz. The rock is a porphyritic diorite. *Sierra Nevada* mine, 1,450-foot level; north drift, 289 feet. Magnified 170 diameters.

FIG. 2. Slide $326^{17.32}$. Brown hornblende passing into chlorite, which is represented as gray. The white patches are quartz and calcite. The rock is earlier hornblende-andesite from the *Sutro Tunnel*, 17,100 feet from entrance. Magnified 70 diameters.

FIG. 3. Slide $464^{21.26}$. Greenish-brown hornblende, in longitudinal section. The central portion of the veins is chlorite, between which and the solid hornblende the space is occupied by quartz. The rock is older hornblende-andesite from croppings 1,200 feet northwest of the Geiger Grade toll-house. Magnified 45 diameters.

FIG. 4. Slide $31^{11.27}$. Pseudomorph of chlorite after augite. The white intrusive mass is feldspar; decomposition has gone on from the surfaces and cracks, producing a green slightly dichroitic chlorite, which remains nearly black between crossed Nicols. The fragments have also decomposed from their centers into a greenish-brown, very fibrous, strongly dichoritic chlorite. The rock is augite-andesite from the *Sutro Tunnel*, 10,055 feet from entrance. Magnified 95 diameters.

FIG. 5. Slide $465^{12.23}$. The outline is that of a cross-section of augite. The smooth gray tint represents a felted mass of chlorite, composed of excessively fine fibers. The coarsely granular mineral is epidote, which can be seen sending denticular crystals into the chlorite. In the upper part of the cut epidote has begun to develop from a second center. The rock is augite-andesite from Crown Point Ravine. Another part of this slide is represented in Fig. 31. Magnified 65 diameters.

FIG. 6. Slide $194^{17.17}$. Pseudomorph of chlorite after hornblende. Granular epidote is developing from five distinct centers in the chlorite. The chlorite close to the left-hand upper edge of the crystal is composed of fibers perpendicular to the crystal face, and appears to resist the encroachment of epidote. The rock is a porphyritic diorite from the *McKibben Tunnel*. Magnified 48 diameters.

FIG. 7. Slide $194^{7.24}$. A group of three hornblendes has been completely converted into chlorite, and in these pseudomorphs epidote has developed from the centers in granular masses and fagot-like bundles. The growth of epidote needles into the chlorite (which is shaded a flat gray) can be excellently observed at the right-hand edge of the cut, and between the left-hand and the middle crystals. In the left-hand crystal there are two small patches of secondary quartz. The rock is porphyritic diorite from the *McKibben Tunnel*. Magnified 40 diameters.

FIG. 8. Slide $233^{19.20}$. Pseudomorph of chlorite and epidote, after mica. The conversion to chlorite probably proceeded from the cleavages, and the conversion of chlorite to epidote has begun upon the same lines. The chlorite as usual is indicated by a flat gray tint. Minute denticles of epidote can readily be seen under high powers, piercing the fibrous chlorite mass. The rock is diorite-porphyry from the head of Ophir Ravine. Magnified 30 diameters.

FIG. 9. Slide $199^{13.25}$. Pseudomorph of epidote after hornblende. The epidote appears to have crystallized from three different centers, and the radial needles strike entirely across the crystal. The rock is a porphyritic diorite from the *McKibben Tunnel*, part of the same mass the pseudomorphic phenomena of which are illustrated in Figs. 6 and 7, and distant only eight feet from it. It is the last stage of the conversion shown in Fig. 7. Slide 199 also shows epidote developing in chlorite patches. Magnified 50 diameters.

FIG. 10. Slide $197^{16.21}$. Pseudomorph of chlorite and quartz after hornblende. The quartz occupies the central portion of the crystal, and seems to have been deposited by substitution for chlorite. The chlorite border is fibrous, excessively fine, and, as usual where this structure occurs, transmits scarcely a ray of light between crossed Nicols. The approximate uniformity of the chlorite zone suggests that the resistance offered by it to decomposition has exceeded that of the chlorite for which quartz has been substituted. The very dark spots in the quartz are limonite, and there are two small granular bunches of epidote in the chlorite, at the lower left-hand corner of the cut. The slide is from the same specimen as Fig. 9. Magnified 100 diameters.

FIG. 11. Slide $295^{10.16}$. Colorless hornblende passing into a green variety of the same mineral seen in cross-section. A large hornblende appears to have been divided into cleavage prisms by chloritic decomposition, much as in Fig. 2, but with the additional development of the clinopinacoidal cleavage.

These prisms are colorless near the center, but green near the border. The figure shows one of a vast number within the same crystal outline, the shaded portion representing green. No change in the angle of extinction is produced by the alteration. The rock is metamorphic diorite from the *Amazon* mine. Magnified 270 diameters.

FIG. 12. Slide $295^{15.27}$. Colorless hornblende passing into a green variety of the same mineral, longitudinal section. No longitudinal section so perfect as the cross-section shown in Fig. 11 has been met with. Many, however, like that portrayed in Fig. 12, show colorless fibers encroached upon by the green mineral. This section also contains a little chlorite, shaded a deeper tint than the remainder of the section. The rock is metamorphic diorite from the *Amazon* mine. Magnified 40 diameters.

PLATE III.

FIG. 13. Slide $20^{9.25}$. Zonal feldspar. The kernel and the outer zone extinguish light when the principal plane of the Nicols is inclined at an angle of about 14° to the twinning plane, and the fine reversed lamellæ are blackest when the angle measures about 14° in the opposite direction. The intermediate zone extinguishes at an angle of 5° in the same sense as the other zones. Just within the outer zone is a belt of nearly opaque inclusions which connects with the groundmass of the rock at the top of the figure. The rock is hornblende-andesite from the quarry 1,000 feet west of the *Yellow Jacket* east shaft. Magnified 50 diameters.

FIG. 14. Fortieth Parallel collection, slide $284^{13.38}$. Feldspar with rectangular glass kernel. The two halves of this crystal extinguish light at angles of 24° and 26° to the twinning plane, and minute twin lamellæ are visible at the lower end of the section. Magnified 140 diameters.

FIG. 15. Slide $349^{14.25}$. Augite section showing discontinuous twin lamellæ. These are shaded dark gray. Two included crystals of iron ore are indicated in black, and some chloritic patches in light gray. The rock is diabase from the *Sutro Tunnel* north branch, 50 feet south of Ophir connection. Magnified 40 diameters.

FIG. 16. Slide $428^{12.16}$. Augite with contorted twin-lamellæ, which are shown in black. The rock is an augite-andesite from near the *Sutro Tunnel* air-shaft (beyond the limits of the map). Magnified 70 diameters.

FIG. 17. Slide $450^{15.21}$. Fragment of brown hornblende with black border on the fractured surface, as well as on the crystal faces, and a second parallel internal belt of magnetite. The figure is from a hornblendic andesite from a cut 1,000 feet east of the railroad station at the Silver City switch. Magnified 60 diameters.

FIG. 18. Slide $194^{6.21}$. Horseshoe-shaped apatite cut so nearly at right angles to the main axis as to remain almost black between crossed Nicols. It occurs in a decomposed hornblende. The rock is dioritic porphyry from the *McKibben Tunnel*. Magnified 220 diameters.

FIG. 19. Slide $454^{22.20}$. Mass of ilmenite showing characteristic markings, from an augite-andesite from Cedar Hill Cañon. Magnified 70 diameters.

FIG. 20. Slide $182^{16.20}$. A peculiar secretion in a glassy augite-andesite from the southwest flank of Mount Kate. It is a brownish mass of pseudo-spherolitic structure filled with black trichites. It much resembles a patch of brown mold. Many others occur in the same slide. Magnified 45 diameters.

FIG. 21. Slide $421^{10.26}$. Symmetrically arranged acicular black inclusions found in the hornblendes of diorites and andesites. The illustration is taken from a longitudinal section of brown hornblende, and the direction of the cleavage is indicated by the arrow. The rock is a porphyritic diorite from the center of Cedar Hill ridge. Fig. 26 is from the same slide. Magnified 600 diameters.

FIG. 22. Slide $210^{12.20}$. Secondary fluid inclusion in feldspar. These inclusions are absent from the fresh portion of the same exposure. The rock is from the quarry 1,000 feet west of the *Yellow Jacket* east shaft. Magnified 800 diameters.

FIG. 23. Slide $462^{10.28}$. The illustration shows the edge of a feldspar above a portion of the groundmass of the slide. The feldspar contains inclusions of brown glass, which are elongated in the direction of the edge of the crystal, and seem thus to indicate a tendency to zonal structure in the formation of the crystal. The inclusions also show a connection with the present face of the crystal, and are continuous in a direction vertical to the face. Portions of the viscid glass having become entangled in the feldspar during its growth, the energy of crystallization seems to have been insufficient to expel or cut off the partially inclosed material. The rock is a glassy younger hornblende-andesite from the Geiger Grade 2,000 feet northwest of the toll-house. Magnified 200 diameters.

FIG. 24. Slide $351^{21.27}$. Double glass inclusion in quartz. No part of this inclusion reaches either the upper or the lower surface of the slide, nor is there any trace of a crack near it. The rock is from the *Overman* mine, 1,142-foot level. Magnified 750 diameters.

PLATE IV.

In the description of the figures on this plate and the succeeding one, the position of the minerals is given by their coördinates referred to the lower left-hand corner of each figure, the ordinates being written before the abscissæ. In seeking a mineral, it is convenient to lay a card, or rectangular slip of paper, on the illustration with its edges parallel to those of the figure, but intersecting the graduated edges of the latter at the given distances. The corner of the card will then coincide with the point sought. This method is capable of any desired degree of exactness and permits of the indefinite multiplication of references.

FIG. 25. Slide $213^{18.18}$. Granular diorite from Bullion Ravine at Water Company's flume. Nicols crossed. Magnified 30 diameters.

GREEN, FIBROUS HORNBLENDE: 20–22; 27–28; 22–13.

LABRADORITE: 12–15; 14–28, and most of the unspecified grains.

QUARTZ: 8–14; 15–23; 17–18. The quartz carries fluid inclusions, some of which show active bubbles.

MAGNETITE: 19–10; 25–27.

At 19–20 epidote is developing in a patch of chlorite, but cannot be well observed with crossed Nicols or with so low a power.

FIG. 26. Slide $421^{18.22}$. Porphyritic diorite from the center of Cedar Hill ridge. Nicols crossed. Magnified 30 diameters.

GREENISH-BROWN HORNBLENDE: 20–20; 20–27; 30–21; 10–22, etc. A small feldspar is inclosed in the large hornblende, and chlorite in small quantities is developing along the cleavages of the latter, producing with crossed Nicols the broad black markings noticeable in the drawing.

FELDSPARS: The porphyritic feldspars in this slide, as at 10–18, appear to be labradorite. Some of the microlites give oligoclase angles of extinction. The greater part of the small feldspars are granular.

MAGNETITE: 8–24; 20–23, and many grains too small to appear individually on this scale. The apatites are also too minute to be shown.

EPIDOTE developing out of chlorite occurs at 18–5, but requires a higher power and different light for study.

FIG. 27. Slide $354^{17.14}$. Quartz-porphyry 1,000 feet southwest of *Lawson's Tunnel*. Nicols at 45°. Magnified 30 diameters.

ORTHOCLASE: 22–5; 20–25; 26–23; 17–15; 15–10.

QUARTZ: 25–10; 15–25. The quartz contains bays of groundmass and numerous fluid inclusions with moving bubbles.

MICA: 15–20; 5–24. The mica is wholly decomposed and replaced by limonite and other secondary products.

Fig 1

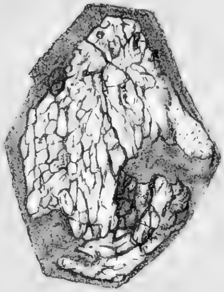

Fig 2

Fig 3

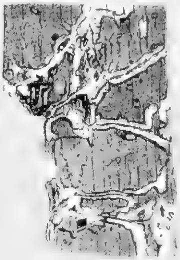

Fig 4

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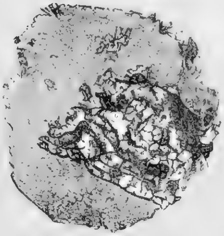


Fig 6

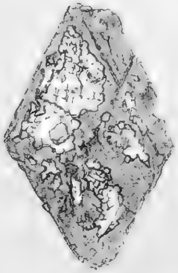


Fig 7

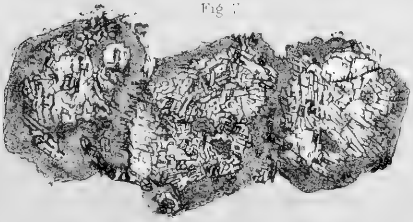


Fig 8

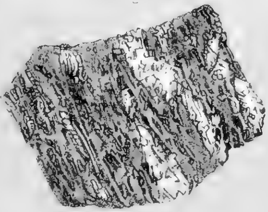


Fig 9

Fig 10

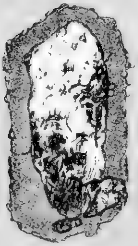
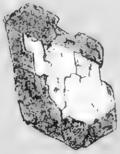


Fig 11



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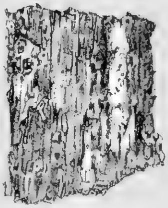


Julius Bien & Co. lith.

Fig. 13.

Fig. 14.

Fig. 15.

Fig. 16.

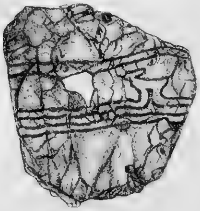


Fig. 17.

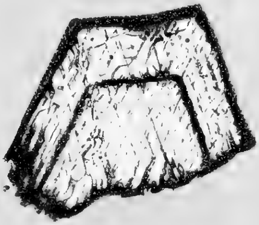


Fig. 18.

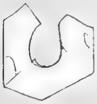


Fig. 19.

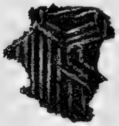


Fig. 20.

Fig. 21.

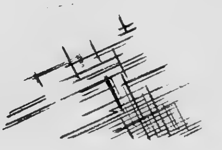


Fig. 22.

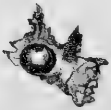
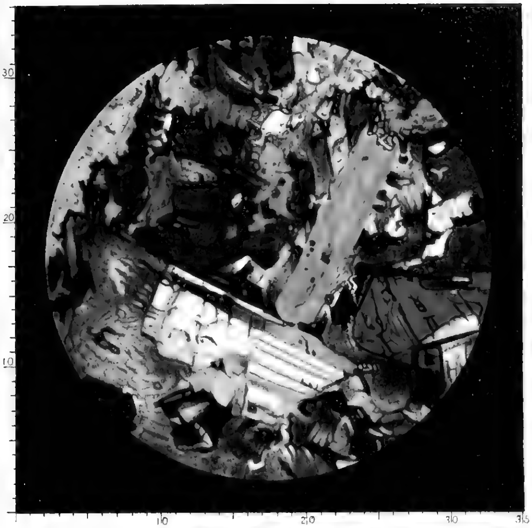


Fig. 23.

Fig. 24.

Julius Bien & Co. lith.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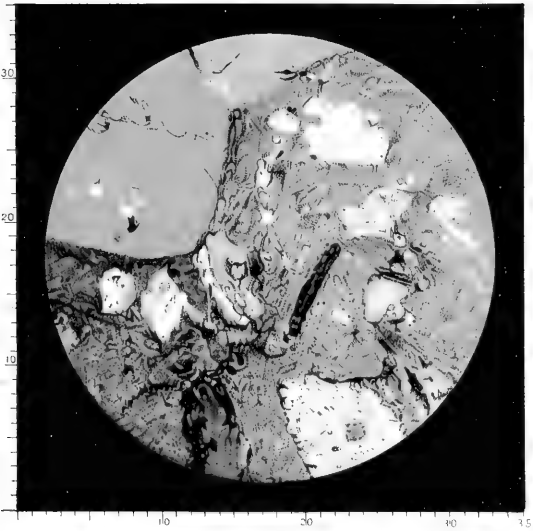
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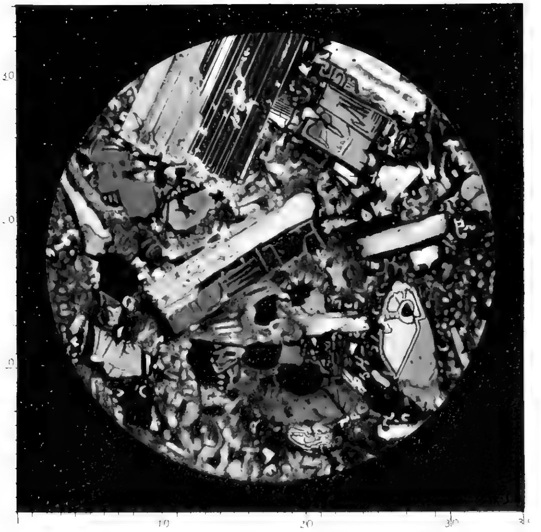
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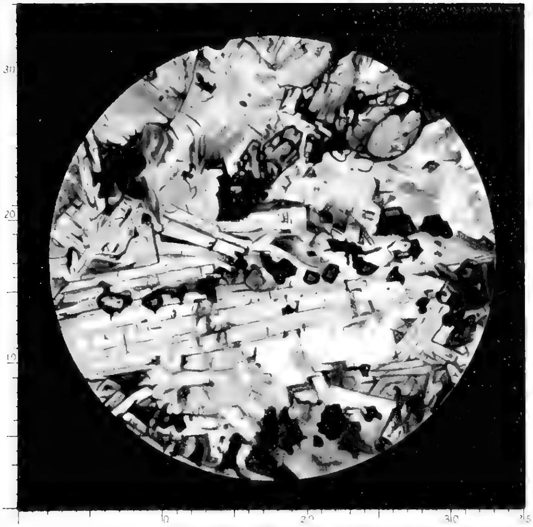
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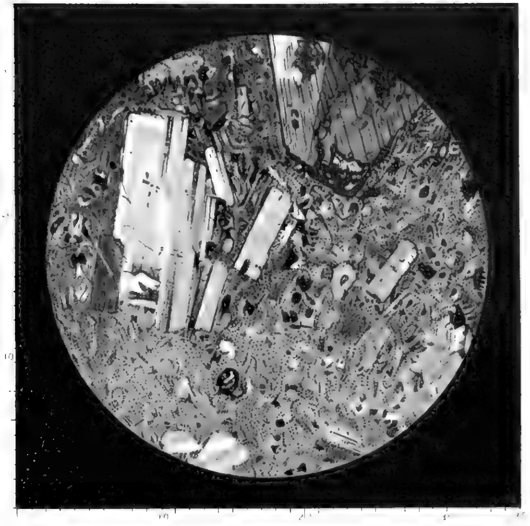
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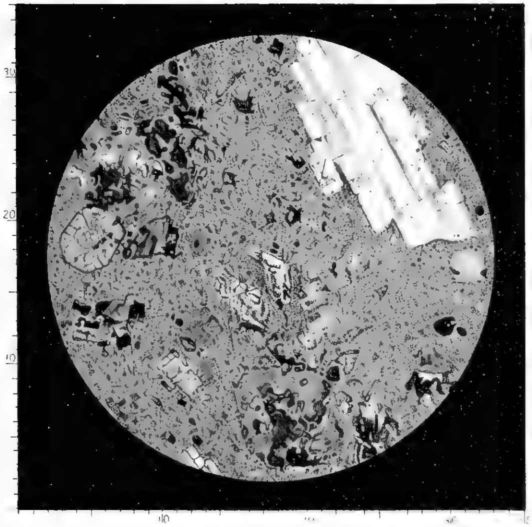
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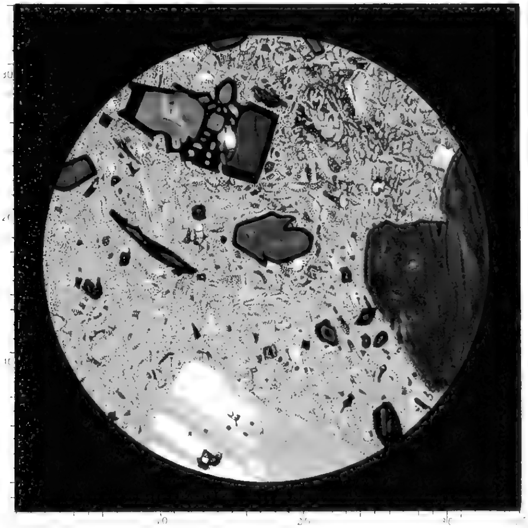
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FIG. 28. Slide $349^{10.21}$. Earlier diabase, *Sutro Tunnel*, north branch, 50 feet south of Ophir connection. Nicols crossed. Magnified 30 diameters.

LABRADORITE: 27–13; 27–23; 23–15; 19–27, and most of the grains constituting the groundmass.

AUGITE: 11–27; 5–20; 21–33; 21–12.

URALITE: 22–8; 7–20. The augite at 21–12 is partly converted to uralite.

MAGNETITE or ILMENITE: 9–20; 10–12; 16–7, etc.

PLATE V.

FIG. 29. Slide $466^{14.29}$. Later diabase ("black dike"). *Chollar* mine, 1,900-foot level. Nicols at 45°. Magnified 120 diameters.

LABRADORITE: 12–18, etc.

AUGITE: 25–26; 14–7; 14–9; 16–20; 25–18, etc. The augite is all more or less obscured by a smoky-brown decomposition product, probably limonite.

MAGNETITE: 6–22; 16–18; 23–7, etc.

FIG. 30. Slide $228^{11.24}$. Earlier hornblende-andesite. Knoll just northeast of *Combination Shaft*. Nicols at 45°. Magnified 23 diameters.

HORNBLENDE: 27–23.

LABRADORITE: 22–10; 20–17; 17–25.

MAGNETITE and ILMENITE: All the black spots.

CHLORITE: 10–29.

FIG. 31. Slide $465^{19.26}$. Decomposed augite-andesite from Crown Point Ravine. No polarizer was used, the sky light happening to be sufficiently polarized to develope the lamellæ of the feldspar. Magnified 20 diameters.

LABRADORITE: 25–25; 11–11.

AUGITE: 19–5; pseudomorphs of chlorite after augite, 7–19; 17–32. In the first of these, epidote is developing as in Fig. 5, which is also from this slide.

EPIDOTE: 8–19; 18–10.

The mass at 25–7 is chlorite, calcite, epidote, and oxides. The black spots in the groundmass are magnetite.

FIG. 32. Slide $473^{10.32}$. Later hornblende-andesite. Quarry 2,000 feet northeast of *Sutro Shaft* III. Nicols at 45°. Magnified 35 diameters.

HORNBLENDE: 19–18; 27–13; 23–3; 13–21; 14–25, etc.

MICA: 19–9; 15–30. The last is almost wholly represented by magnetite, leaving only here and there a particle of the original material.

The one large feldspar and all the microlites appear to be labradorite.

The magnetite grains are readily recognizable.

TABLE 2.—*Silica determinations.*

Dr. G. E. Moore, at my request, made the following determinations:

Porphyritic diorite, from the head of Ophir Ravine, much decomposed, contains	58.56 per cent. SiO_2
Earlier diabase, *Sutro Tunnel*, 19,100 feet from entrance, highly decomposed, contains	59.26 per cent. SiO_2
Later diabase, *Belcher* 1,145, very fresh, contains	49.79 per cent. SiO_2

TABLE 3.—*Analysis of Water from the 600-foot level of the Savage mine, by Professor S. W. Johnson, of Yale College.*[1]

One liter contained—

	Grammes.
Silica	.0305
Alumina and ferric oxide	.0009
Chloride of sodium	.0021
Sulphate of lime	.5044
Sulphate of magnesia	.0308
Carbonate of potash	.0148
Carbonate of soda	.1297
Carbonate of magnesia	.5012
	.7644

TABLE 4.—*Qualitative determination of Comstock mine-waters.*[2]

By EUGENE S. BRISTOL.

	Yellow Jacket, bottom of new shaft.	Yellow Jacket, west drift 500-foot level.	Empire-Imperial, bottom of new shaft.	Hale & Norcross, bottom of new shaft.	Hale & Norcross, west drift 930-foot level.	Savage, 5th station, north drift.	Ophir, bottom of new shaft.
Solid contents, grammes[3]	0.0553	0.3271	0.0615	0.0924	0.0784	0.0660	0.080
Bases	Lime	Lime	Lime	Lime	Lime	Lime	Lime.
	Magnesia	Magnesia	Magnesia	Magnesia	Magnesia	Magnesia	Magnesia.
			Potash			Potash	
	Soda	Soda	Soda	Soda	Soda	Soda	Soda.
			Alumina				
Acids	Carbonic	Carbonic		Carbonic	Carbonic	Carbonic	Carbonic.
	Sulphuric	Sulphuric	Sulphuric	Sulphuric	Sulphuric	Sulphuric	Sulphuric.
	Phosphoric	Phosphoric			Phosphoric	Phosphoric	
			Chlorine				Chlorine.
			Silicic	Silicic (trace)			

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[1] Exploration of the Fortieth Parallel, Vol. III., p. 87.

[2] Exploration of the Fortieth Parallel, Vol. III., p. 88.

[3] In 100 cubic centimeters of water.

TABLE 1.—

[From the publications of the Exploration

Determination.	Locality.	Analyst.	Si O$_2$
Diorite	Eldorado outcrop, Mount Davidson	R. W. Woodward	56. 7 30.2
Do	do	do	56. 5 30.1
Mica-diorite	800′ E. of *Waller Defeat* shaft, point 5,521 (D. 5)	Gideon E. Moore	65. 6 35.0
Porphyritic diorite	Center of Cedar Hill Ridge (D. 2)	do	58. 5 31 2
Metamorphic diorite	*Amazon* mine (D. 7)	do	46. 6 24.8
Earlier diabase	Main *Sutro Tunnel*, hanging wall of LODE	do	56. 4 30.0
Quartz-porphyry ("quartz-propylite")	Hill west of American Flat, Washoe	W. G. Mixter	68. 4 36.5
Quartz-porphyry ("dacite")	Hills above American City, Washoe	C. Coüncler	69. 3 36.9
Hornblende-andesite ("propylite")	Cross-spur, below graveyard, Washoe	W. G. Mixter	60. 8 32.4
Hornblende-andesite	First Hill north of Gold Hill Peak, Washoe	W. Kormann	61. 1 32.5
Augite-andesite ("hornblende-andesite")	Ridge northeast of American Flat, Washoe	W. G. Mixter	58. 3 31.1
Do	Silver Terrace, Washoe	do	59. 2 31.5
Later hornblende-andesite ("trachyte")	Cross-Spur quarry, Washoe	R. W. Woodward	63. 1 33.6
Do	Mount Rose, Washoe	do	63. 3 33.7
Do	do	do	63. 1 33.6
? ("propylite")	Washoe (Virginia City)	W. G. Mixter	58. 6 31.2
"Propylite" horse	*Yellow Jacket*, 830-foot level	do	80. 2
Clay	*Yellow Jacket* east clay	S. W. Johnson	60. 0
Do	*Chollar* west clay	W. G. Mixter	59. 71
Do	*Hale & Norcross* east clay	do	65. 6
Do	*Savage* second station	S. W. Johnson	39. 5

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[1] Including titanic and phosphoric acids.

[2] Supposing all the iron present as ferrous oxide.

[3] Supposing all the iron present as ferric

[Geol. Comstock Lode, Vol. III.]

analyses.

n Parallel, excepting those by Dr. G. E. Moore.]

O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	Li_2O	CO_2	Other components.	Ignition.	Total.	Specific gravity.	Oxygen ratio of—			Oxygen quotient.
														$\dot{R}$	$\ddot{R}$	SiO_2	
.36 8.55	....	6.45 1.43	....	6.11 1.74	3.92 1.57	3.52 0.91	2.38 0.40	....	......	....	1.94	99.39	2.86, 2.88	6.05	8.55	30.24	0.482
.20 8.48	....	6.30 1.40	....	5.99 1.71	3.83 1.53	3.58 0.92	2.41 0.41	....	......	....	1.96	98.85	....	5.97	8.48	30.17	0.479
.87 7.41	1.78 0.53	1.25 0.28	Trace.	3.50 1.00	1.79 0.71	3.20 0.83	3.37 0.57	....	......	P_2O_5 ....0.23 0.13	3.10	100.75	2.65	3.39	7.94	35.53[1]	0.355
.48 7.23	3.93 1.18	2.07 0.46	0.11 0.02	6.44 1.84	3.60 1.42	3.99 1.03	1.69 0.29	....	......	P_2O_5 ....0.30 0.11	3.62	100.61	2.71	5.06	8.41	31.65[1]	0.425
.32 8.09	4.82 1.45	5.99 1.33	0.10 0.02	9.29 2.66	6.69 2.64	3.46 0.89	2.02 0.34	....	......	P_2O_5 ....0.44 0.25	2.44	100.24	2.9582	7.88	9.54	25.52[1]	0.683
.99 7.47	3.26 0.98	3.82 0.85	0.12 0.03	6.98 2.00	3.54 1.40	3.83 0.99	1.91 0.32	....	......	P_2O_5 ....0.32 0.18	2.47	99.78	2.7972	5.59	8.45	30.70[1]	0.457
.86 6.92	....	3.80 0.84	....	1.90 0.54	....	3.22 0.83	5.08 0.86	....	0.94	....	2.26	100.50	2.63, 2.67	3.07 2.23	6.92 8.19	36.50 36.50	0.273[2] 0.285[3]
.9 8.34	....	4.1 0.91	....	1.6 0.45	1.3 0.52	2.0 0.51	3.6 0.61	....	......	....	2.1	101.9	....	3.00 2.09	8.34 9.70	36.96 36.96	0.307[2] 0.319[3]
.54 8.17	....	5.42 1.20	....	5.65 1.61	1.76 0.70	3.71 0.96	1.41 0.24	....	1.41	....	2.31	100.39[4]	2.66, 2.68	4.71 3.51	8.17 9.97	32.43 32.43	0.397[2] 0.415[3]
.61 5.41	11.64 3.49	....	....	4.33 1.23	0.61 0.24	3.85 0.99	3.52 0.60	....	......	....	4.35	101.03	....	5.39 3.06	5.41 8.90	32.59 32.59	0.331[2] 0.366[3]
.17 8.46	....	6.03 1.34	....	6.19 1.77	2.40 0.96	3.20 0.82	3.02 0.51	....	2.85	....	0.76	99.95[4]	2.72, 2.76	5.40 4.06	8.46 10.47	31.10 31.10	0.445[2] 0.467[3]
.20 8.48	....	6.69 1.48	....	5.51 1.57	2.90 1.16	3.31 0.85	1.39 0.24	....	......	....	2.80	100.02	2.6	5.30 3.82	8.48 10.71	31.58 31.58	0.436[2] 0.460[3]
.00 7.45	4.34 1.30	1.52 0.33	....	4.45 1.27	2.07 0.83	3.87 1.00	2.65 0.45	....	......	....	2.00	100.03	2.4, 2.5, 2.5	3.88	8.75	33.67	0.375
.81 8.30	3.42 1.02	0.83 0.18	....	5.12 1.46	2.07 0.83	4.27 1.10	2.26 0.38	Trace.	......	....	0.88	99.96	2.5, 2.4	3.95	9.32	33.76	0.393
.54 8.17	3.22 0.96	0.83 0.18	....	5.15 1.47	2.06 0.82	4.44 1.14	2.22 0.37	Trace.	......	....	0.95	99.54	....	3.98	9.13	33.67	0.389
.90 8.34	....	4.11 0.91	....	5.87 1.67	2.03 0.81	2.07 0.53	3.19 0.54	....	......	....	6.53	100.36	2.65	4.46 3.55	8.34 9.71	31.28 31.28	0.409[2] 0.423[3]
.39	2.17	....	Trace.	0.54	Trace.	1.94	2.19	....	......	Pyrite 1.69	1.83	100.02	....	......	......	......	......
.15	4.38	....	....	6.00	1.40	0.45	1.23	....	3.17	Pyrite 1.84; P_2O_5 0.34.	8.09 H_2O	99.07	....	......	......	......	......
.59	5.04	....	....	0.73	4.41	1.01	3.98	....	......	Pyrite 3.58; P_2O_5 trace.	4.19	100.24	....	......	......	......	......
.39	2.11	....	....	1.66	2.85	2.36	4.64	....	......	Pyrite 2.84; P_2O_5 trace.	2.80	100.34	....	......	......	......	......
.97	4.47	....	....	9.20	3.40	....	3.11	....	6.20	Pyrite 9.18; P_2O_5 trace.	9.95 H_2O	101.00	....	......	......	......	......

[4] These totals do not agree with the items, no doubt in consequence of misprints; the oxygen-contents of each constituent, however, corresponds to the percentage of the oxide given, and the errors therefore probably occur in the statements of the carbonic acid or of the loss by ignition.

TABLE 1.—*Chemical analyses.*

[From the publications of the Exploration of the Fortieth Parallel, excepting those by Dr. G. E. Moore.]

Determination.	Locality.	Analyst.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	Li_2O	CO_2	Other components.	Ignition.	Total.	Specific gravity.	Oxygen ratio of—			Oxygen quotient.
																			$\dot{R}$	$\ddot{R}$	SiO_2	
Diorite	Eldorado outcrop, Mount Davidson	R. W. Woodward	56.71 30.24	....	18.36 8.55	....	6.45 1.43	....	6.11 1.74	3.92 1.57	3.52 0.91	2.38 0.40	....	....	....	1.94	99.39	2.86, 2.88	6.05	8.55	30.24	0.482
Do	....do	....do	56.58 30.17	....	18.20 8.48	....	6.30 1.40	....	5.99 1.71	3.83 1.53	3.58 0.92	2.41 0.41	....	....	....	1.96	98.85	....	5.97	8.48	30.17	0.479
Mica-diorite	800′ E. of *Waller Defeat* shaft, point 5,521 (D. 5)	Gideon E. Moore	65.68 35.01	0.98 0.39	15.87 7.41	1.78 0.53	1.25 0.28	Trace.	3.50 1.00	1.79 0.71	3.20 0.83	3.37 0.57	....	....	P_2O_5 ....0.23 0.13	3.10	100.75	2.65	3.39	7.94	35.53[1]	0.355
Porphyritic diorite	Center of Cedar Hill Ridge (D. 2)	....do	58.55 31.21	0.83 0.33	15.48 7.23	3.93 1.18	2.07 0.46	0.11 0.02	6.44 1.84	3.60 1.42	3.99 1.03	1.69 0.29	....	....	P_2O_5 ....0.30 0.11	3.62	100.61	2.71	5.06	8.41	31.65[1]	0.425
Metamorphic diorite	*Amazon* mine (D. 7)	....do	46.65 24.86	1.02 0.41	17.32 8.09	4.82 1.45	5.99 1.33	0.10 0.02	9.29 2.66	6.69 2.64	3.46 0.89	2.02 0.34	....	....	P_2O_5 ....0.44 0.25	2.44	100.24	2.9582	7.88	9.54	25.52[1]	0.683
Earlier diabase	Main *Sutro Tunnel*, hanging wall of LODE	....do	56.40 30.06	1.14 0.46	15.99 7.47	3.26 0.98	3.82 0.85	0.12 0.03	6.98 2.00	3.54 1.40	3.83 0.99	1.91 0.32	....	....	P_2O_5 ....0.32 0.18	2.47	99.78	2.7972	5.59	8.45	30.70[1]	0.457
Quartz-porphyry ("quartz-propylite")	Hill west of American Flat, Washoe	W. G. Mixter	68.44 36.50	....	14.86 6.92	....	3.80 0.84	....	1.90 0.54	....	3.22 0.83	5.08 0.86	....	0.94	....	2.26	100.50	2.63, 2.67	3.07 2.23	6.92 8.19	36.50 36.50	0.273[2] 0.285[3]
Quartz-porphyry ("dacite")	Hills above American City, Washoe	C. Coüncler	69.3 36.96	....	17.9 8.34	....	4.1 0.91	....	1.6 0.45	1.3 0.52	2.0 0.51	3.6 0.61	....	....	....	2.1	101.9	....	3.00 2.09	8.34 9.70	36.96 36.96	0.307[2] 0.319[3]
Hornblende-andesite ("propylite")	Cross-spur, below graveyard, Washoe	W. G. Mixter	60.82 32.43	....	17.54 8.17	....	5.42 1.20	....	5.65 1.61	1.76 0.70	3.71 0.96	1.41 0.24	....	1.41	....	2.31	100.39[4]	2.66, 2.68	4.71 3.51	8.17 9.97	32.43 32.43	0.397[2] 0.415[3]
Hornblende-andesite	First Hill north of Gold Hill Peak, Washoe	W. Kormann	61.12 32.59	....	11.61 5.41	11.64 3.49	....	....	4.33 1.23	0.61 0.24	3.85 0.99	3.52 0.60	....	....	....	4.35	101.03	....	5.39 3.06	5.41 8.90	32.59 32.59	0.331[2] 0.366[3]
Augite-andesite ("hornblende-andesite")	Ridge northeast of American Flat, Washoe	W. G. Mixter	58.33 31.10	....	18.17 8.46	....	6.03 1.34	....	6.19 1.77	2.40 0.96	3.20 0.82	3.02 0.51	....	2.85	....	0.76	99.95[4]	2.72, 2.76	5.40 4.06	8.46 10.47	31.10 31.10	0.445[2] 0.467[3]
Do	Silver Terrace, Washoe	....do	59.22 31.58	....	18.20 8.48	....	6.69 1.48	....	5.51 1.57	2.90 1.16	3.31 0.85	1.39 0.24	....	....	....	2.80	100.02	2.6	5.30 3.82	8.48 10.71	31.58 31.58	0.436[2] 0.460[3]
Later hornblende-andesite ("trachyte")	Cross-Spur quarry, Washoe	R. W. Woodward	63.13 33.67	....	16.00 7.45	4.34 1.30	1.52 0.33	....	4.45 1.27	2.07 0.83	3.87 1.00	2.65 0.45	....	....	....	2.00	100.03	2.4, 2.5, 2.5	3.88	8.75	33.67	0.375
Do	Mount Rose, Washoe	....do	63.30 33.76	....	17.81 8.30	3.42 1.02	0.83 0.18	....	5.12 1.46	2.07 0.83	4.27 1.10	2.26 0.38	Trace.	....	....	0.88	99.96	2.5, 2.4	3.95	9.32	33.76	0.393
Do	....do	....do	63.13 33.67	....	17.54 8.17	3.22 0.96	0.83 0.18	....	5.15 1.47	2.06 0.82	4.44 1.14	2.22 0.37	Trace.	....	....	0.95	99.54	....	3 98	9.13	33.67	0.389
? ("propylite")	Washoe (Virginia City)	W. G. Mixter	58.66 31.28	....	17.90 8.34	....	4.11 0.91	....	5.87 1.67	2.03 0.81	2.07 0.53	3.19 0.54	....	....	....	6.53	100.36	2.65	4.46 3.55	8.34 9.71	31.28 31.28	0.409[2] 0.423[3]
"Propylite" horse	*Yellow Jacket*, 830-foot level	....do	80.27	....	9.39	2.17	....	Trace.	0.54	Trace.	1.94	2.19	....	....	Pyrite 1.69	1.83	100.02	....	....	....	....	....
Clay	*Yellow Jacket* east clay	S. W. Johnson	60.02	....	12.15	4.38	....	....	6.00	1.40	0.45	1.23	....	3.17	Pyrite 1.84; P_2O_5 0.34.	8.09 H_2O	99.07	....	....	....	....	....
Do	*Chollar* west clay	W. G. Mixter	59.71	....	17.59	5.04	....	....	0.73	4.41	1.01	3.98	....	....	Pyrite 3.58; P_2O_5 trace.	4.19	100.24	....	....	....	....	....
Do	*Hale & Norcross* east clay	....do	65.69	....	15.39	2.11	....	....	1.66	2.85	2.36	4.64	....	....	Pyrite 2.84; P_2O_5 trace.	2.80	100.34	....	....	....	....	....
Do	*Savage* second station	S. W. Johnson	39.52	....	15.97	4.47	....	....	9.20	3.40	....	3.11	....	6.20	Pyrite 9.18; P_2O_5 trace.	9.95 H_2O	101.00	....	....	....	....	....

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[1] Including titanic and phosphoric acids.

[2] Supposing all the iron present as ferrous oxide.

[3] Supposing all the iron present as ferric oxide.

[4] These totals do not agree with the items, no doubt in consequence of misprints; the oxygen-contents of each constituent, however, corresponds to the percentage of the oxide given, and the errors therefore probably occur in the statements of the carbonic acid or of the loss by ignition.

TABLE 5.—*Analyses of Comstock ores.*[1]

	California mine.	California mine.	Ophir mine.	Yellow Jacket mine.	Yellow Jacket mine.
Silica	67.5	65.783	63.38	98.310	96.560
Sulphur	8.75	11.35	7.919	.693	.160
Copper	1.30	1.31	1.596		
Iron	2.25	2.28	5.463	.575	2.800
Silver	1.75	1.76	2.786	.150	.050
Gold	.079	.57	.059	.005	.001
Zinc	12.85	11.307	14.455		
Lead	5.75	6.145	4.151		
Antimony			.087		
Loss	.25			.267	.429
	100.00	100.00	99.896	100.00	100.00
	London.	Swansea.	G. Attwood.	W. F. Rickard.	W. F. Rickard.

TABLE 6.—*Analyses of Comstock ores.*[2]

	Savage.	Kentuck.
Silica	83.95	91.49
Protoxide of iron	1.95	.83
Alumina	1.25	1.13
Protoxide of manganese	.64	
Magnesia	2.82	1.37
Lime	.85	1.42
Sulphide of zinc	1.75	.13
Sulphide of copper	.30	.41
Sulphide of lead	.36	.02
Sulphide of silver	1.08	.12
Gold	.02	.0017
Bisulphide of iron	1.80	.92
Potash and soda	1.28	1.05
Water	2.33	.59
	100.38	99.48
	W. G. Mixter.	A. Hague.

TABLE 7.—*Feldspars of the Younger Hornblende-andesite, from Mount Rose, Slide 474.*[3]

	Grammes.
Weight of rock treated by Thoulet's method	11
Weight of material of specific gravity above 2.75	1.7
Weight of material of specific gravity between 2.75 and 2.70	1.8
Weight of material of specific gravity between 2.70 and 2.68	1.6
Weight of material of specific gravity below 2.68	5.8

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[1] Exploration of the Fortieth Parallel, Vol. III., page 80.

[2] Exploration of the Fortieth Parallel, Vol. III., p. 80.

[3] See page 67.

The following analyses were made for Dr. G. W. Hawes by Mr. F. P. Dewey:

Feldspar of specific gravity between 2.75 and 2.70.

	Per cent.	Atomic ratio.		Oxygen ratio.	
SiO_2	59.51	0.9918	10.11	31.738	7.95
Al_2O_3	23.83	0.2312	2.46	11.567	2.89
Fe_2O_3	1.54				
CaO	7.48	0.1576	1.606	3.992	1.
MgO	0.96				
K_2O	1.12	0.0981	1.		
Na_2O	5.35				
	99.79				

Feldspar of specific gravity between 2.70 and 2.68.

	Per cent.	Atomic ratio.		Oxygen ratio.	
SiO_2	62.29	1.0382	10.65	33.22	8.69
Al_2O_3	20.74	0.2150	2.20	10.32	2.96
Fe_2O_3	2.19				
CaO	7.01	0.1414	1.45	3.82	1.
MgO	0.65				
K_2O	1.22	0.0975	1.		
Na_2O	5.25				
	99.35				

TABLE 8.—*Assays of Comstock rocks.*[1]

By J. S. CURTIS.

Rock.	Locality.	Bullion contents reckoned as silver.
Granite	*Red Jacket* mine	$0.03
Granular diorite	Bullion Ravine, at intersection of Water Company's flume	0.19
Do	Bullion Ravine, 200 feet above flume	0.04
Do	Bullion Ravine, 2,000 feet above flume	0.03
Do	Most westerly diorite cropping	0.08
Dark, fine-grained diorite	*McKibben tunnel*	0.11
Dark, coarse-grained diorite	Bottom of *Union* shaft, 2,625 feet	0.15
Porphyritic diorite	Head of Ophir Ravine, decomposed	0.17
Do	*Ophir*, 2,500, *Union* connection, decomposed	0.30
Do	*Savage*, 2,100, south drift 20 feet from east cross-cut	0.12
Granular diorite	*Caledonia*	0.05
Micaceous diorite-porphyry	*Overman*, 1,600, 250 feet east of shaft	0.11
Do	800 feet east of *Waller Defeat* shaft	0.07
Earlier diabase	*Sutro tunnel* at *Savage* connection, fresh	0.22

[1] For remarks on these assays see page 223.

TABLE 8.—*Assays of Comstock rocks*—Continued.

Rock.	Locality.	Bullion contents reckoned as silver.
Earlier diabase	*Sutro tunnel*, 50 feet north of junction with North Lateral, fresh	$0.20
Do	*Overman*, 1,600-foot level at main winze, somewhat decomposed	0.18
Do	*Sierra Nevada*, 2,500-foot level, end north drift, somewhat decomposed	0.17
Do	*C. & C.*, 1,650, 116 feet from shaft, west drift, somewhat decomposed	0.07
Do	*Sutro tunnel*, 19,100 feet, somewhat decomposed	0.14
Do	*Sutro tunnel*, 50 feet west of South Lateral, somewhat decomposed	0.11
Do	*Sutro tunnel*, North Lateral, 1,000 feet north of *C. & C.* connection, much decomposed	0.10
Do	*Sutro tunnel*, North Lateral, 600 feet north of *C. & C.* connection, highly decomposed, charged with pyrite	0.10
Do	*Sutro tunnel*, South Lateral, 250 feet north of *Julia*, highly decomposed, charged with pyrite	0.11
Do	*Sutro tunnel*, 50 feet west of South Lateral, highly decomposed	0.11
Do	*Sutro tunnel*, North Lateral, 250 feet north of *C. & C.* connection, highly decomposed, charged with pyrite	0.11
Later diabase	*Chollar*, 1,900, 40 feet east of incline, fresh	0.05
Do	*Julia* dump, fresh	0.11
Black slate	Charged with pyrite	0.14
Metamorphic diorite	*Amazon* dump	0.08
Quartz-porphyry	*Caledonia*, 1,400-foot level, 350 feet east of *Caledonia* shaft	0.00
Do	Quarry, 1,500 feet southwest of *Justice*	0.03
Earlier hornblende-andesite	North Twin Peak	0.00
Do	Spur northeast of *Combination* shaft	0.03
Do	1,200 feet northwest of Geiger Grade Toll-House	0.05
Do	Near *Vivian* mine	0.04
Augite-andesite	*Forman* shaft tank, point 6,158	0.04
Later hornblende-andesite	Quarry northeast of *Sutro* shaft III	0.14
Do	Quarry near *Utah* mine	0.03
Basalt	1,250 feet southeast of Roux' Ranch	0.17

CHAPTER IV.

STRUCTURAL RESULTS OF FAULTING.

Views of previous observers.—Before proceeding to a description of the occurrence of the rocks forming the subject of the preceding chapter, it seems necessary to discuss the faulting action traceable on and near the LODE, for it has had an important share in determining the present position and relations of the rocks. As has been seen in Chapter II., Baron von Richthofen regarded the LODE as a true fissure, only following the contact between the syenite (diorite) of Mount Davidson and the east country rock for a portion of its length because of the low resistance offered by this contact. He also insisted that faulting both preceded and followed the deposition of ore. He does not state, I believe, whether he regarded the west wall of the lode as a continuation of the exposed surface of Mount Davidson, but implies that it is not, for he speaks of the course of the vein as "somewhat" dependent upon the shape of the slope. Mr. King, at the time of writing his memoir, considered the vein as lying upon a continuation of the slope of the exposed west country, an opinion to which he was led by the striking resemblance between the contours of the west wall and those of Mount Davidson. Subsequently, from an examination of the character of the west wall, he came to the conclusion[1] that the contact between east and west country was itself a faulted surface. Mr. Church recognized abundant evidence of faulting action, but regarded the contact of the east and west country as continuous with the exposed surface.

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[1] Privately communicated to me.

Evidence of faulting.—The evidence of faulting is manifold. The irregular openings of the vein, the presence of horses, the crushed condition of the quartz in many parts, the presence of slickensides and of rolled pebbles in the clays, are all conclusive on this point. Both to the east and west of the vein, too, the country rock shows a rude division into sheets, and along the partings between the plates evidences of movement are perceptible, decreasing in amount as the distance from the vein increases, according to some law not directly inferable. All the evidence points to a relative downward movement of the hanging wall.

The question of the character of the west wall, whether it is a faulted surface or a continuation of a former exposure of the east front of Mount Davidson, is not to be settled by mere inspection. A cross-section, to scale, taken from Mr. King's maps, shows immediately that while the dip of the lode is 45° or more, the maximum slope of Mount Davidson is about 30°. This fact, taken in connection with the character of the west wall where exposed, indicates that the surface is a result of faulting. A natural surface, too, sloping for a long distance, at an angle of about 45°, is very unusual. On the other hand the coincidence between the contours of the west wall and those of the exposed surface has been recognized from the earliest days of mining on the LODE, and it seems a less violent supposition that the steep face of the mountain passes over into the still steeper wall of the vein, than that the range has experienced an erosion modifying its angle 15° and more, and has still retained the details of its topography otherwise unaltered.

It is plain that the elucidation of the faulting action on the COMSTOCK is a very important structural problem, and that it is most desirable to account quantitatively for the results as well as to prove the existence of a notable dislocation, and no apology is therefore required for presenting to geologists a somewhat detailed discussion of the principles involved.

Action of friction on the surfaces of a single plate.—The most striking and widespread evidence of the faulting is the apparent relative movement on the contact surfaces between more or less regular sheets of the east and west country rocks for a long distance in both directions from the LODE. Each sheet appears to have risen relatively to its eastern neighbor, and to have sunk as compared with the sheet adjoining it on the west. The consideration of a sheet or plate of rock under the influence of friction of a relatively opposite character on its two faces, therefore, forms the natural starting point for an examination of the observed conditions.

Friction a force.—What is called friction[1] is a complex phenomenon which has never been satisfactorily reduced to a mathematical expression, and is perhaps incapable of such a reduction. It is usually regarded as a mere resistance, a force to which the negative sign is indissolubly attached. Professor Reuleaux[2] has insisted upon the incorrectness of this view and has

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[1] It is generally considered that the sensible movements, say of a rough block of stone dragged over a pavement, are of the same character as those involved in the friction of smoother surfaces. On the larger scale it is plain that projections of the moving body will meet those of the underlying surface, and exert a pressure upon them precisely as in the case of the teeth of gearing. When the draught has reached a certain intensity, and when the points of contact are small surfaces, approximately normal to the direction of translation, the projections on one or the other surface will give way, and heat will result. If the areas of actual contact are small surfaces, inclined at a considerable angle, the moving body will rise to surmount them. In falling again a portion of the energy of position will be converted into heat by the impact, but as all bodies are to some extent elastic, the energy of position will not all be dissipated.

If a block of granite is at rest upon a pavement, it assumes the lowest possible position, the maximum number of points of contact are established and the projections on the two surfaces overlap to the greatest possible extent. When the same block is set in motion, the energy imparted to it prevents its settling into maximum contact.

It is plain that the resistance of the block will be greatest at the moment when motion begins, or that the so-called friction of rest is somewhat in excess of the friction of motion. It would also seem that the friction of rest is merely the maximum value of the friction of motion, and such is the result of the recent investigations of Messrs. Jenkin & Ewing. The greater the velocity of the moving body the less thoroughly will the projections of the two surfaces interlock; on the other hand, points which at a low velocity would meet one another nearly in vertical lines, will at high velocities meet on a line considerably inclined, and the horizontal component of the elastic force developed by impact will act as a resistance. Morin took the elasticity of carriage springs into consideration in determining the resistance of a pavement to the passage of vehicles. It appears to me that it must also enter into the true expression for the coëfficient of friction. The excess of the friction of rest over that of motion is evidently due in part to the fact that when at rest the energy of position which must be overcome is at a maximum, while after motion has set in a portion of this energy is elastically returned to the moving body. Besides those elements of friction which have been mentioned, adhesion also undoubtedly plays a part, at least in the case of very smooth surfaces.

The following deductions from the experiments of Coulomb and Morin are approximations only:

(1.) Friction is proportional to the pressure normal to the contact of the rubbing surfaces.
(2.) It is independent of their extent.
(3.) It is independent of their velocity.

According to Rankin the excess "of friction of rest over the friction of motion is instantly destroyed by a slight vibration." A vibration of course develops the elastic force.

The friction of lubricated surfaces appears to me wholly different from that of dry ones. A shaft should not come in direct contact with its bearing, and the work done would seem to consist in a very active stirring of a thin layer of oil. The amount of this work will be dependent on the adhesion of the lubricator to shaft and bearing as well as upon the geometrical character of the solid surfaces.

[2] The Pneumatics of Machinery, by F. Reuleaux, translated by A. B. W. Kennedy, p. 595. The translator states that similar views are maintained in Bell's Experimental Mechanics, a work I have not met with.

given instances from which it appears certain that friction, like other forces, may cause or accelerate motion as well as retard it. He does not, however, explain how positive forces result from friction.

Transmission of energy by friction.—Material surfaces are distinguished from mathematical planes by the presence of minute projections and depressions. If a material sheet W is forced to move over a sheet P_1, the projections interlock, and if the sheets are prevented from moving in the direction of the normal to their contact plane, the projections must either be ground off or be bent and compressed. If W begins its motion with a fixed quantity of energy, and if P_1 is fixed, the entire energy will ultimately be expended in heat, sound, etc., on the contact. But if P_1 is movable a portion of the energy of W will be communicated to P_1, because the projections on the under surface of W exert a pressure on those presented by the upper surface of P_1, which is either in the direction of the motion of W or which may be resolved into two pressures, one of which is in the direction of the movement and the other normal to the contact plane.

Distribution of energy through a system of sheets.—If P_1 is in contact with a third plate or sheet P_2 the energy received by P_1 will be expended wholly or in part in overcoming the resistance on the contact P_1 P_2. If these sheets are the earlier members of a series of sheets W, P_1, P_2, P_3, ... , of indefinite number, then each sheet which moves will communicate a certain amount of energy to the next, and since the resistance of friction is proportional to the distance through which it acts, each sheet which receives energy from its predecessor must move.

The velocities of moving sheets may be treated as uniform.—Suppose a system of equal sheets of indefinite extent vertically arranged and terminated at the top by the horizontal plane A B. Let the system be under a compressive horizontal pressure. If, through the action of some external force, W rises through a distance b, it will communicate a certain energy to P_1, which will in turn impart energy to P_2, and so on. Since the sheets are in all respects alike and the pressure at each contact is the same, the frictional resistance or negative force at each contact will also be the same, while, as more or less vibration must always accompany faulting, the friction of quiescence does not need to be taken into consideration; but as energy is dissipated at each contact, the velocity of the sheets will not be equal. According to Morin's law, however, the truth of which will be assumed, the frictional resistance is independent of the velocity. The sheets will start and stop

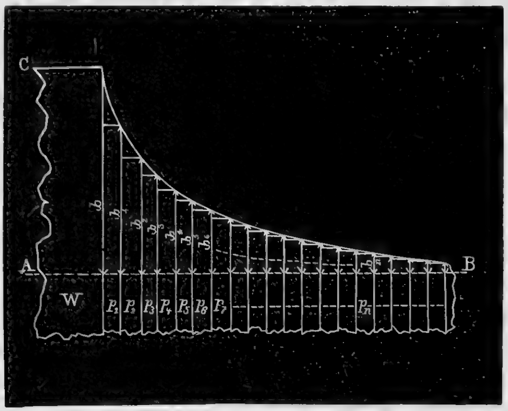

FIG. 3.—System of equal, vertical, movable sheets.

at the same instant, and there is no error, except that inherent in Morin's law in supposing each sheet to move throughout its path at a uniform velocity.

Ratio of the movements of sheets.—Let the total movement of P_n be b_n and its entire movement up to a given instant be y_n. Then, since the velocities may be regarded as constant,

$$\frac{y}{y_1}=\frac{b}{b_1}=C_0$$

and

$$\frac{y_n}{y_{n-1}}=\frac{b_n}{b_{n-1}}=C_n;$$

or the ratio of the movements of any two adjoining sheets is constant. Since each sheet controls the movements of all its successors, of which there are supposed to be an infinite number, each sheet bears the same relation to those which follow it. If the first n sheets were rejected and P_n were forced to move through a distance b, P_{n+1} would move through a distance b_1. Hence

$$\frac{y_n}{y_{n+1}} = \frac{b}{b_1}$$

and

$$C'_0 = C'_n = m;$$

or the movements of any two successive sheets are in the same constant ratio;

$$\frac{b}{b_1} = \frac{b_1}{b_2} = \dots\dots = \frac{b_n}{b_{n+1}} = \dots\dots = m. \qquad (1)$$

Hence, too,

$$\frac{b_n}{b_{n+c}} = m^c.$$

Locus of the edges of sheets.—If BC is taken as the x-axis of the locus of the edges of the sheets and WP_1 as the y-axis,

$$\frac{y_x}{y_{x+dx}} = \frac{y}{y+dy} = m^{dx},$$

or

$$\frac{dy}{y} = 1 - m^{dx} = -\ln m dx;$$

whence

$$y = Am^{-x}, \qquad (2)$$

which is the ordinary logarithmic curve and the equation of the locus of the projecting edges of the sheets. The locus of the other edges found at the reëntrant angles is

$$y = Am^{-(x+1)}.$$

Modification for case of a finite number of sheets.—In any natural or experimental case the number of movable sheets will necessarily be finite. The locus which will be formed if P_n is fixed, can be obtained by supposing that after the infinite curve

$$y' = Am^{-x}$$

has been formed, P_n and all its successors are forced back to their original position on the line AB. Each sheet from W to P_{n-1} would then be drawn down through a certain distance, which can readily be shown to be given by the equation

$$y'' = b_n m^{x-n} = Am^{x-2n}.$$

The locus actually assumed will therefore be

$$y = y' - y'' = Am^{-x} - Am^{x-2n} = Am^{-x}(1 - m^{2(x-n)}).$$

Comparison of the two loci.—The variation of this equation from the logarithmic curve is great when the number of movable sheets is small, but when this number is great the effect of y'' on the locus is imperceptible. If, for example, $m = 1.4$ and $n = 25$,

$$b_n = Am^{-n} = A\ 1.4^{-25} = 0.00022A,$$

which on ordinary scales would be scarcely visible. The value taken for m is one which has been noted in experiments to be described on a succeeding page. If $0.0001A$ is regarded as a negligible quantity, then the locus of the edges of the sheets may be regarded as coincident with the logarithmic curve $y = Am^{-x}$ when for the first fixed sheet P_n

$$n > \frac{4}{\log m}.$$

Logarithmic distribution of energy.—The force exerted at each contact of a system of sheets is that of friction, and when the friction is uniform throughout the system, only the distance through which the force acts at each contact varies with its distance from the first contact. If on the contact $P_n\,P_{n+1}$ the surfaces are such as to present a greater or smaller number of opposing projections per linear unit than exists upon other contacts, the force or friction would also differ. But the energy received by P_n would be unaffected by this difference, and the ratio of the energy expended upon the contact $P_n\,P_{n+1}$ to that transmitted to subsequent contacts will depend not upon the number of projections but upon the physical (elastic) properties of the material of which the sheets are composed. By Morin's law the friction, and therefore also this ratio, are unaffected by the velocity, and the same amount of work will consequently be done on the contact $P_n\,P_{n+1}$ as if the friction were the same as on other contacts. If the whole energy applied to the system is E, and if the frictional resistance on the successive contacts is f, f_1, f_2, etc.,

$$E = f(b - b_1) + f_1(b_1 - b_2) + \ .\ .\ .\ + f_n(b_n - b_{n+1}) + \ .\ .\ .$$

The absolute movements of the sheets will be dependent upon the total energy and upon the different resistances, and so also will be the curve or broken line assumed by the edges of the sheets; but any term

$$f_n(b_n - b_{n+1})$$

is dependent only upon E. If w is the work done on any contact,

$$w_n = f_n (b_n - b_{n+1}),$$

and if L denotes the work done on the first contact, WP_1, the general equation for the work on all contacts is

$$w = Lm^{-x};$$

or the distribution of energy is logarithmic however the friction may vary, so long as the material composing the sheets is the same throughout the system, and supposing friction independent of velocity.

Morin's law is merely an approximation, but should an exact relation be discovered between friction and velocity it would be an easy matter to give the variation of the friction its proper weight in the equation for a faulted surface.

Locus of edges of sheets when the friction varies regularly.—Cases may readily arise in which the friction varies regularly from contact to contact, as would happen for example in a system of sheets between which the pressure was produced by the weight of the sheets themselves. Suppose the case of friction increasing from f at the contact $W\,P$ by a small increment ft. Then for any distance x from the origin, the frictional resistance will be $f(1+xt)$. If dx is the thickness of a sheet, the relative motion at x will be dy and the work done $f(1+xt)\,dy$. If the friction were constant and equal to f, the work done on the same contact would be derivable from an equation, say

$$y_1 = Am^{-x},$$

and would amount to

$$f\,dy_1 = -fA \ln m\, m^{-x}\, dx;$$

and since it has been shown that the work on any contact is independent of the frictional resistance,

$$f(1+xt)\,dy = -fA \ln m\, m^{-x}\, dx;$$

or

$$y = -A \ln m \int \frac{m^{-x}\,dx}{1+xt},$$

which is not integrable when $m > 1$.

Approximate equation.—If the pressure is produced by the weight of the sheets and if these are numerous, t is a very small quantity and its square may sometimes be to the senses a vanishing quantity. When this is the case the equation

$$y=\frac{Am^{-x}}{1+xt}$$

sensibly represents the locus. For the value of *w* may be written

$$\Delta yf\,(1+xt)=f\,(b-b_1)\,m^{-x}$$

or

$$\Delta y=\frac{b-b_1}{1+xt}m^{-x}=\left(\frac{b}{1+xt}-\frac{b_1}{1+xt}\right)m^{-x},$$

while the approximate equation gives

$$\Delta y=\left(\frac{b}{1+xt}-\frac{b_1}{1+\frac{xt}{1+t}}\right)m^{-x};$$

and since

$$1+\frac{xt}{1+t}+\frac{xt^2}{1+t}=1+xt,$$

the two equations give the same results, if t_2 is inappreciable.

It has already been pointed out that, since the distribution of energy is logarithmic, the sum of the relative movements is dependent on the variation of the friction. If therefore the friction is a minimum at the contact $W\,P_1$, a greater amount of energy will be required to move W through a distance A than if the friction were constant. The total energy required will be the same as it would be if each relative movement took place by itself. Assuming the approximate equation deduced for this case, it can readily be shown that, if W moves a distance A, the total energy required by the system is

$$fA\left(1+t\sum_1^x\frac{m^{-x}}{1+xt}\right).$$

Since there is nothing essentially positive in the nature of t, all the foregoing equations become applicable to the case of a decreasing frictional resistance by merely reversing the sign of t. Landslides might furnish cases of this character. Suppose a mass of material divided into sheets resting on a hillside, and that through weakened coherence the mass descended such a distance as might be necessary to do a work $f\,A$ on the contact $W P_1$. This energy will be distributed through the system, and were the friction uniform the resulting curve would be a simple logarithmic one. But as the friction will decrease towards the surface, the locus will be approximately

$$y = \frac{A m^{-x}}{1 - xt}.$$

To produce this configuration, however, an energy of only

$$f A \left(1 - t \sum_1^\infty \frac{m^{-x}}{1 - xt}\right)$$

is required, and the system will consequently reach it with a *vis viva*

$$f A t \sum_1^\infty \frac{m^{-x}}{1 - xt} = f A_1.$$

The system will continue its movement till this energy is expended and its final configuration will be

$$y = (A + A_1) \frac{m^{-x}}{1 - xt}.$$

Experimental verification.—If the various assumptions made are correct, a fault under certain conditions will result in a surface, a vertical section of which at right angles to the strike of the fault will present a logarithmic curve. Before proceeding to any further deductions, it is evidently desirable to test the correctness of the postulates experimentally. I have supposed the sheets of rock of infinite size as compared with their exposed margins, because on this supposition the pressure per unit of area of each parting will be the same. If the plates were thoroughly flexible, and if the pressure were applied on a limited zone parallel to the croppings and removed by a distance greater than b from either end of the plates, then the pressure exerted on each plate would be the same, and would be distributed over an equal area, and the resulting curve would still answer to the general formula deduced. These conditions we can approximately reproduce. If a pile of, say, one hundred slips of very thin, flexible and uniform paper, eight or ten inches long, with sharply cut edges, are laid upon a flat surface, and a narrow weight of three or four pounds is placed across them, the pressure under the weight may be considered as constant.

In the experiments I have made the weight employed was about 5,000 times as great as that of a single slip. If a blunt edge, such as that of a ruler, be now applied at right angles to the longer dimension of the slips, close to the weight, with a light pressure, and be drawn away from the weight a fraction of an inch, a slight relative movement will be perceptible. If this application of energy to the system be repeated a score of times, the ends of the pile of slips will be found to form a curved surface instead of a plane[1] If the frictional resistance is proportional to the pressure, this curve must sensibly coincide with that given by the equation

$$y=\frac{Am^{-x}}{1+xt},$$

for $t^2=\frac{1}{5000^2}$, and will altogether escape detection. The thinness of the paper considerably obscures the character of the curve, but there is no error in principle involved in plotting it on the assumption that the sheets are of any thickness which may seem best adapted to bring out its geometrical relations. For the given increment the curve will approximate pretty nearly to the simple logarithmic curve. For the one hundredth-contact the latter would give

$$y_1=Am^{-100}$$

and the equation for increasing pressure

$$y=\frac{Am^{-100}}{1+0.02},$$

or

$$y_1=1.02\,y.$$

Unless the experiment is carried on until the lowest movable sheet has traversed a sensible distance, the original position of the edges of the sheets marked by the fixed slip gives the asymptote of the original curve. Fig. 4 on the next page shows a curve AB plotted from experiment with its asymptote, and a logarithmic curve CD of the form $y=Am^{-x}$ plotted from its equa-

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[1] I noticed long since that pressmen in printing offices, by drawing the thumb-nail across a pile of sheets, force each of the upper sheets to project beyond the one next beneath it, so that one sheet at a time can be removed conveniently and without delay. I observed that a regular curve resulted, but presumed that it was a conic section. Having satisfied myself analytically that the curve produced by faulting was logarithmic, this observation recurred to me as a means of testing my results experimentally.

tion. The deviation is exceedingly slight, and the experimental curve stands almost as well as the other the very delicate constructive test of the equality of subtangents.[1]

Variations of the experiment.—The slips I have employed are of a nearly uncalendered paper. If for one of them a highly glazed slip is substituted a comparatively large relative motion takes place on its surfaces, but the only visible effect which the introduction of such a slip produces on the locus of the others is a dislocation at the point where it is inserted. There is in fact no evidence that the work done on any contact is altered by the introduction of a contact offering a smaller frictional resistance.

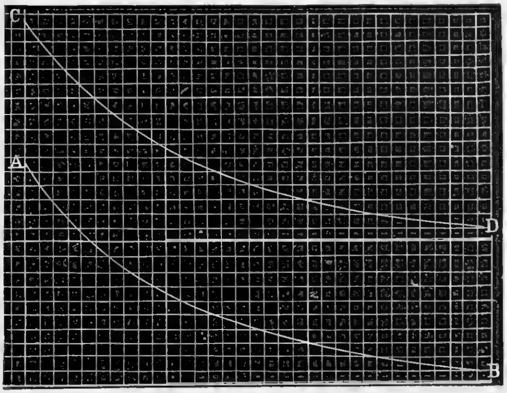

FIG. 4.—Calculated and observed curves.

If the ends of the slips at the beginning of the experiment occupy an inclined instead of a vertical plane, the result is a logarithmic curve referred to axes inclined at the same angle In plotting it is well to reject the upper three or four slips, because these are principally affected by inequalities in the application of pressure and draught.

By employing a system of from three to ten slips of heavy writing paper, using a thick pad of blotting paper for a support, and applying the

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[1] Such an experiment forms a check upon the theory, but does not furnish absolute proof of it, because arcs of other curves, known or unknown, might be constructed which would agree very closely with the experimental result. Among familiar curves, that presenting the greatest general similarity to the logarithmic curve is the hyperbola referred to its asymptotes, and a hyperbolic arc very closely agreeing with the experimental curve can be calculated. But the experiment gives the position of the asymptote which for the nearest hyperbolic arc would occupy a distinctly different position, and the supposition that the curve was hyperbolic would also lead to seemingly untenable hypotheses as to the communication of energy. All that can be claimed, however, strictly speaking, is that the theory accounts for the facts within the limits of the errors of observation, and that no other equally plausible explanation of the facts has suggested itself to me.

draught with great care, the locus

$$y = Am^{-x}\,(1 - m^{2\,(x-n)})$$

can be produced on such a scale that both its elements are sensible.

Reduction and interpretation of the equation.—A few data as to the computation and representation of the logarithmic curve may be of use to those who have to do with special cases of faulting, either technically or geologically.

Equation referred to the cropping as origin.—In the form of the equation deduced,

$$y = Am^{-x}, \qquad (1)$$

the curve is referred to its asymptote and the fault line as axes. In ascertaining the value of the constants applicable to any given surface, however, it will be more convenient to refer it to the fault line and a line perpendicular to the latter at the point where it reaches the earth. If the fault dips at 90°, and if the original surface was level, the equation will then be

$$y = A\,(m^{-x} - 1) \qquad (2)$$

If the original surface was not horizontal, but formed an angle ϑ with the x-axis, then retaining the same axes each y will be diminished by $x \tan \vartheta$, and the equation becomes

$$y = A\,(m^{-x} - 1) - x \tan \vartheta; \qquad (3)$$

and in this case the asymptote of the curve would still cut the y-axis at $-A$, but would make an angle ϑ with the x-axis or would be parallel to the original surface. Since the angle ϑ merely expresses the relative directions of the x-axis and the original surface, this equation is general, and applies, whatever may be the dip of the fissure and whatever may have been the slope of the original surface. If β is the dip of the fissure and δ is the slope of the original surface, we also have

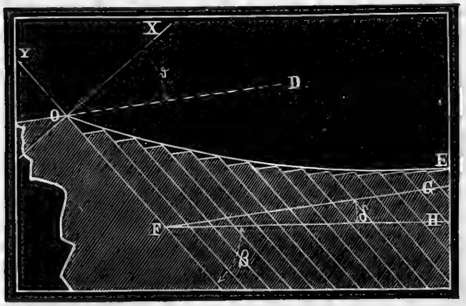

FIG. 5.—$y = A(m^{-x} - 1) - x \tan \vartheta$.

$$\vartheta = 90^\circ - \beta \pm \delta,$$

in which δ has the positive sign if the surface sloped in the same sense as the fissure plane, and the negative sign if the dip and the slope were in opposite directions.[1] This formula therefore makes it possible to reconstruct the original surface, in so far as it is unmodified by other causes.

Reduction of equation to simplest form.—Equation (3) is the most convenient form for the calculation of the constants involved, because the direction of the y-axis, and commonly also the position of origin, can be directly observed,[2] but for plotting and for some purposes of discussion the equation can be advantageously reduced to another form. The equation of the asymptote is

$$y+A=x\tan\vartheta.$$

If, therefore, we refer equation (3) to the intersection of the asymptote and the y-axis and adopt the asymptote as a new x-axis, (3) will reduce to the form

$$y_1=Am^{-x_1}.$$

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[1] I have preferred to characterize these angles in this way rather than to adopt the ordinary but not universal convention as to positive and negative angles, because this is a discussion of structural geology. The mathematical question involved is simply whether β and δ lie in the same quadrant or in adjoining ones.

For similar reasons common logarithms instead of natural logarithms have been used in all formulas, the direct applicability of which to natural occurrences renders it possible that computations may be based upon them.

[2] In computing the logarithmic curve which most nearly applies to a given surveyed section line it is necessary to know the dip of the fissure and the position of three points on the surface relatively to the rectangular coördinates the origin of which is the cropping and the y-axis the dip-line. The computation is greatly simplified by so selecting the arbitrary values of x (x_1, x_2, x_3) that $x_1=\frac{1}{2}x_2=\frac{1}{4}x_3$. The three equations then become

$$y_1=A\left(m^{-x_1}-1\right)-x_1\tan\vartheta;$$
$$y_2=A\left(m^{-2x_1}-1\right)-2x_1\tan\vartheta;$$
$$y_3=A\left(m^{-4x_1}-1\right)-4x_1\tan\vartheta.$$

Solving these equations for the three constants, it will be found that

$$\log m=\frac{-\log\left(\sqrt{\frac{2y_2-y_3}{2y_1-y_2}}-1\right)}{x_1};$$

$$m^{-x_1}-1=\sqrt{\frac{2y_2-y_3}{2y_1-y_2}}-2;$$

$$A=-\frac{2y_1-y_2}{\left(m^{-x_1}-1\right)^2};$$

$$\tan\vartheta=A\,\frac{\left(m^{-x_1}-1\right)-y_1}{x_1}.$$

Mere inspection also shows that

$$x_1 = x \cos \vartheta,$$

and the equation referred to the inclined coördinates indicated will be

$$y = Am^{-x \cos \vartheta}. \qquad (4)$$

By a proper selection of a unit and by removing the origin to a different point on the x-axis according to well known rules of analytical geometry,[1] this equation may be reduced to the form shown in Fig. 6,

$$y = 10^{-x}, \qquad (5)$$

or

$$x = -\log y;$$

and the points on the curve may be directly plotted from a table of logarithms. The curve evidently cuts the y-axis at the point where y is equal to the natural unit $\frac{1}{h}$, found as indicated in the foot-note. If the equation were plotted on rectangular coördinates, $\frac{1}{h}$ would also be the constant value

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[1] As the COMSTOCK LODE excites a lively interest in many localities where books of reference are rare, it may be a matter of convenience to some of my readers to give this reduction in full.

Let

$$h = \cos \vartheta \log m,$$

or

$$10^h = m^{\cos \vartheta};$$

then introducing this value into (4), we have

$$y = A\,10^{-hx}.$$

Let the origin be transposed on the x-axis by a quantity a, yet to be determined; then

$$y = A\,10^{-h(x+a)} = A\,10^{-hx}\,10^{-ha}.$$

Now let

$$a = \frac{\log h + \log A}{h}.$$

The introduction of this value brings the equation to the form

$$hy = 10^{-hx},$$

because for the chosen value of a

$$A\,10^{-ha} = \frac{1}{h}.$$

If, further, $\frac{1}{h}$ is taken as the unit and x and y are each multiplied by it, we get

$$y = 10^{-x}.$$

of the subtangent, and the curve would cross the y-axis at an angle of 45°; but this is not the case when the equation is interpreted on oblique coördinates.

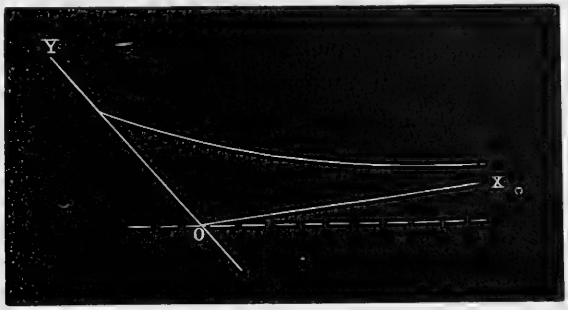

FIG. 6. $y = 10^{-x}$.

Point of minimum radius of curvature.—The position of the y-axis of the logarithmic curve depends upon the unit chosen. There is, however, one fixed point on the locus, that of minimum radius of curvature. This must be deduced from the general equation referred to rectangular coördinates (3), and the value of x corresponding to it is

$$x_0 = \frac{\log(4\,A \ln m) - \log(\sqrt{8 + 9\tan^2\vartheta} - \tan\vartheta)}{\log m}.$$

From this formula the value of x_0 for all simpler cases can easily be derived. For the simplest equation, viz:

$$y = \varepsilon^{-x},$$

$$x_0 = \frac{\ln 2}{2} \text{ and } y_0 = \frac{1}{\sqrt{2}}.$$

Spacing of contours.—As the topography of a country is usually represented for geological purposes by contours, it would be interesting to discuss the spacing of the contour lines on a map of a faulted surface. For an originally level surface and a vertical fault we have immediately

$$\Delta x = \log y - \log(y + \Delta y);$$

in which Δx is the variable horizontal interval between contour lines and

$\varDelta y$ the constant vertical difference between contour planes. But the equation for the case of an oblique fault is so complicated as to be of no value. The ideal map would be one in which the contour planes were so close that $\frac{\varDelta x}{\varDelta y}$ would be sensibly equal to $\frac{dx}{dy}$; and, indeed, where the slope is considerable this is often the case, but when the surface-line becomes nearly horizontal the difference between the two ratios is large.

Angle of tangent to the horizonal.—The angle which a tangent to the curve

$$y = 10^{-x}$$

referred to inclined coördinates makes with the horizontal may be found as follows, without going through a troublesome transformation of coördinates. Let dx and dy be the differentials at the point of tangency obtained from the above equation, and dx_1 and dy_1 the differentials for the same point if the y-axis were vertical and the x-axis horizontal. Consider β as a positive acute angle and δ also as a positive acute angle when it falls in the same quadrant with β, but as negative when it falls in an adjacent quadrant. Let α be the angle which the tangent makes with the horizontal. Then, as appears from the figure,

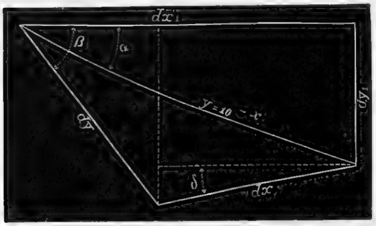

FIG. 7.—Explanation of a faulted surface.

$$\tan \alpha = -\frac{dy_1}{dx_1},$$

and the equation of the curve referred to inclined coördinates gives

$$y \ln 10 = -\frac{dy}{dx},$$

and by a simple projection

$$\tan \alpha = \frac{-dy \sin \beta + dx \sin \delta}{-dy \cos \beta + dx \cos \delta};$$

or by reduction

$$\tan \alpha = \frac{y \ln 10 \sin \beta + \sin \delta}{y \ln 10 \cos \beta + \cos \delta}.$$

If δ is a minus angle (the case shown in the figure) the curve will be horizontal when

$$-\sin\delta = y \ln 10 \sin\beta,$$

or when

$$y = \frac{-\sin\delta}{\ln 10 \sin\beta};$$

but if δ is a positive angle (falling in the same quadrant with β) the curve will have no horizontal tangent.

Fault involving double curvature.—As has already been pointed out, since gravity is likely to be an insignificant force compared with other forces acting on the sheets of a faulted country, it is a matter of indifference whether we regard the actual motion of the foot wall as upward or that of the hanging wall as downward. If, therefore, contrary to the assumption thus far made, the foot wall instead of the hanging wall were divided into sheets, and if the latter were to sink relatively to the former, we should get a reversed logarithmic curve asymptotic to the original surface of the foot wall; and other things remaining equal, its equation would be

$$y = A\,(1 - m^x) + x \tan\vartheta.$$

If the rock on both sides of the fissure is the same, or possesses the same physical properties, and is divided into plates of the same thickness, the energy brought to bear at the fissure will be distributed in both direc-

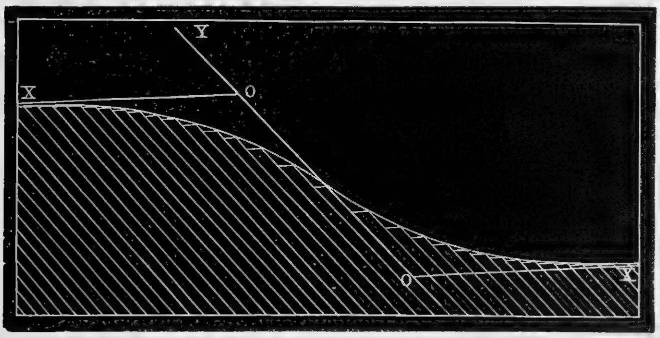

FIG. 8.—Double fault curve.

tions on the contacts between the plates, and the cross-section of the country will show two logarithmic curves with a common tangent at the origin in Fig. 8. Each curve can of course be reduced to the form

$$y = \pm 10^{\mp x}.$$

Case involving different rocks.—If the fissure were on a contact between two different rocks, the one might be divided into thinner plates than the other, and they might have different coefficients of friction. If the coefficient being the same the thickness of the plates varied, the origin would remain unchanged, but the curves would be different. The curvature depends on the throw of the fault and on the number of partings, and it can readily be shown that the natural unit of the curves formed will be proportional to the thickness of the sheets of rock. The two curves will therefore not have a common tangent. Conversely it is evident that the relative thickness of the sheets is calculable from the observed curvature, but the absolute thickness of the one or the other is a matter of observation. If the coefficients of friction are unequal, the inequality will manifest itself only at the contact, for the fundamental equation of condition

$$\frac{f(b_n - b_{n+1})}{f(b_{n+1} - b_{n+2})} = \frac{b_n}{b_{n+1}}$$

is independent of f so long as f is constant. The curves, however, will not be continuous with one another. There is reason to suppose that, at least between similar rocks, the difference of the coefficients of friction is very small.

Faulting accompanied by formation of parallel fractures.—If a fault takes place on a fissure in otherwise solid rock, and if lateral pressure accompanies the dislocation, a great amount of energy will be brought to bear at the fissure. If, as before, the foot wall is supposed to rise, the hanging wall as a whole may be regarded as a fixed mass either from its cohesion with the surrounding country, or from the indefinite amount of inertia which it opposes to movement. As has been shown earlier in this chapter, friction is a force which produces motion as well as destroys it, and Professor Reuleaux is doubtless correct in asserting that motion always results from friction, although it may be "only as small alterations of form in the body acted upon" Rocks are by no means absolutely rigid or absolutely inelastic, and under the conditions supposed a strain must be produced in the hanging wall. Sedimentary strata, and especially the coal measures, furnish innumerable known examples of this action, indicated by the permanent flexure of the ends of the strata as indicated in Fig. 9. This is of course a familiar fact which has from time immemorial furnished miners with a practical rule for recovering the seam beyond a fault.

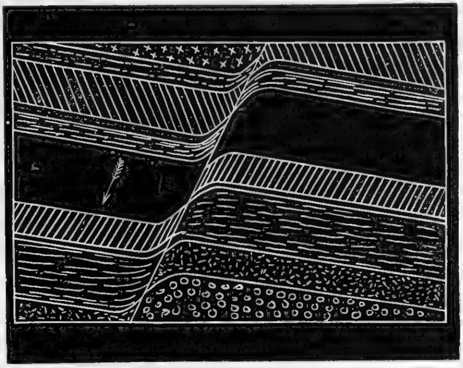

FIG. 9.—Fault accompanied by a strain.

When a fault takes place in the comparatively rigid massive rocks a similar strain must also be produced. Its effect will depend upon its intensity and on the elastic properties of the rock. These latter are so little known that it is scarcely worth while to investigate the conditions mathematically, but it is certain that if the strain surpasses a limit defined by the cohesion of the rock, a sheet of the latter will be sheared off from the main mass. If the compression attending a fault in a massive rock is very great, and if the rock is very rigid, this action may be repeated indefinitely, and either or both walls may be divided into sheets of nearly equal thickness and divided by partings nearly parallel to the original fissure. On the other hand, if the stress does not reach the ultimate cohesive resistance of the rock, the energy must be expended in heat and a strain which will be permanent or not as the rock is elastic or inelastic.

Evidence furnished by observation.—In coal mines there is abundant evidence of permanent strains produced by faulting. In massive rocks a division into sheets sometimes accompanies faulting, but it might be asserted that the two phenomena were unconnected. A very unobtrusive structural action serves, however, to establish a relation. In hilly regions where the soil is deep, small landslips are common during wet weather, often involving the movement of only a few square rods of ground for a few feet. The material in this case is far from rigid, but on the other hand it possesses a minimum of elasticity. I have examined hundreds of such slips in the Contra Costa Hills of California, and noted with surprise the fact that they are almost invariably accompained by a separation of the moving mass into sheets far more regular than might have been expected, and parallel to the initial surface of motion.

It does not appear to me that the character of the curve assumed by the edges of the sheets will be affected by the consumption of energy involved in shearing them from the mass of country rock, for the work done at each fracture will be the same and the effect will appear in the constants of the equation, not in the form of the function.

Frequency of compressive strains in faulting.—Dislocations of the earth's surface may no doubt occur under the most various dynamical conditions, and no general law can be laid down as to the presence or absence of tangential pressure. It is evident, however, that the lateral extension of a faulted area is increased by faulting whenever the hanging wall sinks or the foot wall rises. If A is one-half of the total slip measured on the dip of the fissure, the increase of horizontal distance between any two points on the logarithmic surfaces of the rising and sinking countries respectively, so far removed from the fault plane as to occupy positions which are sensibly on the asymptotes of the curves, will be

$$2\,A \cos \beta.$$

It is evident that this increase in lateral extension will be accompanied by lateral pressure and consequent friction, unless the fault is the result of a tangential tensile strain. The general theories of dynamical geology, and the study of sedimentary rocks, however, show that strains in the earth's crust are commonly compressive.

Surface produced when the fissure is a plane.—It has been shown that under certain conditions the surface line of the cross-section at any point of a faulted country will be a logarithmic curve, or a combination of two logarithmic curves. If therefore the fault fissure intersects the earth's plane surface on a straight line, the faulted surface will be that which would be generated by the horizontal movement of the logarithmic curve or curves along the z-axis of the equation

$$y = A\,(m^{-x} - 1) - x \tan \vartheta$$

and in the case of a double curve in an area of a single rock, or of rocks with the same coefficient of friction, this z-axis will be found at an elevation equal to half the vertical distance between the asymptotes of the curves.

Surface produced when the fissure is not a plane.—Commonly, however, the intersection of a fault fissure with the earth's surface is not a straight line, but an undulating or broken one. If we still suppose the original surface of the area a plane, the surface after faulting will be that which would be generated by the movement of the logarithmic curve or curves along the broken or undulating line corresponding to the z-axis, and this line will be the locus of the point of inflection of the double curve. The line corresponding to the z-axis will then be the intersection of a plane parallel to the original surface of the earth with the surface as modified by the fault, and if the original surface was level, the intersection will be a contour. Each inflec-

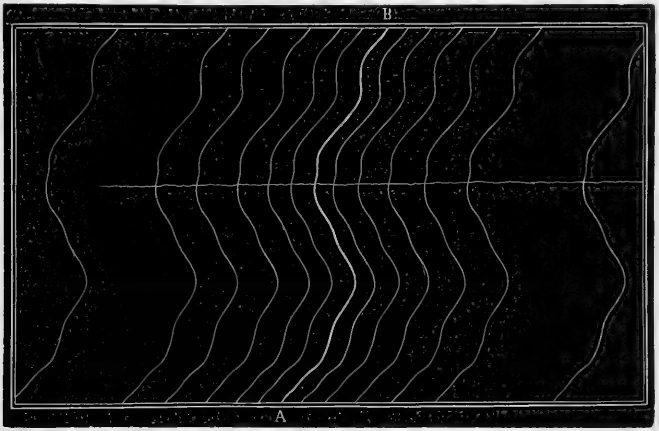

FIG. 10.—Contour map of a faulted surface.

tion of the trace of the fissure on the original surface concave toward the lower country will be represented on the faulted surface by a ravine, and each inflection convex toward the lower country will result on the faulted surface in a ridge.

Fig. 10 shows a contour map of the country shown in Fig. 8, the fissure having reached the original flat surface of the earth on the undulating line AB.

It is evident that if the form of the trace were capable of expression by an algebraic equation, the equation of the faulted surface could be immediately deduced, but such cases are not likely to occur, as deviations of the trace from the right line are probably due to local variations in the physical properties of the rock. Even when the original surface was irregular the same law holds, *mutatis mutandis;* for the locus of the point of inflection of the double logarithmic curve will still be parallel to the trace. The edges of the sheets on each side of the fault will be parallel to the locus of the point of inflection, and where this is a contour they will also be contours.

It frequently happens that the dip-line of a fissure is straight and nearly constant for long distances from the surface, while the strike varies. When this is the case the intersection with the foot wall of a surface parallel to the original surface at any depth below it will give the same line, and if the locus of the point of inflection of the surface curve is a contour, the contour of the foot wall of the fissure at any point will be identical with it and with those of the altered surface, as far as the faulting action extends unmodified.

Fissures into the hanging wall.—The diagrams show at a glance that when a fault takes place under the conditions specified, the rock of the lower country near the fault, as seen in cross-section, assumes the form of a sharp wedge, which is exposed to the same heavy pressure as the rock at greater depths. In an actual case in nature, it is scarcely possible to suppose that this wedge would remain intact. A very slight obstruction to the smooth rise of the foot wall would produce a crack across this edge at some considerable angle to the dip of the fissure, and such a crack might very probably be held permanently open by fragments of rock. Fissures diverging into the hanging wall might not unlikely form at greater depths as well, but would partly close again, leaving behind only openings of limited size, because the pressure and motion of the superincumbent mass would suffice to grind to powder most of the intervening fragments.

Relation of chimneys to surface topography.—If in faulting, the rising country shifts in the direction of the strike of the fissure, of course chimneys will form where the strike undulates. Where the surface is modified by faulting in the manner discussed, such chimneys will always lie on the same side of ravines on the surface, and opposite them will be found crushed ground arising from the pressure of the walls upon one another.

Infrequency of a rise of the hanging wall.—Throughout the foregoing discussion I have supposed that the relative movement of the foot wall of the fissure was upward, according to the well-known empirical rule. Were the reverse case to occur, the resulting curve would still be a logarithmic one, but would be constructed in the acute angle between the fault line and the asymptote parallel to the original surface, and unless faulting has gone on but to a very slight extent, or unless the fault line dips at very close to 90°, the resulting surface will not merely be precipitous, but form a reëntrant curve, and the upper country will overhang the lower (Fig. 11). Countless faults have been formed in past geological eras, the surface indications of which have been utterly obliterated, but there must be a very great number which still exhibit their features in a recognizable form; and if it were a usual thing for the hanging wall to rise, overhanging surface would not form one of the rarest of topographical phenomena.

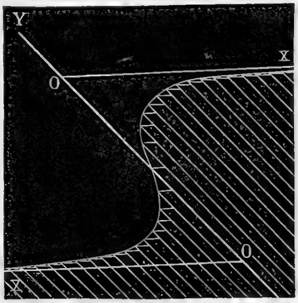

FIG. 11.—Rise of the hanging wall.

Applications of the theory to the COMSTOCK, *and other instances.*—The evidences, already alluded to, of the division of the east and west country of the COMSTOCK LODE into parallel sheets lend probability to the supposition that the faulted structure of the central portion of the vein may come under the conditions which have been explained in the preceding portion of this chapter, and, as a matter of fact, if the *Sutro Tunnel* section be taken as a representative one, it is easy to find a logarithmic curve which shows a close coincidence with the surface. The eastern and western branches of the curve referred to the fault line, and a perpendicular to the fault line at the cropping of the vein are, respectively,

$$y_1 = 1470^{\text{ft.}} \, (1.00161^{-x_1} - 1) - x_1 \tan 44^\circ \, 27',$$

$$y_2 = 1470^{\text{ft.}} \, (1 - 1.00298^{x_2}) + x_2 \tan 44^\circ \, 27'.$$

Knowing these values, the experiment on slips of paper can be modified to obtain a corresponding result. The only change needful is to pile the slips in such a way that their ends instead of falling in a vertical plane will lie in a plane forming an angle of 45° 33′ with the table. The result is a curve, which, when plotted on the assumption of a suitable thickness of the sheets, is indistinguishable from that of one or other of the above equations. Precisely as in the former experiment, too, the position of the asymptote precludes the supposition that the curve is hyperbolic. There is, therefore, very strong reason to believe that the *Sutro* section surface line is composed of two logarithmic curves, and no reason known to me to suppose that it is not.

Atlas-plate VII. shows the surveyed surface line of the *Sutro* section plotted from the contour map, and in the same figure the curve plotted from the equations given above. The same plate also shows the curves represented by the equations plotted by themselves with their axes and asymptotes, and the curve obtained from experiment. By comparing the surveyed line with the surface maps, it will appear that its deviations from the curve given by the equations are the evident results of plainly limited erosion, the section crossing two considerable ravines in the east country, and passing along the flank of another in the west country.

Constants.—The dislocation measured on the dip of the lode is 2 A, or, for the present case, 2,940 feet. The dip of the lode at this section is 43°, and the dislocation measured vertically is therefore 2,005 feet. The angle ϑ is 44° 27′ and δ is therefore 2° 33′, or the original surface sloped contrary to the dip at this angle. The natural unit of the east curve is 2,012 feet, and if the equation is referred to the asymptote and a line parallel to the fault line and crossing the asymptote at 274 feet west of the fault line, it becomes for the natural unit,

$$y = 10^{-x}.$$

The natural unit of the west curve is 1,085 feet, and if it be referred to its asymptote and a line parallel to the fault line and crossing the asymptote at a point 143 feet west, its equation is

$$y = -10^{x}.$$

The equation of the tangent for the *Sutro* section values shows that the horizontal point of the east curve is at 2,840 feet from the fissure measured on a line parallel to the asymptote, and that of the west curve at 1,820 feet measured in the same way. The tangent to the east curve at the fault makes an angle of 26° with the horizontal, while the tangent to the west curve makes an angle of 32°. This sudden increase of inclination immediately west of the croppings is a familiar feature of the landscape in Virginia. Had the diorite been separated into plates of the same thickness as those of the east country, the two curves would have had a common tangent at the croppings.

The position of the points of greatest curvature presents no significant peculiarity, so far as I am aware, and is expressed by a somewhat involved logarithmic function. This point in the east curve is at a distance of 686 feet from the fault plane, measured on the asymptote. In the west curve it lies at 951 feet from the same plane. The values of the minimum radii are 6,640 feet and 3,580 feet in the east and west curves, respectively. These radii are simply and directly proportional to the natural units of the curves.

Topography chiefly due to faulting.—The west croppings of the COMSTOCK, from the *Bullion* to the *Ophir*, are nearly horizontal, and the original surface, as has been shown, sloped to the west at an angle of only two and a half degrees. The theory of faulting propounded would therefore lead one to expect a pretty close agreement between the contours of the faulted slope and those of the west wall; for on the *Sutro Tunnel* section, at least, there is evidence of but slight erosion. Such an agreement appears from a comparison of the horizontal sections with the surface map, and has long been well recognized among those who have had to do with the mines.

The ravines which furrow the range are not therefore the result of erosion, but of faulting. Once formed through the dislocation of the country, they have, of course, received the drainage, and have been modified thereby to some extent.

East vein.—It has been shown that even if a fault takes place on a fissure perpendicular to an original surface, the hanging wall will assume the shape of a sharp wedge, and that under the conditions of pressure necessary to produce a logarithmic surface, it is unlikely that this wedge would remain intact. Such a fracture occurred in the faulting of the Comstock, and opened the famous "east vein", from which a large part of the ore produced has been extracted. Baron von Richthofen regarded this structure as a result of faulting, and as a surface phenomenon. I have simply shown in addition how the east country came to assume the tapering form most favorable to such a fracture.

Origin of the sheeted structure. Theory of eruptive stratification.—The character of the sheets of rock into which the walls of the Comstock are divided is an open question, for one observer has maintained that they form a series of thin, bedded, regular layers of rock, presenting a fine example of eruptive stratification. It is true that in confined spaces in several of the rocks a stratified or laminated texture is visible; but in the half-dozen such cases known to me the phenomenon extends for very short distances, often only a few feet, and appears to be the result of some local variation in the composition of the rock; for not only can I perceive no general uniformity in the direction of the layers in these different spots, but I have a single hand-specimen which shows portions of two sets of them at an angle of nearly 90° to one another. These occurrences, however, cannot be meant in the statement referred to, for they are rare. As applied to the great mass of rock I am also unable to agree with it. To me it is nearly inconceivable that a granular crystalline rock like the diorite of Mount Davidson, containing only crystals of "secondary consolidation," should ever have been sufficiently fluid to permit of eruptive bedding The face of Mount Davidson shows no lamination, though the division into parallel sheets is strikingly apparent. The surfaces of the sheets in the same locality are not similar to those commonly formed by bedding, and are indistinguishable from fractures, nor is the persistence of the sheets comparable with that of sedimentary strata. The *McKibben Tunnel* in Spanish Ravine passes through diorites in part somewhat porphyritic, in part of the dark, highly hornblendic variety. A quartz seam is cut by the tunnel, but no dikes of later rocks. There is a greater superficial resemblance to a bedded structure here than on Mount Davidson, but close examination shows that most of the apparent differences in color and texture are referable to degrees of decomposition. Decomposition has set in from the partings of the sheets of rock, often leaving the central portion of a sheet less affected than its faces. In the diabase, hornblende-andesite, and augite-andesite of the east country, the phenomena are similar. There is ample evidence of fracture and of decomposition following lines of fracture. Sometimes individual sheets or portions of sheets have in a measure escaped decomposition on account of the presence of protecting clay seams and the like, and these have been mistaken for dikes, or flows of andesite or other rock; but careful examination shows that they differ only in the degree to which they have yielded to decomposing agencies, and in no other respect. The partings are not such as we should expect in bedded flows. There is no trace of lamination except the irrelevant local occurrences mentioned, and while it might well be that the greater part of the seams had been reopened by upheaval, it cannot be supposed that no adherent laminæ would escape separation. In short, my observations wholly fail to accord with the hypothesis that these rocks were laid down in horizontal beds, and afterward tilted. Even if observation furnished considerable grounds for such an interpretation of the facts, I should hesitate to accept an explanation which appears to me wholly at variance with what we know of the occurrence of similar rocks elsewhere.[1] The deposition of a single igneous rock over several square miles, in thin horizontal beds, implies a watery fluidity and a very high specific heat. So far as I know only one or two of the later volcanic rocks are

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[1] Mr. Church, indeed, states (*l. c.*, p. 153) that "diorite is one of the fine-grained, thin, running lavas." But he cites no authorities for, or instances in proof of, this statement, which is at variance with the commonly accepted opinion, and with the indications of its composition and micro-structure.

known to flow in such a manner, and these only under exceptional conditions, for even basalt commonly accumulates in large masses around the orifices from which it issues; nor am I aware of any distinct evidence that the granitoid rocks have ever flowed like a lava, or reached a higher degree of fluidity than the plastic state.

Energy displayed in the fault on the Comstock.—We have no means of reducing to known units the pressure and resultant friction which accompanied the faulting action on the COMSTOCK, but the imagination at least may be brought to bear upon the subject by considering the amount of dislocation. If the west country is supposed to have revolved about a distant fixed fulcrum, through a sufficient angle to account for its present relative elevation, then the east country must have been pushed bodily eastward for a distance of 2,150 feet. The maps and sections show that certainly not less than a cubic mile of rock must have been thus driven out of place in spite of all opposition, and the amount of horizontal dislocation involved is not lessened by supposing the west country to have moved instead of the east. Compared with the energy necessary to produce such a movement, that requisite merely to raise each of the sheets composing the mass, in opposition to friction through a mean distance of about 150 feet, certainly seems small.

Dynamical theory of sheets.—I have shown that the tendency of the faulting movement is to separate sheets of rock, and that sheets thus separated will arrange themselves along the logarithmic curve when divided from the mass. The possibility thus presented does not conflict with my observations, and I am led to the belief that the sheeted structure of the east and west country is due to the formation of fractures parallel to the faulting surface, and that these fractures are the result of faulting under intense lateral pressure.

Inferences from the fault as to the age of the Lode.—Some light is thrown upon the age of the COMSTOCK as an ore vein by the relations of the fault to the ore, and to the erosion. The "east vein," being a secondary fissure, cannot have formed till faulting had made considerable progress, while the crushed condition of the quartz[1] and the phenomena attending it show that faulting

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[1] The evidence that the "sugary quartz" is really crushed will be given later.

action has succeeded, as well as preceded, the deposition of the ore and gangue. The regularity of the curve, on the other hand, shows that the original surface line along the *Sutro* section was sensibly straight, and lay on a gentle western slope. The agreement of the contours of the range with those of the west wall and of the cross-sections with the curve obtained from theoretical considerations, proves that the erosion since the commencement of the faulting action is sensible (on a scale of 800 feet to the inch) only where most intensified—*i. e.*, in the ravines. The faulting and the deposition of ore have therefore occurred since the DISTRICT was subjected to any considerable amount of general degradation. The level condition of the country prior to the fault appears to me probably the result of erosion, and if so the DISTRICT must have been a plateau or a high mountain valley—in short, an area of denudation.

Fault probably the result of a rise in the west country.—It is perhaps impossible to demonstrate whether the absolute movement involved in the faulting was the rise of Mount Davidson, or a sinking of the east country. If the east country has sunk, the former level near the middle of the LODE must have been nearly that of Mount Davidson, and the DISTRICT must have occupied the crest of a rather sharp undulation running nearly east and west. If the main movement was an uplift of Mount Davidson, and its neighbors to the north and south, the original general level was about that of the present country east of the LODE. The DISTRICT must then have been near the top of a gentle undulation approximately parallel to the Sierra. The latter supposition accords with the general character of the present topography of the Great Basin area much better than the former, and seems to me much more probable on general as well as local grounds.

Diminution of evidence of fault near the ends of the Lode.—To the north and south of Mount Davidson the evidence of faulting diminishes. From the *Overman* far into the *Sierra Nevada* claim, a distance of two and one-third miles, the amount of fault has been great, and the indications are unmistakable. Beyond these points the disturbance of equilibrium has been to some extent adjusted in a different manner. This is partly indicated on the surface map by the union of the andesite fields, which are separated opposite the middle portion of the LODE by diorites. Towards the ends of the LODE the dynamic action seems to have been distributed in part by a forking of the fissure, and in part by the formation of east-and-west cracks.

Coëfficient of friction of rocks involved in the fault.—The rocks involved in the faulting action on the *Sutro* section are diorite, diabase, hornblende-andesite, and augite-andesite. They must all have sensibly equal coëfficients of friction, for the curve in the western diorite is apparently continuous with that of the other rocks which lie east of the vein, and there is no evidence of discontinuity in the eastern curve as it passes the contacts. All the east rocks, too, appear to divide into plates of the same thickness, while the diorite has split into sheets of less than half that of the others.

Rules applicable to prospecting in uneroded districts.—It is, of course, most unlikely that the Comstock is the only vein in which the deposition of ore is recent, and has been accompanied by faulting, and some conclusions as to the occurrence of veins in such cases may be welcome to some of the readers of this paper.

In a locality modified by faulting action under lateral pressure, the fact will appear in the parallelism of the exposed edges and faces of rock-sheets.

If erosion has not seriously modified the surface resulting from the faulting action, the logarithmic curve will be recognizable to the observer looking in the direction of the strike.

The main cropping of the vein is to be sought at the point of inflection of the curve, which will be found nearly or exactly midway between the top and bottom of the hillside. One or more secondary vein croppings should be looked for below the main cropping, and these, so far as yield is concerned (but not in regard to location of claim), may prove more important than the main cropping.

The dip of the vein will be to the same quarter as the slope of the surface, but, of course, greater in amount. The flatter the surface curve, the smaller the angle of dip will be. The mean strike will be nearly or quite at right angles to the direction of the spurs and ravines of the faulted area.

If besides the movement of one or other wall in the azimuth of the dip, there has been a dislocation in the direction of the strike, chimneys will open, all of them on the same side of the different ravines. Surface evidences will often enable the prospector to determine on which side the chimneys are to be found. On the barren sides evidences of crushing and of closure of the fissure are probable.

The fissure is more likely to have a constant dip (barring the secondary offshoots). than a constant strike; but, of course, irregularities in dip like those in strike will open chambers which may be productive.

Offshoots into the hanging wall may occur at any depth, but none except those near enough to the main cropping to reach the surface, where it has a very considerable slope, are likely to be continuous.

Application of theory to landslips.—Besides the deep-seated fissures produced by profound disturbances of the earth's crust, there are comparatively superficial phenomena which seem to come under the laws deduced in this chapter. In regions where the soil is deep and covered with low-growing vegetation, such as grass, the details of the topography are not molded by the direct action of the rain, but by landslips; oftentimes, indeed, of very small extent, but repeated or increased year after year. The hanging wall of such landslips commonly separates into distinct layers, as has been stated in a preceding paragraph. These sheets must arrange themselves on the locus

$$y = \frac{Am^{-x}}{1 + xt}$$

if the arguments presented on p. 164, *et seq.*, are correct. A yearly repetition of this action, sometimes modifying the hanging wall and sometimes the foot wall of the slips, will eventually give the whole topography a logarithmic character; even the position of the gullies, and consequently the lines of direct erosion, being determined as indicated on page 177. The similarity between some of the logarithmic curves illustrated in this chapter and the slopes of the gently-rounded hills common in grassy regions with deep soil, needs only to be suggested.

CHAPTER V.

THE OCCURRENCE AND SUCCESSION OF ROCKS.

Methods of determining succession.—Determinations of the order of succession of eruptive rocks involve considerable difficulties. Superimposition alone is an insufficient indication of relative age, for intrusions and laccolitic accumulations of younger rocks may underlie older ones. Neither are inclusions of one rock in another always a safe guide. Cases are not unknown where intrusive masses of a younger rock in an older might readily be mistaken for inclusions of an older rock in a younger one. I have even observed instances, though not in the Washoe District, of slabs of older rocks embedded in later eruptions in such a manner that but for other and overwhelming evidence as to the order of succession, they might have been interpreted as dikes of the older rock in the younger. Moreover, when the rocks in question are closely allied, as is very frequently the case, local modifications of one rock may readily be confounded with inclusions of a different but similar species. Such an error is peculiarly likely to occur where there is brecciation. As has been pointed out on page 82, masses of a single rock subjected to partial decomposition may also simulate inclusions or dikes of one rock in another. Thus while at first sight it might appear that dikes and inclusions furnish the most unimpeachable evidence of succession, this class of evidence is peculiarly deceptive except where the rocks are fresh and characteristic, the exposure perfect, and the cases abundant Where any of the rocks are very recent, evidences of erosion form an important argument as to succession, as will be seen from the remarks on the later hornblende-andesite.

No single method of determining the succession of eruptive rocks is ordinarily sufficient, and due weight must be given to all the facts bearing upon their relative age. Difficulties in the determination of succession, however, are not peculiar to the geology of massive rocks; for there are many instances of the reversal of sedimentary strata, and with sufficient care the order of succession of eruptives can generally be established with as much certainty as can that of sedimentary rocks in greatly disturbed areas.

Order of succession.—The order in which the rocks of the WASHOE DISTRICT have appeared upon the surface is as nearly as can be ascertained the following:

Granite,
Metamorphics,
Granular diorites,
Porphyritic diorites,
Metamorphic diorites,
Quartz-porphyry,
Earlier diabase,
Later diabase ("black dike"),
Earlier hornblende-andesite,
Augite-andesite,
Later hornblende-andesite,
Basalt.

It is possible that strata since metamorphosed may have been laid down upon the diorite as well as previous to it. The evidence of the succession of diabase to quartz-porphyry would be more satisfactory if the contact between them were more extensive, and of the age of the basalt there is no direct evidence except that it is later than earlier hornblende-andesite. The other points as to succession are clearly established. One of the most interesting is the occurrence of hornblende-andesite after as well as before augite-andesite, proving a recurrence in the character of eruptions. It thus has a direct bearing upon the general theory of the succession of volcanic rocks. In the following pages some notes are presented on the occurrence and distribution of each of the series.

Granite.—Granite is extensively developed to the west of the Virginia Range, but reaches the surface in the WASHOE DISTRICT only in a single small area near the *Red Jacket* mine, C. D. 6. It occupies a considerable space beneath the surface, however, for it has been met in the *Baltimore* and the *Rock Island,* and by a tunnel, just beyond the limits of the map, to the northwest of the *Florida.*

The granite must fall away very rapidly to the north and east, or it would be encountered in the Gold Hill mines. Whether this is the consequence of a fault or of a steep slope, there is no opportunity for deciding. Near the *Red Jacket* the granite here and there shows partings which might be remains of a former stratification; but a similar system of parallel cleavages is not uncommon over small areas in rocks of an unquestionably eruptive character, and I met with nothing which could be cited as definite proof of a sedimentary origin.

In the *Wales Consolidated,* granite is directly overlain by metamorphic diorite, at the *Rock Island* by schists and limestones, and at the *Baltimore* apparently by eruptive diorite, metamorphics, quartz-porphyry, and augite-andesite. It must, therefore, have been denuded to a considerable extent before each of several eruptions. It is nevertheless far fresher than most of the rocks in the DISTRICT, and no considerable quantity of ore has been found associated with it, though some metalliferous quartz has been met with at its contact with younger rocks; but traces of ore are very likely to occur at any contact in a district like WASHOE, where every point has been racked by dynamical action and the whole subterranean area has been flooded with mineral solutions. It is possible that ore similar to the *Justice* body may be found on the contact between metamorphic diorite and granite south of that mine, but there is nothing to indicate that the granite is likely to act otherwise than mechanically in the deposition of ore.

Metamorphics.—There is a small area of distinctly stratified rocks to the south of American Flat, near the *Florida.* They are limestones and micaceous schists, badly broken and contorted, and much metamorphosed. I did not succeed in detecting anything like a fossil in them, in spite of an earnest search. They are colored as Mesozoic from the general analogy of this portion of the Great Basin, as elucidated by the Exploration of the Fortieth Parallel. In a cut on the American Flat road, just south of the *Florida*, there occur two seams of coal-like matter half an inch in thickness. The metamorphics extend into American Flat under the area laid down as Quaternary, where the detritus is too thick to permit of tracing the contact between the metamorphic and eruptive rocks with certainty. The *Rock Island* shaft is inaccessible, but a careful examination of the dump and the descriptions of an employé leave no doubt that it passed through metamorphics into underlying granite. There is nothing to show that any eruptive rock other than granite has been met with at the *Rock Island*. A little coal is said to have been found well down towards the granite, and was no doubt such an occurrence as that mentioned above. Metamorphics of the same character appear to an insignificant extent north of American Flat, and in the *Caledonia*, as is shown on the section through that mine.

In the Gold Hill mines black slates form the foot wall of the Lode to a large extent. Thin sections made across the lamination show that the dark color is due to absolutely opaque particles without metallic luster, and these disappear on prolonged heating in an oxidizing flame, but are not affected by acids. They are therefore graphite. The rock contains pyrite, which is very irregularly distributed. The slate is often confounded with "black dike" (younger diabase), with which, however, it shares only the black color. In a fairly good light the slaty structure serves to distinguish it without difficulty The diorite at the *Yellow Jacket* appears to overlie these slates, though no single mine-opening shows a contact. The masses of mica-diorite shown in the *Yellow Jacket* section can hardly be in their original position, though very likely they have been transported but a very short distance; but at the surface the dioritic mass is in sight to within a few hundred feet of the *Yellow Jacket*, where it seems to disappear under the andesites, and it is almost impossible to suppose that the great exposure of slates in the *Yellow Jacket* and the *Belcher* is not one surface of a body which extends beneath the neighboring diorite. On the other hand, in the *Caledonia* diorite underlies the metamorphics, and it therefore seems probable that the plastic diorite was forced horizontally between sedimentary masses as well as vertically to the surface or, at all events, to higher points than any now occupied by stratified rocks. Further indications of such a history are observable in the *Sierra Nevada*, where a thin and not very extensive body of highly crystalline stratified limestone is completely inclosed in diorites, which are granular on one side and porphyritic on the other. I am able to offer no better suggestion than that this mass was carried into its present position by the granular diorite, and covered over sooner or later by a porphyritic outflow.

Eruptive diorite.—Besides the dioritic mass forming Mount Davidson and the adjoining hills, there is somewhat obscure surface evidence of a large area of this rock beneath later eruptive masses. Near the *Forman* shaft are several small patches of mica-diorite, which, however, might easily be passed unnoticed; and in the Flowery district, about a mile and a half east of Flowery Peak, dioritic porphyries again appear. Diorites occur in almost all the COMSTOCK mines from the *Silver Hill* north to the *Utah*, and are also found in those of the Flowery region. The dump of the *Lady Bryan*, for example, consists largely of fresh, coarsely granular, quartzose diorite To the west and northwest of Mount Davidson it also appears to be covered by but a thin cap of andesite, so that at least two islands of the older rock are wholly surrounded by the younger. Diorite forms the foot wall of the LODE throughout the Virginia mines and is replaced in this position by metamorphics in Gold Hill. On the hanging wall it is found in the *Yellow Jacket* in masses apparently displaced, and in the *Sierra Nevada* and *Utah* it forms both walls of the fissure which has been mainly explored. Fragmentary masses also appear embedded in diabase at intermediate points but not to an important extent. Before the eruption of the earlier diabase, the diorite no doubt formed a continuous mass, partly overlying and partly underlying the metamorphic strata, and probably extended over the country now occupied by later rocks along the line of the *Sutro Tunnel*. If so, this area has sunk under the subsequent outflows, but how far it is as yet impossible to say, though it is a matter of importance to the future of the LODE. At the time of the faulting the whole west wall in Virginia and Gold Hill seems to have risen, the dislocating tendency having been adjusted towards the ends of the fissure by diverging cracks. This action has moulded the eastern face of the range opposite Virginia City and the northern por-

BULLION RAVINE LOOKING EAST. DIORITE
MT. KATE IN THE MIDDLE DISTANCE

tion of Gold Hill. To the north of the *Union* shaft the porphyritic diorites swing to the northeast. On the surface they disappear under the andesites, while underground the explorations north of the *Ophir* have been almost wholly confined to the dioritic area, and afford no means of tracing the extension of the diorites beneath the cap. Near where the contact between the diorites and the diabase probably occurs are the heavy croppings known as the *Scorpion.* Whether these actually correspond to the contact or not can only be told by exploration; but, if not, that contact has left no trace upon the surface in this region, which would be very remarkable if the deductions made in the last chapter as to the age of the LODE are correct. It is not unlikely that the dioritic rocks are continuous, or nearly so, under the Flowery Ridge, and are thus connected with the occurrences at and near the *Lady Bryan.* Diorite seems to have preceded the quartz-porphyry, for it occurs in the *Justice*, and in the *Caledonia*, beneath the porphyry.

Relations of porphyritic to granitoid forms.—The relations of the dioritic porphyries to the granular mass are interesting. The former are constantly found overlying the granular rock, but a line of demarkation can seldom be drawn, transitions and mixed masses being of constant occurrence. Roughly the area between Bullion and Spanish ravines is granitoid, and the masses beyond these limits porphyritic; but this is a very rude approximation, for fine porphyries occur in the very midst of the mass of Mount Davidson, and granular patches are to be found throughout the hornblendic porphyries. The micaceous porphyries also appear to overlie the hornblendic variety, into which, however, they merge. The conditions suggest a physical explanation Some geologists now believe that the crystalline structure of rocks depends solely on the pressure under which they have consolidated. Such an explanation of the present case, however, seems to me unsatisfactory. The variation in a horizontal direction is nearly as marked as that in a vertical line, and though there is an exposure of at least 2,500 feet, vertically, allowing for the displacement by faulting, the deepest granular diorites are not more coarsely crystalline than those on the top of Mount Davidson. Nor are the other rocks from the bottom of the mines in any perceptible manner different from those collected at or near the surface. The cause of the difference between the granular and the porphyritic diorite, if these rocks are admitted to be of eruptive origin, must, I think, be sought in a period anterior to the extrusion of the mass. The granular diorite is composed of crystals of "secondary consolidation," interlocking grains, the relative position of which cannot have changed subsequent to their formation. This rock must, therefore, have crystallized in its present position, barring, of course, any movements to which it may have been subjected after solidification. The porphyries, on the other hand, are composed of well-developed crystals in a granular groundmass. These crystals must have grown slowly in a magma sufficiently fluid to permit of free movement, and this condition is not likely to have been present after eruption. A state of considerable fluidity is also indicated by traces of brecciation in some of these rocks, and of fluidal structure in the arrangement of microlites in a few slides. But the strongest evidence of a fluid condition is furnished by the little dike close to the *Eldorado* croppings. The walls are granitoid, and the center of the dike is semi-porphyritic, showing green fibrous hornblende and a granular structure, though some porphyritical crystals are imbedded in it. But for an inch from the walls of the dike the rock is a dark, solid porphyry which contains brown hornblendes, and is in all respects similar to the most porphyritic varieties found in the DISTRICT. The contact with the walls is perfect, and the occurrence admits of no natural explanation but that of a hot intrusive fluid.

Hypothesis suggested.—The porphyritical crystals formed before eruption must have sunk to the bottom of the fluid mass, for the specific gravity of hornblende is far greater than the mean density of the diorite, and the relation can hardly have been reversed at the temperature at which they formed. Little as we know of the subterranean conditions of eruption, it is probably safe to assume that the upper portion of a fluid or plastic mass would be extruded before the lower, and that the portion holding the porphyritical crystals in suspension would be the last to appear. The dike of porphyry between granitoid walls already referred to seems to show that this was the case, while the frequency of transitions is evidence that the extrusion was a nearly continuous process. The granular groundmass of the porphyries is finer-grained than the granitoid rock, but this does not necessarily prove that it cooled under different conditions, for a certain difference in chemical composition would almost inevitably accompany the supposed separation by specific gravity; and besides the porphyritical crystals, other more minute solid particles would probably also sink, and tend to the multiplication of centers of crystallization.

Possibility of a metamorphic origin.—While the evidences of the eruptive character of this diorite are tolerably strong, they are not so conclusive as to exclude a consideration of the possibility that the rock may be metamorphic. As has been shown in Chapter III., one variety of the metamorphic diorite is almost indistinguishable *per se* from the rock of Mount Davidson, and another variety of the latter is distinctly brecciated. It is exceedingly difficult, if it is not in the present state of knowledge impossible, to comprehend how the formation of pure and sharply developed crystals can go on in media not sufficiently mobile to be regarded as fluid; yet we know that tourmalines, garnets, and other minerals are sometimes beautifully developed in metamorphic rocks, which have not only retained their lamination, but have offered an efficient resistance to the pressure of thousands of feet of overlying strata. Most of the indications of the eruptive character of the Mount Davidson and Cedar Hill diorite, taken singly, are thus not absolutely incompatible with a metamorphic origin. But until the origin of the granitoid rocks has been more satisfactorily elucidated than heretofore, it is certainly the duty of the geologist, while giving possible alternatives due weight, to judge each occurrence on its own merits, and to seek explanations in comprehensible processes, rather than through unexplained analogies. At present an eruptive origin can alone be regarded as probable for the WASHOE diorites.

Metamorphic diorite.—The grounds for considering the metamorphic diorite as such, have already been given. It is a very puzzling rock in the field, and may readily be mistaken in different occurrences for granite, diorite, augite-andesite, or basalt. Wherever the underlying rock is exposed it is sedimentary, except at the *Wales Consolidated*, where the metamorphism has penetrated to the underlying granite. It is also associated in the most intimate way with the quartz-porphyry, and does not appear between the stratified rocks and eruptive diorite. If the area occupied by the quartz-porphyry were made continuous, it would completely cover all the metamorphic diorite in the DISTRICT; and the evidence is tolerably strong that the metamorphism is due to the action of the porphyry on the strata over which it flowed. Metamorphic diorite occurs on the COMSTOCK only at the extreme south end, in the *Silver Hill* and *Justice* mines. Mines have been sunk in it south of Silver City—for example, the *Amazon*—and have struck ore which was calcareous and carried mixed sulphurets. The *Justice* ore associated with this rock was of a similar character.

Quartz-porphyry.—The quartz-porphyry which appears on the map is merely the northeasterly corner of an extensive area of this rock. A noticeable peculiarity is that it is everywhere decomposed, and everywhere to almost precisely the same degree, while it is fissured only to a very slight extent. It seems scarcely possible that this decomposition should have taken place from below, for the underlying granite and metamorphic diorite are for the most part very fresh. The decomposition would seem rather the result of the action of surface waters, favored by a porous structure. This structure is perhaps due to the unequal contraction of quartz and feldspar in cooling. Before later eruptions covered it, the porphyry occupied the surface for a considerable distance farther to the northeast than at present, for it appears in the *Belcher* ground and in the *Forman* shaft. In both these cases it underlies hornblende-andesite, while in the *Belcher* 1648, and in the *Overman*, it also seems to underlie diabase. The accessible points at which these two rocks come in contact, however, are so few that the order of their succession is less satisfactorily made out than that of any other important members of the series of rocks found in the WASHOE DISTRICT. The quartz-porphyry does not appear to be intimately associated with the ore bodies of the COMSTOCK, though occurring near to some of those in the Gold Hill mines; nor have any considerable quantities of ore been discovered in this rock in outlying mines. It also assays little or nothing. It is worthy of note that quartz-porphyries in some mining districts have almost certainly supplied the deposits with their charge of precious metals, though the WASHOE occurrence is so barren.

The felsitic modification of the quartz-porphyry is confined to a limited area near the granite. To what cause the difference between its structure and that of the ordinary variety may be due I cannot suggest.

Earlier diabase.—The diabases are almost wholly confined to the mines, only two small patches having been discovered on the surface. Of these, that between the *Julia* and *Ward* shafts appears normal in character though much altered, and as it occurs at the bottom of a ravine vertically above the main body of the rock nothing is easier than to account for its presence. Such is not the case with the mass in Ophir Ravine. 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. There is also no evidence of any connection between this area and the main mass east of the LODE. As has been explained in Chapter III., I am by no means sure that it should not be regarded as a local modification of diorite, rather than an independent eruption. Apart from the interest attaching to such an occurrence it is of little importance, no further consequences, so far as I know, depending on its determination. As may be seen from the sections, diabase approaches the surface very closely immediately below the city of Virginia, so closely that at least a few croppings would be expected in the ground covered by the town. It is highly probable that a considerable area might have been traced before the settlement was made, but the ground is now so graded and built up that a careful search failed to reveal any rock in place.

Relations to the Lode.—The earlier diabase forms the east or hanging wall of the LODE throughout its more productive portion; that is, from the *Overman* to the *Sierra Nevada*, and from the surface, or very close to it, down to the lowest depths yet reached. It also penetrates the west country, at the north end of the LODE, in stringers, as may be seen on the horizontal section on the *Sutro Tunnel* level, Atlas-sheets VIII. and IX. This fact scarcely requires explanation, for that a single clean fracture of the diorite mass should have been effected at the time of the diabase eruption is almost inconceivable. If the diabase succeeded the diorite it would be natural to expect diabase in fissures within the diorite masses, and fragments of diorite inclosed in diabase. It has already been pointed out that these occur. There is a considerable sheet of diorite east of the bonanza of the *California* and *Consolidated Virginia* mines, and similar masses were encountered in sinking the new *Yellow Jacket* shaft. In the higher levels, too, it is probable, from the accounts of former examinations, that diorite horses were encountered. On this point, however, there is some uncertainty, for before the identification of diabase in the east country much of the hanging wall now exposed would undoubtedly have been recognized as an older rock and confounded with diorite. The stringers of diabase in the *Sierra Nevada* and the *Utah* mark fissures unquestionably belonging to the COMSTOCK system, and that in the former mine at least were accompanied by a very trifling amount of ore. The history of the LODE and the chemical discussions which form the subjects of other chapters, make it highly improbable that bodies of any consequence will ever be found near these stringers. The main contact of the diabase with the diorites swings sharply to the northeast in the *Sierra Nevada* ground, and has not been explored beyond that point. Diabase does not appear south of the *Overman*, and the *Forman* shaft passed from hornblende-andesite into quartz-porphyry at 2,200 feet from the surface. If, therefore, as there is reason to believe, the latter rock preceded the diabase, this will not be encountered in the *Forman* shaft. The extension of the diabase in an easterly direction is somewhat uncertain. On the line of the *Sutro Tunnel* the diabase is only about 1,300 feet wide, measured horizontally. It is certainly wider than this at the *Osbiston* shaft and the new *Yellow Jacket*. The *Osbiston* is believed to have met diabase at a depth of about 1,000 feet, though the locality was not accessible, while the new *Yellow Jacket* passed into it at less than 400 feet from the surface, indicating an extensive body still farther east.

The lithological varieties of the diabase have been sufficiently described in a former chapter. In structure it resembles the diorite, being split up near the LODE into rough sheets parallel to the main fissure, as has been explained in Chapter IV. I have been wholly unable to see any evidence that this rock was not emitted at a single outbreak. Its position, lying as a mass upon a diorite wall sloping at an angle of about 45°, together with the details of the relations of the two rocks, shows that it is younger than the diorites. That it is also probably younger than the quartz-porphyry is shown by the occurrences in the *Overman*, which are not fully satisfactory only because they are so limited.

"Black dike."—The younger diabase, as has been seen, is identical with the trap of New Jersey. It has often been confounded with the black slates of the Gold Hill mines, and black rocks and clays have sometimes been classed with it in the north end mines. In the upper levels it was met with only in an indistinguishably decomposed form. I was not able to authenticate its occurrence north of the *Savage*, and found it, wherever struck, of a very uniform width, always a few feet, never more than a couple of yards. From the *Savage* to the *Overman* it generally marks the contact between the older diabase and the west wall with precision, but on one level of the *Chollar* it is 80 feet west of the contact, and in the *Yellow Jacket* a narrow belt of slate sometimes lies east of it. In the *Overman* the dike diverges from this contact, extending towards American Flat as far as the *Caledonia.* The uniform thickness of the dike shows that no considerable movement between the diabase and the west wall took place at or previous to its eruption, for otherwise the fissure which it filled must have presented the enlargements and contractions characteristic of veins the walls of which have experienced a relative motion. The divergence of the dike towards American Flat explains the so-called forking of the vein. A certain amount of solfataric action is perceptible along the dike fissure, accompanied by the deposition of quartz which is not wholly barren The American Flat vein is a stringer, the position of which was predetermined by this fissure.

Earlier hornblende-andesite.—The mine workings show that the contact between the earlier diabase and the earlier hornblende-andesite is very steep, and that it must be represented by a line something like that indicated in the section through the *Sutro Tunnel*, Atlas-sheet VI. The inference from this section is strong that the body of older hornblende-andesite cut by the tunnel occupies a portion at least of the fissure through which it was erupted. The eastern surface of the diabase is far too steep to admit of the supposition that it was ever exposed. Previous to the outbreak of the hornblende-andesite the diabase must either have extended much farther east than now, or a mass of diorite must have occupied the place now filled by hornblende-andesite. In either case, the rock lying east of the present limit of the diabase must have been submerged by the andesite eruption; and of the two suppositions the former seems the more probable. The augite-andesite stands in much the same structural relation to the earlier hornblende-andesite as the latter holds to the diabase, and the east and west surfaces of the hornblende rock, as seen in the tunnel, are parallel to one another and to the Lode.

Even on the surface, indications of the parallelism of the contact between the two andesites and the Lode are observable. If a line is drawn at a distance of 4,500 feet east of the vein, it will fall very close to the easternmost edges of the earlier hornblende-andesite, and include only one considerable tract of the augite rock between it and the Lode. The *Forman* shaft is nearly at the center of this tract, and the section through it shows that hornblende-andesite exists below the surface. The contact between these two rocks in depth is therefore probably nearly parallel to the Lode throughout the whole length of the latter.

Besides the area of earlier hornblende-andesite to the east of the Lode, it covers a large extent of country to the west of the diorite. Before the fault occurred the top of the range was probably about on a level with the east wall, and it seems probable that the whole exposure of earlier hornblende-andesite is ascribable to a single eruption, or an unbroken series of eruptions. I can find no indication of bedding, nor of the distinct lava streams which give evidence of intermittent action in the neighborhood of modern volcanoes. At first the andesite most likely buried the diorite completely, but the latter must have been reëxposed by erosion before the fault took place. The hornblende-andesite, as well as the diabase, is divided into sheets by a system of parallel fissures. If the conclusions drawn in Chapter IV. are correct, this fissure system was developed by faulting at a comparatively recent period, but the tendency to parallelism in the structure of the country was first exhibited as far back as the earlier hornblende-andesite eruption.

The area north of Silver City is remarkable for the unusual development of hornblende crystals, which are frequently an inch and a half in length, and occasionally more. In this area, too, there are several sharp cones one or two hundred feet in height, which suggest volcanic vents, but no craters are traceable; and the evidence of degradation opposite Virginia, especially the flatness of the surface previous to the fault, as is proved from the present regular character of the fault-curve, makes it improbable that distinguishable relics of craters or cones of eruption should remain. In the area north of Cedar Hill Cañon this andesite is much less homogeneous than usual, varying in texture from coarse to fine frequently, and almost without transitions. These differences have been emphasized by decomposition and erosion, which have carved out projecting dike-like sheets, fantastic columns, and the like, from the heterogeneous mass.

That this rock is younger than the quartz-porphyry and the diabase is very evident from the sections, since it overlies these rocks vertically in wide areas, while there is nothing in their relations suggesting laccolitic masses.

There are some east-and-west veins in the hornblende-andesite near Silver City, which are said to have yielded in the aggregate considerable quantities of bullion. The only mines which could have thrown any light on the origin of this ore, however, were closed at the time of the examination. They are near the *Justice* mine, which shows a great complication of rocks in its ore-bearing region, and the ore of the east-and-west veins is very probably due to the same general causes as the *Justice* ore-body. The andesites themselves do not give considerable assays.

Augite-andesite.—In its general features, the occurrence of augite-andesite closely resembles that of the preceding rock. It, too, appears to have issued on a fissure nearly parallel to the LODE and to have spread very extensively over the country; indeed, the present surface shows a greater area of it than of the earlier hornblende-andesite. It is possible that its eruptions were not confined to the fissure cut by the *Sutro Tunnel*. Basalt Hill, B 6, for example, still some 300 feet high, may well be a relic of a still larger eruptive cone, rather than a remnant of an overflow from a fissure at a considerable distance. Like the older andesite the relations of the augite rock to the faulted surface near Virginia seem to show that it was eroded down to a level in that region before the fault occurred. Its character throughout the DISTRICT is, as a rule, very uniform. It is possible, however, that a few localities described as hornblende-andesite are in reality local modifications of this rock. Thus the rock containing the hornblendes with two concentric belts of magnetite, a crystal from which is shown in Fig. 17, Plate III., is exposed only by a cut 1,000 feet east of the railroad station, in C 7. It is within but very near the edge of an area of augite-andesite, which appears everywhere to lie directly upon quartz-porphyry or still older rocks. If hornblende-andesite proper occurs here, it should show at the contacts; but the nearest area of the hornblende rock is 6,000 feet away. If this is properly to be classed with the augite-andesites in spite of its mineralogical composition, it is quite possible that the three small patches of earlier hornblende-andesite shown on the map, each of them entirely surrounded by augite-andesite, may also be of this character.

Independence of the augite-andesite eruption.—The two rocks are so much alike that some lithologists doubt the propriety of classifying them as different species, but in the WASHOE DISTRICT they are certainly different eruptions. The contacts in the *Sutro Tunnel*, the *Forman* shaft, and at many points on the surface are well defined, and the mineralogical character is persistent over very large areas, in spite of a few doubtful localities. It has been seen that there are also points where it is very difficult to say whether the rock is to be regarded as diorite or diabase. The absence of such occurrences would be a matter of surprise, for the character of a rock depends upon combinations of chemical and physical conditions, which cannot be identical at any two points. Each so-called rock species represents an endless number of such combinations, and some of these are indistinguishable from those attending the formation of allied species. The strange fact is not the occurrence of transitions, which are after all exceptional, but the persistence of rock types not only within limited areas but throughout the world.

In determining the succession of the hornblende and augite-andesites position alone can be relied upon, for the two rocks are so closely allied that it would be impossible to distinguish with certainty between an inclusion and a local modification in composition. The indications of position, however, all tend to the supposition that the hornblendic rock is the older, as may be seen from an inspection of the sections.

Occidental lode.—The Occidental lode occurs in augite-andesite. Unfortunately the principal mines were closed at the period of the investigation, and it could not be studied satisfactorily. The dump of the *Occidental* mine seems to show that a contact with micaceous diorite is encountered in the workings. This lode is plotted on the map from distinct croppings and mine surveys, and its trace is a further remarkable illustration of the parallelism of structure so frequently referred to. Even the sinuous form of the Comstock is almost exactly reproduced in the Occidental lode. Bedded flows aggregating over a mile in thickness could never have resulted in so nearly perfect a parallelism.

Later hornblende-andesite.—The *Sutro Tunnel* section shows a fourth very steep contact between augite-andesite and younger hornblende-andesite; but the eastern portion of the former, though covered for the most part, did not sink in the younger rock below the level of the tunnel, and even reaches the surface near the mouth of the adit. The manner in which the portions of diabase and earlier hornblende-andesite which lay to the east of the masses now in place disappeared, is a matter of speculation; the *Sutro Tunnel* section shows that the corresponding area of augite-andesite really sank into the later hornblende-andesite. Had it settled a few hundred feet farther, it would have left as little trace behind it as did the earlier rocks. So far as the Washoe District is concerned, however, the eruption of later hornblende-andesite was probably less violent and less voluminous than that of either of the preceding andesites, and was therefore not so likely to bury the east country to a great depth. Above ground, instead of lying on a curved surface reducible to an original plain, it forms a range of mountains extending to the north far beyond the limits of the map. These do not appear to have suffered greatly from erosion, for even near the summits they are largely composed of tufa and tufaceous breccia, which could offer little resistance to water currents. It does not appear to me that the existence of this range in its present form is compatible with the supposition that a large area of the same rock has been removed by erosion. Making allowance for faulting, the older and firmer rocks have been worn down to a tolerably smooth and uniform surface, upon which the present younger hornblende-andesite range lies in rugged masses. Had the older andesites and the diorite been cut away after the formation of these hills, the latter must have suffered at least as much as the older rocks.

Evidence of slight erosion.—There is no evidence that they have done so; on the contrary, if the contours of the map within the area laid down as younger hornblende-andesite are examined, it will be seen that these are not such as commonly result from deep erosion. Compare, for example, the steep slopes of the Flowery range with the older hornblende-andesite declivity west of Ophir Hill. In the latter locality every water-way has eaten deeply into the rock, and every slightest undulation in the line of cliffs has given rise to an eroding streamlet during wet weather. On the Flowery range the drainage channels are far apart, and very shallow, and many undulations which in a deeply eroded district would be sure to be emphasized by water carving show nothing of the sort. The contact line between this rock and the augite-andesite seems to me unlike contacts developed by erosion. It has a very different character from the other contacts in the DISTRICT, and reminds one strongly of the forms assumed by slag slowly oozing over the floor of a smelting-works. The structure of the rock, as seen on large exposures, appears to indicate subaërial rather than subterranean deposition. Plate VII. shows the east flank of Mount Rose, and is accurately reproduced from a photograph. Rude, thick layers of eruptive material, mostly tufa and breccia, are plainly visible in this locality, though they are traceable over no great distance. It is easy to see how such beds might form in successive eruptions, or through the variations in activity of a single prolonged eruption; but it is difficult to account for such a structure in a mass which has cooled beneath the surface, and has been exposed by erosion. Such a mass would be characterized by dike-structure rather than by beds.

The physical character of the varieties of this rock, considered with reference to their occurrence, is also difficult to reconcile with the supposition that the range is a mere relic of erosion. As has been explained, in Chapter III., some of the younger hornblende-andesite is dense and glassy, and other modifications are firm enough to resist decomposition better than ordinary augite-andesite. In an eroded district these harder rocks would be looked for on the summit, and the soft tufas would be found, if at all, in protected localities; but, as has been pointed out, the tufas are most abundant at the summits. Deeply eroded areas of eruptive rocks almost always show patches isolated, or patches nearly separated from the main field, by the action of water. To a certain extent this is the case with the younger hornblende-andesite, for the two little areas near the *Sierra Nevada* mine were unquestionably cut off from the tongue of this rock extending from the Flowery range towards the *Utah*, by the erosion of Seven Mile

EAST FLANK OF MT ROSE. LATER HORNBLENDE-ANDESITE

Cañon. Mount Abbie, on the other hand, shows amphitheatrical basins, which are not impossibly relics of craters, and that mountain very likely represents a separate, though unimportant, eruption. But had the rock covered much more country than at present, it is almost certain that other patches would have been cut off exactly as those near the *Sierra Nevada* have been, and as various tracts of augite-andesite, quartz-porphyry, etc., have been separated from one another. It has been supposed that there were such patches near the *Combination* shaft and the new *Yellow Jacket*, but the statements rest upon erroneous determinations.

In the *Sutro Tunnel* the fissure system parallel to the Lode extends to the younger hornblende-andesite, but though this rock, particularly near its western limit, shows evidences of dynamical action, I was not able to make certain of any regular partings within its mass. On mere geometrical grounds it could hardly be expected that the fissures would be traceable in this rock, for at so great a distance from the Lode the logarithmic curve and its asymptote sensibly coincide.

There can be no doubt that the younger hornblende-andesite succeeded the augite-andesite. In the *Sutro Tunnel* section it is seen directly overlying and inclosing the augitic rock, and on the divide between Mount Kate and Mount Rose the augite-andesite can be traced passing horizontally beneath the trachytic-looking porphyry. The peninsular-like area near *Sutro Shaft* III. would seem, too, to be a flow from the main body, not an independent or subsidiary eruption; for the tunnel, though passing close by this area, shows none of the younger rock west of Shaft II., nor is there any sign of special disturbance of the augite-andesite in the tunnel near Shaft III.

Basalt.—Besides the five little patches of basalt shown on the map, there is another of about the same size directly west of these, and just beyond the limits of the map. It is said that a few miles farther south there are considerable areas of this rock. Two of the five occurrences shown are very characteristic mesas, and the rock is in every way typical. The only remarkable fact connected with it is its small extension. No general effect upon the history of the District has been certainly traced to it. Though the basalt comes in contact only with pre-Tertiary rocks and earlier hornblende-andesite, there can be little doubt that it is the youngest of all. Its relations to the andesites have been observed in a great number of localities in the western United States, and it has always been found to succeed them. This general evidence is strengthened in the present case by the extreme freshness of the olivine, which even under the microscope often shows no trace of decomposition. As olivine is the most readily decomposed of all the lithologically important minerals, this fact is evidence that the basalt is very recent.

Period of solfatarism.—The geologists who have studied the COMSTOCK have always sought to connect the solfataric action, which is so important a feature of the DISTRICT, with one or other of the volcanic eruptions. Since the augite-andesite and the rocks which preceded it are deeply altered by solfatarism; and even portions of the younger hornblende-andesite are also thus affected, the general decomposition cannot be placed earlier than the eruption of the last-mentioned rock. Portions of an eruptive rock may be immediately decomposed by the emanations accompanying its ejection, but before an extensive area can be decomposed throughout, it must probably cool and be shattered by mechanical action sufficiently to admit a somewhat free penetration of active solutions. If the solfataric action is due to one of the eruptions, it must then be either to that of the younger hornblende-andesite or to that of the basalt. But direct evidence of such a connection is wanting. The focal line of solfatarism is at or close to the LODE. The younger hornblende-andesite area shows no trace of it except where it approaches the vein; and, as has been mentioned, the basalt shows no effects of solfataric decomposition. It is also somewhat difficult to understand how an eruption can produce extraordinarily intense solfataric action at a locality somewhat remote from the vent of its own fluid ejecta, and not also at or close to that vent; though I by no means deny the possibility of such a coincidence.

While, however, the solfataric action appears to me, beyond question, one of the series of volcanic events of which the history of the DISTRICT is so full, it does not seem to be necessarily connected immediately with an eruption of lava. There are mud volcanoes; and solfataras are often active at periods of time remote from those of eruptions in their neighborhood, and though the emission of heated waters frequently attends igneous eruptions, there appears no reason to suppose that vast quantities of heated fluids may not be driven to the surface without an accompaniment of lava. The solfataric action and the fault are certainly contemporaneous, and may together form the entire volcanic manifestation of the period in which they occurred. If they were independent of the eruption of younger hornblende-andesite, they must have been subsequent to it; and I believe it most probable that such was the case. Of their time relations to the basalt eruption there is no means of judging.

Collections.—The disputed character of a number of the rocks of the DISTRICT made very full collections essential to the substantiation of the views maintained in this report. A cabinet series of 200 specimens was collected in triplicate, one set being designed for the lithological collection of the National Museum, a second for the geographical collection of the same institution, and a third for the San Francisco office of the Geological Survey. By order of the Director, the size of these specimens is 4 inches by 5 inches, their thickness being from an inch to an inch and a half. Though these specimens, selected with a view to representing the DISTRICT as well as possible, amply suffice for the ordinary purposes of study, so small a number was not found sufficient to justify the geological map and sections. A working collection without duplicates was therefore also gathered. The size adopted was only 1¾ by 2½ inches, in order to lessen the labor of gathering them and to facilitate their use in the office. This collection contains over 2,000 numbers. Slides were ground whenever they seemed likely to afford desirable information, and the total number cut was about 500.

The locality of every specimen was recorded at the time of collection on a map of the surface or of the mines as the case might be. The mine maps employed were on a large scale, and the localities are usually accurate to three or four feet. The surface map being on a comparatively small scale the positions are less precise, but are recorded as accurately as practicable. On the sections of the LODE, shown in the Atlas, the points from which specimens were collected are marked by crosses, while each locality from which there is a slide is indicated by a large black dot. On the surface map a red cross shows the localities microscopically determined, a single cross often representing a number of slides. Accompanying the collections is a copy of the surface map, showing the position of each specimen with its number. The numbers of specimens of which there are slides are underlined, and cabinet specimens are distinguished from those of the working collection. The collections are also fully labeled and completely catalogued.

CHAPTER VI.

CHEMISTRY.

General nature of the chemical activity.—The general results of chemical activity which have been observed in the WASHOE DISTRICT can be very briefly stated. Decomposition is widespread, but while in the greater part of the area it has not seriously modified the character of the rock, the alteration within a certain portion of the region is profound, and often wholly obscures lithological distinctions. This area of extreme decomposition is precisely the most important, lying immediately about the LODE.[1] The characteristic bisilicates of the eruptive rocks have been replaced by chloritic minerals, epidote, quartz, and calcite; pyrite has been deposited in the mass of the rock, and the feldspars have in great part undergone degeneration of a complex kind; finally, ore-bearing quartz has been deposited in the LODE. It is the purpose of the present chapter to give as rational an account of these changes as I am able to suggest, and to trace their geological relations. Any such account must, in the present state of knowledge as to the constitution of minerals, be largely hypothetical; but, although future investigations will probably greatly modify the present conceptions of the nature of inorganic compounds, the best hypotheses at present are those which put the least strain on well-proved theories. The WASHOE DISTRICT affords, as has been seen, a remarkable opportunity for microscopic examination of the results of decomposition; not, however, for their chemical investigation, for no occurrences have been met with in which single alteration products, excepting pyrite, are concentrated in sufficient masses to furnish good material for analysis. Even were this the case, it seems to me that

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[1] See Fig. 1.

little progress can be made until definite criteria are discovered by which the state of combination of the elements in fresh minerals can be decided.

Formation of pyrite.—Perhaps the most striking characteristic of the decomposed rocks of WASHOE is the presence of innumerable bright crystals of pyrite disseminated through the mass. The unaltered rocks do not appear to carry this mineral; if it occurs in them at all it is certainly a very rare ingredient. In the altered rocks pyrite, when present, is abundant nearly in proportion to the degree of decomposition, and, except where it is exposed to the direct action of the atmosphere, it is almost invariably perfectly fresh. All the circumstances thus indicate that it is a product of decomposition. The massive rocks contain iron, chiefly as magnetite and as a component of the bisilicates; and the pyrite must have been formed by the action of soluble sulphurets on one or both of these compounds. The slides of the pyritous rocks, however, frequently show large quantities of sharply defined magnetite, while the bisilicates are in a majority of cases wholly decomposed. There is certainly nothing in the association of pyrite and magnetite to suggest a relation; but the pseudomorphs of decomposition products after the bisilicates are very frequently studded with small pyrite crystals, and occasionally real pseudomorphs of pyrite after augite or hornblende appear to occur. Of these it is difficult to be certain, however; for the size of the pyrite individuals is usually considerable, relatively to that of their hosts; the original crystal form is consequently never unmodified, and is commonly altered beyond recognition. The distribution of the pyrite in the rock also reminds the familiar observer of the distribution of the bisilicates in the same rock, and macroscopical comparison of suites of specimens from the same localities shows that the pyrite to all appearances is associated with the bisilicates, and in extreme cases replaces them. It is easy to lay too much stress on an impression of this sort, yet when such an impression is derived from the examination of many thousand instances it deserves some weight. All the evidence thus tends to the supposition that the pyrite is mainly a decomposition product of the bisilicates and of mica. Such an alteration is quite possible in the presence of alkaline sulphides, or of hydrosulphuric acid; and, as has been seen, the waters even now entering the mines three thousand feet from the surface are charged with the latter reagent. Had oxidizing agencies been active to any great extent below the surface the pyrite must have been decomposed, and the inference from the facts is strong that such has not been the case.

The formation of pyrite might conceivably either take place immediately at the expense of the bisilicates or be formed from secondary minerals; but the ferruginous silicates, chlorite and epidote, are frequently deposited in veins and patches quite free from pyrite, and nothing has been observed in their association with pyrite to indicate an epigenetic connection. It is therefore more probable that pyrite resulted immediately from the action of hydrosulphuric acid and similar compounds on the bisilicates. This action could not possibly be unaccompanied by the formation of other alteration products, for the whole stochiometric relations of the bisilicates would be changed by the abstraction of iron. Since hydrosulphuric acid is a powerful reducing agent, it is *a priori* probable that the accompanying products would contain little ferric oxide, and as the bases in the bisilicates are fully saturated with silicon a separation of silicic acid is indicated.

Formation of chlorite.—The chlorite, which, as has been seen in Chapter III., nearly always results from the decomposition of the ferro-magnesian silicates, is of uncertain species, but it is neither clinochlore nor pennine, and answers well to Werner's chlorite (the ripidolite of G. Rose). This mineral has approximately the composition of a semisilicate, and contains little or no ferric oxide. It is also accompanied in a great proportion of cases by secondary quartz, and often also by calcite. The occurrence of this last mineral shows that carbonic acid, as well as hydrogen sulphide, must have been present during the decomposition of the rocks, and probably from the commencement, for chlorite contains no calcium; and had hydrosulphuric acid alone acted on the bisilicates a calcium silicate must have resulted in the first instance. Of such a preliminary change, however, there is no trace, although, as has been seen in Chapter III., it appears possible to follow the course of decomposition mineralogically from its incipient stages. Calcite, however, is not usually prominent among the decomposition products of the bisilicates in specimens collected under ground, unquestionably owing to its great solubility.

Circumstances favoring the formation of epidote.—That chlorite or chloritic minerals very usually result from the decomposition of hornblende, augite, and mica is a well-known fact, and pseudomorphs of epidote, after these minerals, are also common. The difference is great, for while chlorite contains little or no ferric oxide and no calcium, epidote contains both, but is free from magnesium. It would seem, therefore, as if epidote must be formed under such conditions that ferrous compounds might be oxidized, or such that ferric compounds, at all events, would not be reduced, and, further, under conditions favoring the solubility of magnesian salts rather than those of calcium. It appears to me somewhat difficult to suppose the bisilicates exposed to a sulphidizing action so strong as to result in the formation of pyrite, and yet not sufficiently reducing to prevent the formation of ferric compounds. On the other hand, pyrite, though of very variable stability, often oxidizes with great difficulty, and the oxidation of ferrous compounds may sometimes be effected in its presence. Epidote might, therefore, form in the presence of pyrite, but hardly contemporaneously with it. The behavior of the salts of magnesium and calcium salts towards one another is known to vary greatly with the physical conditions, especially with temperature, and presumably also with pressure, and it is further affected by the concentration of solutions. Thus, Dr. T. S. Hunt[1] found that when solutions of the chlorides and carbonates of these elements are evaporated at ordinary temperatures, calcium carbonate alone is first precipitated; while, when the solution is boiled, magnesium carbonate first separates. This and similar facts tend to the supposition that high temperatures would favor the formation of magnesian chlorite rather than of calciferous epidote.

Conditions under which epidote occurs.—The underground rocks at WASHOE all contain chlorite in abundance, but epidote is uncommon. Thus, a special search was necessary to discover epidote in the underground diabases, while perhaps half the augite-andesites from the surface contain it in considerable quantities. When it occurs at a considerable depth it seems to be either close to the LODE or near strong seams extending towards the surface, as in one or two localities in the *Sutro Tunnel*. On the surface epidote is extremely common, tinging whole areas of the various rocks with its peculiar green, and occurring in many and widely separated localities. Where epidote is

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[1] Chem. and Geolog. Essays, p. 138.

best developed, as in Crown Point and Ophir ravines, the accompanying pyrite is usually decomposed either wholly or in part; and in localities at a small distance beneath the surface, like the *McKibben* tunnel, it is in those belts of rock which are evidently most highly decomposed that epidote is found replacing chlorite.

Probable course of the alteration of chlorite to epidote.—Strong mineralogical evidence has already been offered to show that epidote at WASHOE is an alteration product of chlorite. The indications of relative solubility are worth considering in this connection. Chlorite is manifestly rather easily soluble, and soon after its formation becomes diffused through the groundmass and any porous crystals which may be present, settling, too, in veins when cracks offer an opportunity for such a concentration. Epidote appears to be soluble only in a greatly inferior degree; indeed, its faggot-like masses of crystals seldom show anything which can be interpreted as attack by a solvent. If, therefore, chlorite and solutions of calcium carbonate containing free oxygen are brought together under physical conditions compatible with the formation of epidote, it seems inevitable that epidote should be precipitated, unless still more insoluble substances may also be thrown down under the same conditions.

It is well known that chlorite is frequently altered to a mass of quartz, ferric hydrate, and carbonates. When this change takes place it is probable that at least a portion of the alumina is mingled in some form with the iron oxide, and the carbonates most likely contain magnesium as well as calcium. In the numerous cases of this change which have been observed at WASHOE, the carbonates form a large portion of the resulting mixture, a fact which appears to prove that the active solutions were but slightly charged with carbonic acid, since, had it been otherwise, calcite and magnesite, if separated out at all, would have been redissolved. Cases of the conversion of chlorite to epidote and to carbonates, etc., often occur in the same slide, and presumably under nearly the same physical conditions. It may be that the decisive point is the quantity of carbonic acid present. If the two processes went on at different times such a difference would be readily explicable, and if simultaneously it is not difficult to understand how the quantity of carbonic acid might vary. Though rocks are permeable, the aqueous currents are greatly obstructed, and move in labyrinthine paths of least resistance. Of this the lithologist is constantly reminded by meeting wholly fresh crystals and entirely decomposed ones of the same mineral close together. One tiny current percolating through the rock may meet with comparatively large quantities of carbonates and become saturated, while another in the same neighborhood remains well charged with carbonic acid and oxygen. If the suggestion made is correct, the former coming in contact with chlorite would convert it into a mass of carbonates, quartz, and ferric oxide; while the latter, which would be a solvent for carbonates, would convert chlorite into epidote.

Nature of the decomposition of the bisilicates.—Qualified by all the doubts which have been expressed, the observations considered in connection with the chemical possibilities lead to the following as the most probable statement of the decomposition of the bisilicates of the Washoe rocks. Waters charged with hydrosulphuric and carbonic acids, but containing no free oxygen, at temperatures probably very near the boiling-point, acted upon the fresh augite and hornblende (or mica), producing from them pyrite, chlorite, quartz, and carbonates of the alkaline earths simultaneously Of these a large portion of the carbonates passed into solution. At a later period surface waters at lower temperatures, containing carbonic acid and free oxygen in solution, produced a further alteration of a portion of the chlorite in the rocks near the surface, or peculiarly accessible from it. Where carbonic acid was present in excess epidote resulted; where, through saturation with carbonates, the carbonic acid was deficient, the chlorite was altered to carbonates, quartz, and metallic oxides, no doubt with admixtures of less important compounds.

Magnetite.—No place has been given to magnetite among the decomposition products of the bisilicates. As all the rocks contain large quantities of this mineral constantly associated with the bisilicates, and often so thickly distributed in perfectly fresh crystals (particularly of hornblende) as to leave but little of the host visible, it is difficult to distinguish sharply between the primitive and the secondary occurrences of the iron ore. In fact, I have not been able to make absolutely sure of more than one or two instances of secondary magnetite, though such an origin seems probable enough in many cases. On the other hand, it seems certain that the black border of many hornblendes has been attacked, and has given place to a transparent mineral, which is more or less diffused in and obscured by the groundmass. The natural supposition is that it is ferrous carbonate.

Ilmenite.—Titanic iron ore may often be observed in slides from the DISTRICT passing into leucoxene. The nature of this substance is doubtful, and no occurrence in the DISTRICT is conclusive as to its nature, yet many cases have been observed the character of which would be very satisfactorily accounted for if the supposition of Messrs. Fouqué & Lévy, that leucoxene and titanite are identical, were accepted.

Decomposition of the feldspars.—The feldspars of the WASHOE region have offered a far more effectual resistance to decomposing agencies than the bisilicates, much more, too, than would be supposed from a macroscopical examination of the rocks. In the mines it is very rarely that a particle of augite, hornblende, or mica, can be found, these minerals being nearly always wholly replaced by alteration products; but it is the exception when a moderately hard rock does not show under the microscope well defined and fairly fresh feldspars. When wholly unattacked the feldspars of diabase, of some diorites, and of the older andesites are transparent, and the rocks then show only the tints due to the presence of magnetite and the bisilicates. They are then dark, somewhat basaltic-looking masses. But when only a very minute amount of change has taken place in the feldspars, they become opaque through irregular reflection, and form the most prominent feature of the rock. Rough estimates, made with the help of the microscope, indicate that the decomposition of much less than one per cent. of the feldspar substance suffices to destroy the transparency of the crystals.

The nature of the decomposition of the feldspars is still very obscure. It is usually considered that the triclinic feldspars as well as orthoclase are sometimes converted into kaolin, though Professor Tschermak maintains, as an analytical result, that the hydrated aluminium silicate resulting from the alteration of plagioclase contains but a single molecule of water, and not two, as is the case with kaolin. Saussurite and pinitoid are the names given to complex silicates, or mixtures of silicates and other substances, which often result from the decomposition of feldspars; and mica and epidote are counted among the products of alteration.

Kaolin.—Kaolin is microscopically an obscure mineral. According to Mr. H. Fischer it is amorphous, while Mr. A. Knop found it to consist of delicate hexagonal plates of the rhombic system. Breithaupt named this crystalline modification nacrite, and M. Des Cloizeaux pholerite. If saussurite and pinitoid are really independent minerals, it is certain that these names have also been given to mere mixtures resulting from the extraction of portions of the silicic acid and of the stronger bases.

Evidence of the microscope.—In the WASHOE rocks, as is usual elsewhere, the first indication of decomposition is the appearance of calcite and quartz in the more or less carious crystals. This is doubtless attended by the formation of soluble alkaline silicates, which, however, are not recognizable under the microscope. As the process continues the striations are obliterated, and the final result is a heterogeneous mass showing aggregate polarization, sometimes only faintly translucent, and containing in a recognizable form only grains of calcite and quartz. No amorphous substance has been observed, nor any hexagonal lamellæ answering to the description of nacrite. Mica, too, appears to be absent, although occurring among the decomposition products of similar rocks at no great distance from Virginia. Chlorite and epidote are common in decomposed feldspars, but in many cases it seems certain that chlorite due to the decomposition of the bisilicates has merely permeated the spongy mass; and epidote has repeatedly been observed developing in patches of chlorite, which were surrounded by feldspar substances, just as it has been described and illustrated as occurring in altered bisilicates. No case has been met with in which either mineral was distinctly parasitic on feldspar.

All lithologists agree that chlorite forms from the bisilicates, and that feldspars become carious; it is also acknowledged that chlorite is diffused through the portions of the rock mass in the immediate neighborhood of the point at which it forms. It must therefore penetrate the feldspars where these are partially decomposed, in all rocks in which the bisilicates are to any extent converted into chlorite. It is, of course, by no means necessary that the point at which chlorite gained access to the feldspar should be visible, for entrance is as likely to have been effected above or below the plane of a thin section as in it. If chlorite and epidote really occur as results of the decomposition of feldspar, it should be easy to show the parasitic growth of chlorite in feldspars, just as its development from hornblende has been shown in the present volume.

Chemical analysis.—The microscope gives mainly negative results concerning the decomposition of the feldspars of the WASHOE rocks. Chemical analysis of the decomposition products could lead to no definite results, because no reasonably pure material could be obtained, and the only remaining source of information is the analysis of the rocks. The diabase from the hanging wall of the LODE, which was analyzed, is a very slightly altered rock, and has been described under slide 18. Its feldspars are transparent and have undergone only an inappreciable amount of alteration; the rock nevertheless contains a considerable quantity of water, as is shown by its loss in ignition, 2.47 per cent. Abundant fluid inclusions account for a part of this loss, and the water of hydration of the small amount of chlorite it contains for another portion. The ignition loss no doubt includes a small amount of carbonic acid. The "propylite horse" analyzed by Prof. W. G. Mixter was in all probability decomposed diabase. An inspection of the analysis shows either that silica had been deposited in the rock, or what seems more likely, that the bases had been in large part extracted. It contained 1.83 per cent. of water, or about two-thirds as much as the fresh rock. The bisilicates must have been represented by chlorite, which contains about 12 per cent. of water. The small quantity of aluminium not entering into the chlorite may possibly have existed as kaolin, a supposition neither proved nor disproved by the analysis, which, however, shows that the horse contained at most a small percentage of that mineral. Four analyses of clays made for the Exploration of the Fortieth Parallel by Professors Johnson and Mixter are available. It is here, if anywhere, that kaolin must be indicated. On comparison of these analyses with that of the fresh diabase, it appears that they do not represent concentrations of any special mineral, but merely highly altered rock masses. Barring the pyrite and water, the first three show very nearly the same composition as the fresh rock, while a portion of the silicic acid has apparently been abstracted from the *Savage* clay.

The quantity of pyrite corresponds fairly well with the deficiency of iron in the clays. Taking into consideration that these clays must have contained chlorite corresponding to about 18 per cent. of augite, it appears from the water contents that those from the *Chollar* and the *Hale & Norcross* can have included little or no kaolin. Those from the *Yellow Jacket* and the *Savage*, on the other hand, may have contained both chlorite and kaolin, but the latter only to the extent of a few per cent.

Kaolinization not prevalent at Washoe.—The weight of evidence is thus reasonably strong that in the regions thus far exploited on and near the Comstock, kaolinization, if it has taken place at all, has occurred only to a very trifling extent, and that the degeneration of the feldspars results almost wholly in a mixture of silica, calcite, and unrecognizable minerals, earthy in texture, in part nearly opaque, and of a light color.

Occurrence of ore and the accompanying rocks.—As may be seen from the maps and sections, the Comstock Lode is several miles long, and is found in contact with various rocks. The fissure is not simple, but ramified, and might have been represented as still more complex, for the quartz veins struck by the *McKibben Tunnel* in Spanish Ravine, and by the *Peytona* and other workings on Cedar Hill, are unquestionably either stringers joining the Lode at unknown points, or subsidiary parallel veins due to the same chain of dynamical and chemical causes as the Comstock. It appears from the longitudinal vertical projection that but a small fraction of the fissure has been filled with ore. This statement, however, requires explanation and qualification. Nearly all the vast mass of quartz on the Comstock contains considerable quantities of silver and gold, but none, of course, is extracted which will not pay for working. While auriferous gravels may yield a handsome profit when they contain considerably less than ten cents per ton, and gold quartz may sometimes pay which contains two or three dollars, Comstock ores carrying less than about twenty dollars can usually be extracted only at a loss. Geologically the Comstock must be considered as filled with metalliferous gangue, enriched at numerous spots, which are known by the Spanish mining term "bonanzas."

Vastly the most productive area has been that portion of the main Lode between the *Overman* and the south end of the *Sierra Nevada* mine.

Bullion has also been produced at the *Justice* to the south, and from the veins on Cedar Hill to the north. In the Virginia and Gold Hill mines, and on Cedar Hill, the gangue is quartz, only occasional masses of calcite of insignificant size having been encountered. South of the *Overman*, on the other hand, the gangue is largely calcite.

The quartz of Cedar Hill carries free gold, alloyed, of course, with a little silver. Certain stringers from the main LODE and the "west vein" of the COMSTOCK, as that portion lying to the west of the great horse in Virginia City, above the line at which the two fissures join, is usually called, are of the same character. The *Justice* ore was argentiferous, but very "base," carrying large quantities of galena, zinc blende, etc. The ore bodies on the main LODE in Virginia and Gold Hill, which have yielded almost all of the bullion extracted, may profitably be considered as of two classes. The greater portion of the bullion has been derived from minerals disseminated in the quartz in microscopic particles. Ore of this kind is often distinguishable from barren quartz by bluish stains, but not always. The quality, and even the presence of ore, can in many cases only be told by assay, and superintendents who have taken part in the mining operations almost from their commencement do not hesitate to confess that their judgment of the quartz is often at fault. The behavior of this ore in amalgamation shows that its silver contents is mainly due to argentite. Its gold contents constitutes from one-quarter to one-half its total value. Near the outcroppings many bunches of other ores occurred, such as stephanite, polybasite, ruby silver, etc. These were in some cases accompanied by relatively large quantities of galena and zinc blende. In the great *Consolidated Virginia* and *California* bonanza, several streaks or veins of very rich black silver ores, said to be mainly stephanite, occurred. These were separated from the surrounding ore-bearing quartz very sharply, as if of later origin.

Pyrite is found everywhere, both in the country rock and in the ore disseminated in small crystals. It is less frequent in the quartz than in the country rock, but it is especially abundant in the east country, opposite the ore bodies. It also occurs with frequency in the diorite west of and near the LODE. In all these cases it forms but a small portion of the mass—say from ten per cent. downwards; but in the graphitic slates forming the west wall in the Gold Hill mines, bunches are met with in which it is the predominant constituent. These are, however, usually only a cubic foot or two in size, and appear to occur only close to the vein. As a rule, the slates are not much more pyritiferous than the diabase.

Relations between ores and rocks.—There is an evident relation between the inclosing rocks and the character of the ore. The rocks occurring at and near the *Justice*, with its refractory ores and calcite gangue, are metamorphic diorite, mica-diorite, quartz-porphyry, and hornblende-andesite. The Cedar Hill gold-quartz veins are in diorite. The ores of the more important mines lie on the contact between diabase and diorite.

There seem to be but two probable ways in which these differences can have come about.[1] The ore deposits might have taken place at different times, and therefore under different conditions, or the contents of the fissures may have been extracted from their walls at the same time, and the differences be due to the composition of the surrounding rock. If the Cedar Hill veins were deposited at a different time from the main mass of the COMSTOCK ore, it must have been at an earlier date, for the vast quantities of solutions which reached the COMSTOCK could not have failed to penetrate the fissured diorite. Not only stringers from the COMSTOCK, however, but even the "west vein," are of the same character as the Cedar Hill quartz. When this west quartz was deposited the fissure below was certainly open, and had it been deposited before the argentiferous ore, it is scarcely possible to suppose that it would not also have filled the vein at lower points. If they were to be assigned to different periods, one would also expect to find either gold veins in the east country, or silver veins in the west. In short, there is much to show that these two classes of deposits were contemporaneous; and I know of no evidence tending to show that they are not ascribable to a single period. The *Justice* ore body is not closely enough connected with the more important portion of the COM-

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[1] It is also conceivable that the ores should have been precipitated from solution by the rock forming the walls and the horses, and that the observed differences are due to the character of the precipitant. All the evidence of ore deposits in general, and of the COMSTOCK in particular, however, appear to me to point to changes of temperature and pressure, evaporation and the action of liquid reagents, as the causes of precipitation. In describing the LODE I shall be obliged to recur to this subject.

STOCK to permit of a detailed comparison, such as that given above, but in the absence of proof to the contrary it is probable that it too was deposited at the same time.

Time relations of the ore.—During the period in which the field work for the present volume was done, there was but very little ore in sight. What I have seen of ore near the croppings exposed in a few reopened workings, however, and recollections of the streaks of high-grade ore in the "great bonanza," lead to the belief that these rich concentrations were of later origin than the mass of the ore. The quartz in the *Consolidated Virginia* and *California* was almost everywhere a crushed, powdery mass, while the thin and persistent veins of black ore running through it were very solid. A somewhat similar relation seems to have existed near the croppings, and it is not impossible that these ores were formed at the expense of others of the more usual kind at a later date, and that they occupy spaces opened in the ore masses by faulting action.

Origin of the vein minerals.—It is well known that the able and laborious investigations of Prof. F. Sandberger[1] have added greatly to our knowledge of the distribution of the metals in unaltered rocks, and of the reactions by which in many cases they have been concentrated in veins. Though not the first to show that the bisilicates, as well as mica, sometimes carry small quantities of the heavy metals, he has multiplied the known instances so greatly as to establish the frequency of such a composition. In many cases it is an exceedingly complex matter to prove a possible connection between a vein and the surrounding rock, because the minerals present in noticeable quantities are numerous. This is not the case at WASHOE, for quartz, silver, gold, and sulphur predominate so greatly over all other elements that if the presence of these is accounted for, the problem may be considered solved, unless the solution offered is inconsistent with the presence of small quantities of calcite, galena, zinc blende, etc., and with the general distribution of pyrite.

Origin of the quartz and ore.—No chemical analysis is necessary to detect a possible origin for the quartz of the LODE. Macroscopical and microscopical examinations sufficiently show the enormous destruction of primary sili-

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[1] Untersuchungen über Erzgänge, erstes Heft, 1882. Also, Berg- u. h.-Zeitung, 1877 and 1880.

cates which has taken place throughout a large area. On the other hand, minute quantities of gold and silver can be more easily and more certainly determined by dry assay than by analysis, provided that pure lead reagents can be procured But the selection of suitable material for the investigation of the gold and silver contents of the WASHOE rocks was by no means a simple matter. As has been seen, there is but one spot known in which nearly fresh diabase can be collected, and that close to the COMSTOCK fissure. Moreover, the quantities of the precious metals to be dealt with are so minute that a mere trace of infiltrating solutions of their compounds would impart a comparatively important metallic contents, and that such impregnations occur in some of the rocks there is very good reason to believe. This occurrence of fresh diabase is therefore open to suspicion. If, however, the diabase which forms the east or hanging wall of the LODE is the source of its gold and silver, fresh portions of the rock will show a larger quantity of the precious metals than decomposed samples; while, if the source of the ore were independent of the diabase, decomposed portions of the latter, being more porous, would have been more readily and fully impregnated by the metalliferous solutions. Moreover, it has been shown that pyrite forms at the expense of the augite of the diabase, and as pyrite is known to have a very strong affinity for gold, the decomposed pyritiferous rock should show a greater proportion of gold to silver than the fresh diabase, if this rock is the source of the metals. Were the original distribution of gold and silver and their subsequent extraction nearly uniform, the composition of the ore in the LODE would correspond to the contents of the fresh rock, less that of the decomposed rock and the pyrite, as shown by a limited number of assays. The quantity of the precious metals occurring in the vein should also be calculable from the extent of the decomposed rock. Such ideal conditions, however, are not to be expected. The excessive difficulty of obtaining a representative sample of any gold or silver deposit is familiar to all mining men, and in the COMSTOCK itself great variations, both in the relations of gold to silver and in the total tenor, are of constant occurrence. On the supposition that the metals have been extracted from the diabase these variations indicate great irregularity in the leaching action or in the original distribution of the metals, or, more probably, in both.

Precautions observed in assaying.—The assays tabulated at the end of Chapter III. were made by my assistant, Mr. J. S. Curtis, who, in addition to a thorough training, has had many years of experience in accurate and responsible assaying. In attempting to detect minute quantities of precious metals in the WASHOE rocks, the first difficulty experienced was in obtaining sufficiently pure lead or litharge It was found that even that imported from Germany and sold at a very high price as chemically pure was far too rich in silver and too irregular in its silver contents to answer the purpose. In this dilemma Mr. Rickard, of the Richmond Mining and Smelting Company, in Eureka, was kind enough to place a refining furnace with a new test at Mr. Curtis's disposal, as well as the purest of the lead refined by the Luce & Rozan process in the works under his charge. By careful manipulation Mr. Curtis was able to prepare litharge assaying less than eight cents a ton and of so regular a composition that, with the help of blank assays, the silver contents of the rocks could be very exactly determined.

A series of experiments was then made to determine the time of reduction which would give a maximum result with material so poor in metals as the WASHOE rocks. It was found that this time was much longer than that requisite for the reduction of ore. Refined cream of tartar was the reducing agent employed, with sodium bicarbonate and borax in carefully determined proportions as fluxes. The cupels were made with great care of two parts of bone-ash to one of cedar-ash, the surface being formed of elutriated bone-ash. In cupelling feather-litharge was invariably allowed to form, and throughout the experiments no known precaution was neglected.

Gold detected in the rocks.—In addition to the silver contents of the WASHOE rocks, gold also was detected, but in such minute quantities that little reliance can be placed upon the relative tenor of different samples. It was established, however, that the fresh diabase carries as much as four or five cents in gold to the ton, and furthermore that the pyrite, so abundant in the decomposed rocks, carries both gold and silver, but more of the former than of the latter. Thus pyrite washed from the decomposed diabase 250 feet north of the *C. & C.* connection with the North Lateral of the *Sutro Tunnel*, assayed three cents in silver and eight cents in gold, and pyrite from the Belcher slates gave eighteen cents silver and twenty cents gold. The diorite from Bullion Ravine also showed an indeterminably small trace of gold, while the andesites carry about as much as the diabase.

Silver traced to the augite.—It seemed probable from Professor Sandberger's investigations that the augite of the diabase was the seat of its metallic contents. To test this point, the feldspar and augite were separated by Thoulet's method and separately assayed. It appeared that, for equal weights, the augite was eight times as rich as the feldspathic material, and, as a perfectly clean separation by Thoulet's method is impracticable, this seems substantially equivalent to a proof that the silver is a constituent of the augite.

Results of the assays.—By comparison of the different assays it appears that decomposed diabase carries somewhat less than half as much silver as the fresh rock. Where the decomposed rocks are pyritous, the experiments made do not indicate any essential diminution of the gold contents. This fact, however, is quite possibly due to irregularity in distribution and the minuteness of the quantities of gold to be determined. As the decomposition of the rock in question has proceeded at a great depth beneath the surface, it is highly unlikely that silver should have been extracted unaccompanied by gold. Much of the decomposed rock, too, is nearly free from pyrite, and had the gold contents of such specimens been determined a smaller percentage would probably have been found. The omission was not detected until too late to resume the investigation. So far as quantitative relations are concerned, only the silver can be relied on, though the qualitative detection of gold as well is both interesting and important.

Comparison with the yield of the Lode.—If, then, the COMSTOCK LODE is supposed to have derived its precious metals from the diabase, we should expect to find that it yielded doré silver containing a small quantity of gold. The gold contents has actually been very variable, in some few cases exceeding the value of the silver and in other instances amounting to only a fourth of its value. The LODE has been pretty thoroughly explored to a depth of 2,500 feet, and the extent of diabase exposed may be put roughly at a length of 8,000 feet and a thickness of 2,500 feet. If about 13 cents per ton, or, say, 1 cent per cubic foot, has been extracted from this mass, the total amount thus accounted for is $500,000,000. Over $300,000,000 have been actually put upon the market, and nearly $100,000,000 more have probably been lost in tailings. The low-grade quartz not extracted most likely contains more than another hundred millions, but the sum obtained by calculation is nevertheless a fair approximation to the amount which the LODE must actually have contained. On the other hand, if an attempt be made to account for the ore on any other supposition than that it was derived from the diabase, it seems very difficult to give a plausible explanation for the disappearance of the gold and silver which appear to have been extracted from this rock.

Other rocks.—The diorite also contains precious metals; but while dioritic vein matter is highly charged, and even that at the mouth of Bullion ravine, which is very solid but contains some pyrite and is very close to the LODE, carries a notable quantity, that from the head of the same ravine shows only a trace of silver. These relations are the reverse of those observed in the diabase and appear to indicate an impregnation from the LODE. The diorite also contains a trace of gold. More could hardly have been expected; for, except on Cedar Hill, it has never been found worth while to treat the gold quartz of the DISTRICT, and the Cedar Hill mines have yielded but little.

The andesites and the quartz-porphyry show only very small amounts of silver, but the metamorphic diorite contains eight cents per ton. The analysis also shows that this rock is highly calcareous, and it seems not impossible that the *Justice* ore body, which is associated with the metamorphic diorite, was derived from it. The basalt, on the contrary, is nearly as rich in silver as the older diabase, but no ore is likely to have been extracted from it, for the rock is not only the freshest in the DISTRICT, but is remarkably fresh for any region, many of the olivines showing no trace of attack.

Lateral-secretion theory affirmed.—On the whole, therefore, the chemical and geological evidence point to the lateral-secretion theory as the true explanation of the WASHOE ore deposits, and to the augite of the older diabase as the source of the important ore bodies. It is worth while to note that, according to report, many of the famous silver mines of the world are associated with this rock.

Nature of the solvents.—As has been seen, there is reason to suppose that the active reagents in the decomposition of the minerals of the diabase were sulphhydric and carbonic acids. These acids so usually reach the surface in volcanic regions that there seems no necessity for examining their origin here, but it may be pointed out that solutions of sulphates rising through graphitic slates, such as form in part the foot wall of the Gold Hill mines, would necessarily be reduced to sulphides. Both augite and plagioclase would yield to the attack of carbonic and hydrosulphuric acids; carbonates and sulphides of the alkalies and alkaline earths would be formed, and these are solvents for quartz and sulphides of the heavy metals. There is no difficulty, therefore, in accounting for the solution of the materials filling the COMSTOCK LODE. It is somewhat less easy to trace the precipitation of the ore with certainty. Solutions of silica in water containing alkaline carbonates deposit silicic acid only on evaporation, not on cooling; but when sulphides of the alkalies are also present a reduction of temperature is followed by the precipitation of a portion of the silica. Solutions percolating from the east country into the main fissure, where communication with the outer air was less impeded, may have deposited some of the quartz in consequence of cooling. This possibility, however, seems scarcely adequate to explain the phenomena. Vast quantities of the solvent must have been necessary to carry all the silica occurring on the LODE; and it is difficult to understand how any great amount of cooling can have taken place. If hot solutions are supposed to have issued as springs along the croppings, the influence of exterior conditions on the temperature of the water below the surface must have been insignificant, and Sandberger has found that copious mineral springs deposit sinter about their orifices, but not in the channels leading to them. Even if the solutions may be supposed not to have overflowed, being, as they must have been, in communication with an active source of heat, they would have been maintained at a nearly constant temperature by convection.

Precipitation.—Silica is very readily precipitated from solution, and it is well known that when both silica and carbonate of calcium are dissolved in the waters of hot springs, the acid is deposited near the source and calcite at a greater distance. Sandberger states that when such solutions become saturated with carbonates the silica is precipitated. If so,[1] it is not difficult to understand how a continuous precipitation of silica may have taken place while the carbonates were carried off in solution.

It has been explained that the DISTRICT shows very small evidences of erosion since the deposition of ore began—less than one would suppose compatible with the deposition of quartz from flowing springs on so large a scale. The DISTRICT presents many points of similarity to the neighborhood of Steamboat Springs, where but little water flows off, while abundant columns of steam constantly rise from many vents. If, as seems probable, the condition of things at WASHOE was similar, the precipitation of silica must have been greatly accelerated by concentration of the solutions through evaporation. Precipitated silica is, of course, in great part amorphous, but its conversion into quartz is a well-known change.

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[1] This statement is no doubt founded on experiments, of which I have failed to find an account.

CHAPTER VII.

HEAT PHENOMENA OF THE LODE.

Section 1.

GENERAL DISCUSSION.

High temperatures of the mines.—One of the peculiarities for which the Comstock Lode has been famous ever since deep mining began upon it, is the high temperature of the rock and of the water encountered. In this respect it stands alone among ore deposits, though water heated to 125° F. has been encountered in the Clifford mine in Wales, and very hot water is found in the superficial workings of the cinnabar deposits in the coast range of California. On the 3,000-foot level of the Comstock floods of water have entered the mines at 170° F. Water at this temperature will cook food, and will destroy the human epidermis. Even a partial immersion in it is therefore fatal. In spite of very rapid ventilation, the air in the underground galleries is often intensely heated and is nearly saturated with aqueous vapor. Many deaths among the miners have occurred from prolonged exposure to these unnatural conditions, which also add immensely to the difficulties of geological exploration.

Normal increment of heat.—A great many investigations have been made during the last years, in many parts of the world, on the increase of the temperature from the surface of the earth downward. The observations have not resulted in establishing a uniform rate of increase in any locality, nor is such a result to be expected from any future observations. If the temperature is determined in a freshly drilled hole the record will necessarily be too high, because the surrounding rock is heated by the mechanical action of the drill. But the moment the rock is placed in communication with air from the surface, or with water from higher levels, it begins to cool off. Rocks are always more or less fissured, and a shaft or well of any depth commonly drains the surrounding country, so that water from a higher level is almost invariably present at the bottom. If a shaft is kept pumped out, the equilibrium of waters at a lower level may be disturbed, and currents from greater depths will then rise into the excavation. Even when the surface is unbroken it is well known that there are usually subterranean currents, the course of which is determined by the structure of the rock, and which locally interfere with the regularity of the isogeotherms. While absolute uniformity in the increase of temperature is nowhere to be expected, a vast number of observations show that the variations are usually confined to comparatively thin belts, and that they vibrate about a rate of 1° F. to from 50 to 60 feet of depth. Sir William Thomson makes an increase of 1° F. for every 51 feet of descent the basis of his calculations on the secular cooling of the earth. The marked exceptions occur in regions where there are other evidences of an abnormal temperature, furnished by traces of recent volcanic action or by the presence of hot springs.

Disturbing effect of local causes in mines.—If the observations taken in vertical openings of small diameter, such as artesian wells and mining shafts, are subject to fluctuations from local causes like those above mentioned, this must be to a much greater extent the case in an extensive and complex system of mines, such as those which are being worked on the COMSTOCK LODE. The country is honeycombed to a depth of 3,000 feet. Above 150 miles of galleries have been driven, besides stopes of a very extensive character, and in many of these artificial ventilation has been going on for years. On account of the great heat, the ventilation is naturally rapid, and is artificially stimulated to the greatest possible extent. The air leaves the mines nearly saturated with aqueous vapor, at an average temperature, according to Mr. Church, of 92° F. In this way an enormous quantity of heat has been abstracted from the rock. Although before the opening of the mines the country was almost absolutely dry, about 7,000,000 tons of hot water are now yearly pumped from the LODE. Mr. Church estimates that the heat annually abstracted from the LODE by drainage and ventilation, without considering evaporation, is as great as 55,472 tons of anthracite produce in the best manufacturing usage. The disturbance of the natural distribution of the waters, and consequently also of the heat, is further indicated by the immense pressure which the water often shows on being tapped by the drills in the lower levels. This not infrequently amounts to a head of several hundred feet.

Scattered observations cannot agree closely.—Taking these circumstances into consideration, it appears to me impossible to reach any accurate result by discussing in detail the fluctuation of the temperatures observed at different times in different portions of the LODE. Before ground was broken considerable variations probably existed in consequence of the presence of convection currents. Under the present conditions it appears from the foregoing that great fluctuations from a regular law of increase, and great anomalies which cannot be immediately traced to their sources, must inevitably occur.

A first approximation from such data.—Baron v. Richthofen, although insisting strongly on the abundant evidences of solfatarism, mentions no abnormal temperatures. Mr. King gives a table of observations, from which it appears that the average temperature of the mine waters, from the surface to the 700-foot level, is between 70° and 75° F. At a depth of about 1,100 feet he found water at 108° F. Mr. King remarks: "That to the waters is due the temperature of the whole interior of the LODE is evident from the fact that they average a few degrees higher than the clays or rocky material." He notes only one instance in which the rock and water showed the same temperature. Mr. Church made many careful observations, which he has very fully discussed. He estimates the mean temperature of freshly exposed surfaces on the 2,000-foot level at 130°. The water with which the Gold Hill mines were flooded in the winter of 1880–'81 entered on the 3,000-foot level. It was repeatedly tested by the officers of the mines, and by myself, and was found to have a temperature of 170° F. This water was first struck at a depth of 3,080 feet, by a drill hole from the bottom of the *Yellow Jacket* shaft. Taking into consideration that 170° is not an average, but probably a maximum for this depth, these data indicate roughly a nearly uniform increase of temperature of about 1° for every 28 feet.[1] If the attempt be made to discuss the observations in detail, great irregularities will be found. As Mr. Church very pertinently remarks, "the

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[1] More exactly an increase of 1° in 28.7 feet for the interval of 1,650 feet between the 350-foot and the 2,000-foot levels, and of 1° in 27½ feet for the 1,100 feet between the 2,000 and 3,100-foot levels.

mining works do not follow the lines of heat manifestation, but intersect them in every possible manner."

Better data lately obtained.—Thanks to Mr. Church, better data have been obtained since his memoir was written. At his suggestion frequent observations have been made on the temperature of the rock and the water encountered in sinking the *Combination*, the *Yellow Jacket*, and the *Forman* shafts. A long series of observations has also been made in the *Sutro Tunnel.* These observations and their discussion will be found in the second section of this chapter. Though they might properly be introduced here their voluminous character makes it more expedient to consider them separately. The two chains of reasoning may be regarded as parallel arguments on the same subject.

Explanations of the heat.—Various explanations have been offered to account for the prevalence of high temperatures on the COMSTOCK. The source of heat has been sought in friction, in the oxidation of pyrite, in the kaolinization of feldspar, and in volcanic action.

That heat must have resulted from the faulting action there can be no doubt, but the whole tendency of the evidence is so strongly against the application of Mr. Mallet's hypothesis of terrestrial heat to this instance, that a discussion seems unnecessary. The oxidation of pyrite, too, is a very subordinate phenomenon on the COMSTOCK. It is well known that various occurrences of pyrite differ greatly in their behavior toward oxidizing agents. That found on the COMSTOCK is for the most part very stable, and often remains exposed for years with no greater effect than tarnishing. Most of the water from the LODE, too, shows but a small amount of sulphates. Indeed, there is much more reason to suppose that the formation of pyrite is still in progress, on a small scale, than that the decomposition of this mineral is the source of heat.

Statement of the kaolinization hypothesis.—The hypothesis that the high temperature is due to the kaolinization of feldspar, appears to rest on two positive grounds, viz., that flooded drifts have been observed to grow hotter, and that the solidification of water liberates heat. In the argument supporting this hypothesis, its author makes the following statement:

"The direct evidence that heat is produced when water is brought in contact with these rocks is of constant occurrence in the mines, and is offered, in fact, whenever a pump breaks or is stopped for any reason, and water rises upon a partially decomposed seam. A case of this kind in the *Caledonia* is of more than ordinary interest, for the reason that this was a cool mine, both rock and water being but little above ordinary temperatures. The heat of the air in the drift was probably not above 90° F., but after lying twenty-four hours under water a very marked change took place. The water had reached a thick seam of the kind that is solid enough when dry, but swells with great force when wet. The 12-inch timbers were all splintered, and the temperature of the level had risen probably to 110°, though no observation was taken. Still the fact of increased temperature and of increase from this cause alone was undoubted. Since that time the *Julia*, *Savage*, and *Hale & Norcross* mines have all been flooded and subsequently drained. The *Norcross* has a fine current of fresh air, and I have not observed any complaint of its condition, but both the other mines were reported to be extremely hot after their submersion. They were very much above their usual temperature, and work was frequently stopped to allow them to cool down. Such evidences cannot take the place of exact laboratory experiments, but they are just as incontestable proof of the fact of heat, and high heat, from kaolinization, as if we had its precise measure."

Criticism on the evidence.—It will be observed that it is not stated when the flooding of the drift in the *Caledonia* occurred, or who estimated the temperatures; nor yet whether the water of this particular flood was warm or cold. With regard to the flooding of the *Julia*, *Savage*, and *Hale & Norcross* mines, the only event of the kind known to me was that which occurred in 1876. This flood lasted for three years. Soon after its commencement an official report of the superintendent gave the temperature of the water at 139°, and Mr. Church reports it later (apparently early in 1878) as 154°.[1] The great heat of these mines appears to require no further explanation. I am not able to confirm the observation that flooded drifts grow hotter, except when the water of the flood enters the workings at a high tempera-

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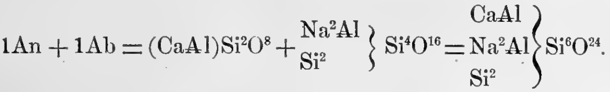
[1] This change of temperature is not remarkable and has not been advanced in favor of the chemical theory of the heat, for many millions of gallons were pumped from the flooded mines. Streams percolating from a large body of heated water through new channels in comparatively cool rock will at first be cooled; but they will grow warmer as the rock is gradually raised to the temperature of the water at the source.

ture. There are many miles of drifts on the COMSTOCK flooded to a greater or less extent; but a great number of observations made by my party show that the water is hottest when it issues from the rock, and cools off by standing in the workings. When the water at its entrance is tepid or cool, it appears to remain so indefinitely, even though it may be stagnant

Examination of the theory of kaolinization.—While no fact can be better established than that the solidification of water liberates heat, no direct conclusions can be drawn from it as to the relations of the complex process of kaolinization. The constitution of the unisilicates is still very obscure, and there is no unanimity of opinion among mineralogical chemists, even as to the formulas by which they should be represented, while almost nothing is known of the reactions which go on during decomposition. It may not be amiss, however, to examine the question from a theoretical point of view.

Feldspar assumed as representative.—As has been shown in Chapter III., the feldspars of the diorite and diabase which form the walls of the COMSTOCK are apparently labradorite and oligoclase Whether Professor Tschermak's theory of the feldspar group is correct or not, a mixture of these feldspars may for the present purpose be regarded as a compound of one molecule of anorthite and one of albite. The mixed or intermediate (andesine) feldspar may then be written

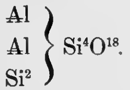


$$1\mathrm{An} + 1\mathrm{Ab} = (\mathrm{CaAl})\mathrm{Si}^2\mathrm{O}^8 + \left.\begin{array}{l}\mathrm{Na}^2\mathrm{Al}\\ \mathrm{Si}^2\end{array}\right\}\mathrm{Si}^4\mathrm{O}^{16} = \left.\begin{array}{l}\mathrm{CaAl}\\ \mathrm{Na}^2\mathrm{Al}\\ \mathrm{Si}^2\end{array}\right\}\mathrm{Si}^6\mathrm{O}^{24}.$$

First step of decomposition.—The examination of thin sections leads me to believe that the first change in the feldspars of the WASHOE rocks is the formation of calcite, accompanied by a separation of silica. The formation of sodium silicate probably takes place at the same time, but is not traceable by optical means, for it will dissolve, and either pass out of the rock or become diffused through it. If from the above formula

$$\mathrm{CaO} + \mathrm{SiO}^2 \text{ and } \mathrm{Na}^2\mathrm{SiO}^3$$

are subtracted, it becomes



$$\left.\begin{array}{l}\mathrm{Al}\\ \mathrm{Al}\\ \mathrm{Si}^2\end{array}\right\}\mathrm{Si}^4\mathrm{O}^{18}.$$

The feldspars of the massive and metamorphic rocks are ordinarily fresh,[1] and they appear to decompose only under peculiar conditions, the details of which are not fully understood, but the circumstances point to the intervention of external energy. Such behavior is characteristic of compounds the formation of which is accompanied by a liberation of heat. The silicates containing a single base appear to liberate but a very small amount of heat, for the thermal effect even of the formation of sodium silicate is very small indeed, and that of calcium and aluminium silicates is, by inference, smaller still. The separation of the feldspars into silicates of the earths will probably, therefore, be accompanied by the absorption of heat, and so will the solution of sodium silicate. I know of no experiments to show precisely what is the thermal effect of the conversion of calcium silicate into calcium carbonate, but the behavior of the carbonate and silicate of sodium, and of calcic carbonate, leaves little doubt that it must be the evolution of a small amount of heat, less than that evolved by the formation of calcium carbonate.

Formation of kaolin.—If kaolin results from the decomposition of these feldspars, there must be a still further separation of silica, and an introduction of hydrogen. The structural formula adopted suggests interesting possibilities. It is, namely, by no means impossible that the silicon represented in the last formula as basic should be replaced by hydrogen by the reaction

$$2Si + 4H_2O = 2SiO_2 + 8H.$$

Were this the case, the result would be silicic anhydride and

$$\left.\begin{matrix}Al\\Al\\H^8\end{matrix}\right\}Si^4O^{18},$$

or twice

$$Al^2O^3, 2SiO^2 + 2H^2O$$

(the ordinary formula for kaolin), if the water is regarded as combined.

The heat liberated by the reaction

$$2Si + 4H^2O = 2SiO^2 + 8H$$

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[1] It has been already remarked that the decomposition of an insignificant percentage of a feldspar crystal robs it of its transparency. Many dull, chalky-looking feldspars, when seen under the microscope, prove to be very slightly altered.

can be calculated; for the combination

$$2H + O = H^2O \text{ (solid) liberates } 70,400 \text{ units of heat,}$$
$$Si + 2O = SiO^2 \text{ liberates } 211,100 \text{ units of heat,}$$

and therefore

$$2Si + 4H^2O = 2SiO^2 + 8H \text{ liberates } 140,600 \text{ units.}$$

The molecular weight of the andesine feldspar under discussion is 757.6, and the heat liberated per unit of weight would be

$$\frac{140,600}{757.6} = 186 \text{ units.}$$

The specific heat of feldspars varies from 0.183 to 0.196. If the andesine under discussion is supposed to have a specific heat of 0.186, the temperature resulting from the substitution of hydrogen for silicon would be 1000° C.

The $2H^2O$ is water of hydration.—If, then, the water in kaolin were chemically combined, a temperature would be produced much above that known to be sufficient to expel the water from clay, and the only inference I can draw is that the water is not, as has sometimes been maintained, chemically combined, but is merely water of hydration. The latter view (which is also generally held) is further supported by the varying amounts of water which various analysts have found in kaolin. As is well known, Tschermak even denies that kaolin is a product of the decomposition of plagioclase, affirming that the resulting hydrated aluminium silicate contains but a single molecule of water.

Nothing known of the heat of hydration of kaolin.—The purpose of the foregoing argument is to show that if any considerable quantity of heat is evolved during kaolinization, it must in all probability be due to the simple hydration of aluminium silicate. But of the heat liberated by the hydration of salts little is known, except (1) that the quantity is usually small, (2) that it is sometimes negative, and (3) that the different molecules of water combine with differing amounts of energy, indicating that the nature of their union differs. Of the heat of hydration of kaolin we know nothing specific, nor am I aware of any analogy which indicates a likelihood that it is sufficient to account for the heat phenomena of the COMSTOCK LODE.

Experiments on kaolinization.—In the hope of reaching more satisfactory results regarding kaolinization than observation or theoretical considerations yielded, I requested Dr. Barus to undertake experiments with a view to testing the asserted rise of temperature when the WASHOE rocks are brought in contact with water.

Material selected.—The rock selected was from a mass cut by the *Sutro Tunnel* in the *Savage* claim, just before the tunnel strikes the vein. It is a diabase, and the freshest encountered under ground opposite that portion of the LODE which has been considerably productive. It is described under slide 18, and its analysis is given at the end of Chapter III. Lest it should be objected that this rock had escaped decomposition through an exceptional structure or a local variation in chemical composition, it may be remarked that no trace of such a difference is perceptible either macroscopically or microscopically, while its exemption from decomposition is fully accounted for by the character of its occurrence. This mass, like most of the fresher rocks in the DISTRICT, is protected by clay seams which have prevented the access of aqueous currents. The hanging wall of the COMSTOCK is to so large an extent obliterated by decomposition that many observant miners deny its existence, but at this particular spot no vein-wall could be better defined. It is marked by a compact smooth clay a foot or more in thickness, immediately over which lies the mass of rock referred to. This is further protected, though not so clearly, by other clay-seams to the east, and is much less shattered than the rock elsewhere.

Method adopted.—The rock was reduced to a gravel and placed within a well-packed steam jacket. Steam was supplied from a boiler beneath, in which the water was kept at a constant level and constantly boiling. The difference of temperature between the rock and the inclosing steam was measured by a thermopile. The electro-motive force was so compensated that a variation of 0.001° C. was clearly indicated, and the experiments extended over five weeks with only four interruptions. The whole plan of the investigation was worked out by Dr. Barus, who will describe it in detail in a separate chapter. The appliances at his command were few and simple, but they were employed with such ingenuity as to enable him to obtain very accurate results. The execution of the experiments was most conscientious and laborious.

No positive results obtained.—The temperature of the rock-mass never rose above that of the surrounding steam. The rock seemed wholly unaffected by the process, except that the fragments were more or less coated with a fine dust, probably due to the salts contained in the water, which was obtained from the Virginia Water Company's pipes.

Little kaolinization at Washoe.—Some time after the execution of these experiments a special examination of the slides and a comparison of chemical analyses led me to the conclusion that there has been only a trifling amount of kaolinization in the WASHOE rocks. This fact makes the experiments none the less important, for the heat of the LODE might be due to other chemical changes than kaolinization.

Conclusions regarding the hypothesis.—In short, the observations as to the rise of temperature of flooded drifts lack confirmation; experiment fails to show that hot water or steam have any action on the east country rock of the LODE; there appear no theoretical grounds for the assertion that kaolinization would produce a considerable amount of heat, and no evidence that any considerable amount of kaolinization has gone on in the DISTRICT. It is still possible that when kaolinization occurs heat is liberated. It is also possible that at temperatures above 212° and at pressures above one atmosphere, feldspars are kaolinized near the COMSTOCK fissure, but it no longer appears reasonable to ascribe the heating of drifts, which are nearly at the normal pressure, to the action of water below the boiling point upon the rock. The scene of kaolinization, if it exists at all, must therefore be at great depths, such as are indicated in the discussion of the increase of temperature from the surface downward. It cannot be demonstrated that the heat of the COMSTOCK is not due to the prevalence at unknown depths and pressures of a chemical change of unknown thermal relations, neither is there any evidence that it does arise from such a cause; and the suggestion that the heat of the Steamboat Springs and the ordinary variations of earth temperatures are induced by kaolinization, is therefore foreign to the subject of this memoir.

Solfataric action.—The only remaining supposition is that which connects the heat of the COMSTOCK with the chain of volcanic phenomena. What is known as solfataric action is ill understood, and must remain so until many of the mysteries of vulcanism have been made plain; but of certain facts there is no doubt. In the neighborhood of active volcanoes, and often also in regions where eruptions have ceased, gases and water charged with more or less active reagents reach the surface through crevices. In its earliest stages a solfataric spring frequently emits gas or water charged with fluorine and chlorine compounds, which are replaced at a later stage by hydrosulphuric and carbonic acids. The action of these reagents on the rocks is manifold, but usually gives rise to characteristic appearances, such as bleaching, accompanied by an extraction of a smaller or greater portion of the bases. The appearances due to solfatarism are, of course, accurately known, from immediate observation in the neighborhood of active volcanoes. On the other hand, it is very seldom that effects likely to be confounded with those of solfatarism are found at any great distance from localities marked by the occurrence, present or past, of volcanic eruptions. No two phenomena in geology are more intimately connected than volcanoes and solfataras. The connection between ore deposits and eruptive rocks is also in a large proportion of cases a very close one, and where ore deposits and evidences of solfataric action are found together in a volcanic region, it is certainly natural to conclude that an abnormal temperature of the rock and water is also due to vulcanism. The burden of proof rests on him who offers any other explanation.

Decomposed area at Washoe.—Extreme alteration is for the most part limited to the area lying between the COMSTOCK and the Occidental Lodes, though it also extends up some of the ravines to the west of the great vein.[1] Even within this area there are great variations in the degree of decomposition. While a portion of the rock on the surface is tolerably well preserved, there are belts nearly parallel to the LODE, in which it is so altered that it might be mistaken for more or less discolored chalk. These belts can be followed under ground, and retain in dip as in strike an approximate parallelism to the vein. Towards the edges of the surface area it is common to find nodules of rock in place which are fairly fresh at the center, but show pro-

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[1] See Fig. 1, page 73.

gressive decomposition towards the outside. Large masses of fresh rock also occur in a similar way, as has been described in the discussion of propylite. It is clear from these occurrences that had the decomposing action been prolonged sufficiently, no undecomposed rock would have remained. Under ground the decomposition is more universal, if one may judge from the *Sutro Tunnel*. From Shaft II. to the LODE no fresh rock is exposed by the tunnel, except the small mass of diabase close to the hanging wall which has been referred to. This marked difference between the superficial and subterranean rocks should be considered in connection with one of the deductions made in discussing the structural results of faulting—viz., that the country has undergone but little erosion since the deposition of the ore. Indeed, it may be regarded as independent evidence tending to the same conclusion.

Rocks involved.—The three rocks which occur in the belt of highly decomposed east country are diabase, hornblende-andesite, and augite-andesite. The andesites are found extensively in other portions of the DISTRICT, where, however, they are decomposed to but a trifling extent. There is no reason known to me to suppose that the decomposed andesites are of different eruptions from the fresh occurrences; on the contrary, the decomposition dies out gradually in continuous areas. Neither is there any evidence that the fresh and the altered masses are of a different composition.

Evidence of an external cause.—Had the resolution of the complex rock minerals into simple compounds been spontaneous, the nodules of rock described could not have formed, for the action must have been nearly uniform throughout. Neither could they have been formed if the presence of moisture had been sufficient to induce decomposition, for all rocks, except perhaps obsidian, are permeable by water. Solutions of carbonic acid, hydrosulphuric acid or the like, on the other hand, if brought in contact with compact masses of material susceptible to their action, would grow weaker as they penetrated towards the centers of blocks, and would bring about just such results as those referred to.

Evidence that the solutions ascended.—If surface waters had produced the decomposition, the andesites at the surface throughout the DISTRICT would have suffered nearly uniformly, and the amount of decomposition must have decreased as greater depths were reached. If, subsequent to the decomposition, erosion had taken place, the rocks at lower elevations would be found fresher than those on the hills. The reverse is the case. But if decomposition was produced by waters rising from great depths, the area of alteration would depend on the structure of the rock, on the existence of fissures through which they could reach the surface, and from which they could act upon the material bounded by these fissures; which accords with the observations. Moreover, the resemblance of the products of decomposition in this DISTRICT to those occurring in solfataric regions is very strong, and their dissimilarity to those produced by ordinary surface action equally great.

These considerations appear to me conclusive that the decomposition was effected by aqueous currents rising from lower depths, and that these currents carried in solution reagents capable of producing the effects familiar in solfataras.

Nature of the reagents.—There is some positive evidence as to what these reagents were, for the water struck in the *Yellow Jacket* at 3,080 feet from the surface was so strongly charged with hydrogen sulphide as seriously to inconvenience the miners, and evidence is given in the chapter on chemistry that hydrosulphuric acid must have played an important part in the rock decomposition. The Steamboat Springs, which lie on a fissure parallel to the COMSTOCK, and on the opposite side of the Virginia range, are also charged with solfataric gases.

Origin of the reagents volcanic.—There is no conceivable reaction between water and the components of the eruptive rocks, which would have produced hydrogen sulphide, and the other solfataric gases. Their origin must, therefore, be sought outside of and below these eruptive rocks. It would certainly be permissible to argue immediately from the agency of solfataric gases to volcanic action, but it may also be suggested that the vast quantity of hydrosulphuric and carbonic acids which have been consumed could not have been produced at low temperatures, and that, when formed at unknown but certainly great depths, they could have been brought to the surface or the mines only by convection currents, which were stimulated by heat. These considerations force me to the belief that below the COMSTOCK, perhaps at a depth of three or more miles, there is a large body of highly heated rock in contact with sedimentary material. The well-known reactions which take place under such circumstances in the presence of water have produced solfataric gases as long as the supply of sulphates and of reducing agents held out. Of these there is now a mere trace. Whether this highly heated rock is part and parcel of the surface rocks of the WASHOE DISTRICT is a question which can only be answered in terms of probabilities; yet as these rocks must have come from a focus of volcanic action in about the same vertical line, the chances are certainly in favor of the supposition that the high temperature of the LODE is a later member of the series of phenomena, of which the ejection of the younger hornblende-andesite, or possibly of the basalt, was an early manifestation.

The rocks all moist.—The dissemination of heat through the rocks of the COMSTOCK has been regarded by one geologist as a point very difficult of explanation. He regarded the rocks as dry, and assuming their conductivity to be the same as that of the Calton Hill trap, which Sir William Thomson has made famous, he found the transmission of heat insufficient to account for the facts. The rocks are in great part dry, as miners use the word—*i. e.*, many exposures do not drip water; but though paying especial attention to the subject, I found none which were not moist. Chips and specimens, for example, always changed color after half an hour's exposure to dry air, except when taken from flakes which were already partially separated from the mass and exposed to a drying current. The rocks of the DISTRICT are not glassy but crystalline, and that such rocks in the immediate neighborhood of vast bodies of water at pressures equivalent to a head of, say, from 1,000 to 3,000 feet, ever since they cooled many thousand years ago, should remain dry, would be strange indeed, and quite opposed to all that is known of the permeability of rocks by water. But when it is taken into consideration that far more than 99 per cent. of this rock is highly decomposed, it is almost inconceivable.

Source of the water unexplained.—The source of the water conveying the heat to the COMSTOCK is somewhat mysterious. The country is a sage-brush desert, and the rainfall is not over ten inches. The slopes are steep and the evaporation immense. The mines are now so deep that they might drain a large extent of country, but great quantities of water were met with when the workings were within a few hundred feet of the surface and could apparently drain but a very small area. Before mining began, however, little or no water issued from the surface. When the first floods were encountered it was supposed that there must be great accumulations of water in subterranean caves, and that water-ways leading to them had been cut by the workings. But no such openings were ever reached in the mines, and it came to be supposed that the water had accumulated in the interstices of shattered rock masses. Broken as the rock is, however, it is very closely packed, so that the interstitial space is but small, and considering the vast quantities of water which have been pumped from the mines, I cannot think the explanation adequate.[1] The pressure under which the water is frequently met is a significant feature of its occurrence. Though there may be other workings on the same level, and though the country above may be extensively opened up, a new source will sometimes show a head of several hundred feet. The deeper the point at which the water is struck the hotter it usually is, and there appears to be some tendency of the temperature of the water from a single source to increase as it is drained. But if it were accumulated in a mass of shattered rock of limited extent, the water and the rock throughout the entire space would necessarily assume a perfectly uniform temperature, and channels tapping such an accumulation at different levels would emit streams of the same temperature. As has been seen, the rock is commonly cooler than the water, and the general reasoning in the foregoing paragraphs points to the rise of currents from great depths. An attempt will be made to reconcile these facts.

Hypothesis of its origin in the Sierra.—In the Gold Hill mines the foot wall of the LODE in the lower levels is composed of metamorphic rocks dipping to the east, as do those also on the whole which occur at the southwestern corner of the map. But from the COMSTOCK west the country, excepting one or two small masses of granite, is completely covered by volcanic rocks, for a distance of about 12 miles, or until the main range of the Sierra Nevada is reached. This grand feature of the continent is far too complex to be simply characterized as an anticlinal, but the declivities opposite the COMSTOCK show more or less metamorphosed strata with an easterly dip, and it is fair to infer that for some distance from its vast mass, *i. e.*, in the country between it and Virginia, the strata underlying the fields of andesites dip

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[1] Seven million tons of water, the estimated annual discharge, is about 600 feet cube.

in the same sense. If so, a portion of the drainage of the Sierra must reach great depths beneath the WASHOE DISTRICT, depths at which the temperature must be very high. It seems probable enough that meeting the fissure of the COMSTOCK and the partings subsidiary to it, the water thus conveyed to the region of heat rises to the mines. The hypothetical structure suggested is illustrated in Fig. 12.

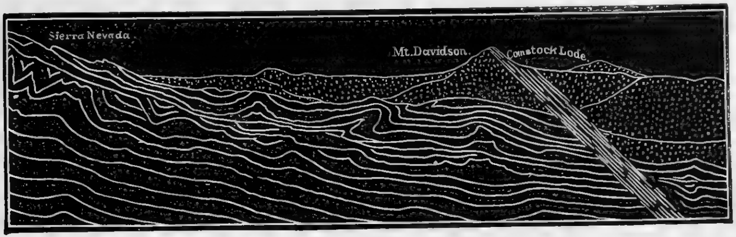

FIG. 12.—Ideal section across the Virginia Range.

What it would account for.—In a country so disturbed by volcanic action and so highly metamorphic as that underlying the WASHOE DISTRICT probably is, the circulation must be much obstructed. Comparatively open water channels leading from the Sierra are likely to connect only with fissures almost capillary near the LODE, and *vice versâ.* This would account for the fact that some springs in the mines yield a steady supply of water, while in other cases a great body is eventually pumped out and leaves only an insignificant flow. It would also account for the increase of the heat of the water with the depth, and its decrease at considerable distances from the LODE and its accompanying fissures; for if narrow water channels extend from a distant source of heat towards a constantly radiating surface, equality of temperature can never result. The rising currents must constantly lose heat. Descending currents will also be established, which will, however, cause only local irregularities in the increment of temperature. Where great quantities of water are drained from a single source, the tendency would plainly be to a rise of temperature, and the head which the floods so often show would find an ample explanation in the supposed connection with channels from the great range. No reasoning on such points, however, can be conclusive, for the opportunities of establishing the truth of the hypothesis are very meager.

SECTION II.

THERMAL SURVEY.

Temperature observations.—Valuable temperature observations have been taken on four lines near the COMSTOCK, viz., in the *Combination*, new *Yellow Jacket*, and the *Forman* shafts, and in the *Sutro Tunnel*. These observations were all made at freshly exposed points as the excavations progressed, at a distance from all other workings, and while not unaffected by some of the disturbing causes mentioned on page 229, form a far more trustworthy guide as to the theoretical conditions of the LODE than a similar number of determinations made in the mines. Each set, too, was observed as a matter of routine duty, so that successive observations must have been affected by nearly constant errors; and though many of them were made with less precaution than a physicist would have employed, their great number goes far toward compensating for any roughness in the method. Whoever is familiar with the tone of speculative excitement which prevails in the mining regions of the far West, a tone but little in harmony with scientific research, will agree with me that great credit is due to the officers of the mines for making and preserving these records. It would be well for the advancement of pure and applied science if such a spirit were general among those whose occupations bring them in contact with natural phenomena.

Computation of the observations.—The following tables and diagrams need but little explanation. On plotting the temperatures taken in the shafts, no indication of curvature could be perceived, and a straight line was therefore assumed as expressing the relation of temperature to depth.

The equation of this line is

$$t = a + bd;$$

where t is the temperature in degrees Fahrenheit corresponding to the depth d in feet, and a and b are constants to be calculated. The computations by the method of least squares were performed by Dr. Barus and Mr. Reade.[1] For the sake of comparison they also computed the observations made at the Rose Bridge Colliery, and I add the Sperenberg observations with Mr. Heinrich's equation. The *Sutro Tunnel* data cannot be treated in the same way, for they show an unmistakably curvilinear locus. A curve was drawn empyrically through the plotted points, no weight being given to any preconceived idea of the character of the law of increment. Subtangents were constructed and found to be almost exactly equal; or, in other words, it was found that the graphical approximation nearly coincided with the locus of an exponential equation

$$t = 80 + 34\, l^{0.000\,32\,+},$$

in which l denotes the horizontal distance from the LODE.

The method of least squares is, of course, applicable to the computation of an equation of this character, but the calculation is so serious an undertaking as to be worth while only when a magnificent series of observations is to be reduced. In the present case no exterpolation is desired, and a determination of the character of the curve with an approximate knowledge of the value of the constants is sufficient for the purposes of the discussion.

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[1] The method of least squares furnishes the formulas

$$a = \frac{\Sigma t \,.\, \Sigma d^2 - \Sigma d \,.\, \Sigma dt}{n \Sigma d^2 - \Sigma d \,.\, \Sigma d},$$

$$b = \frac{n \,.\, \Sigma dt - \Sigma d \,.\, \Sigma t}{n \,.\, \Sigma d^2 - \Sigma d \,.\, \Sigma d},$$

in which due preference is given to the temperatures corresponding to a greater depth. The observations become relatively more accurate as temperature and depth increase, and seem also to have been made with greater care.

TABLE I.—COMBINATION SHAFT. ROCK TEMPERATURES.

[Observations made by the superintendent.]

COLUMNS 3 and 4.—Observations of depth and temperature, respectively, as taken.
5 and 6.—Means of consecutive sets, of five observations each, of depth and temperature, respectively.
7.—Temperature as calculated from the constants derived.
8.—"Error" or observed temperature minus the calculated result.

[Depths are given in feet; temperatures, in degrees Fahrenheit.]

$a = 66.0$. $b = 0.0252 \pm 0.0007$.

No.	Date.	Depth observed.	Temperature observed.	Mean depth observed.	Mean temperature observed.[1]	Mean temperature calculated.	Error.
	1877.	*Feet.*	°*F.*				
1	July 17	1,476	106				
2	18	1,479	104				
3	19	1,482	103				
4	20	1,485	105				
5	21	1,489	100	1,482	103.6	103.4	+ 0.2
6	22	1,492	105				
7	23	1,495	103				
8	24	1,498	103				
9	25	1,501	102				
10	26	1,504	104	1,498	103.4	103.8	− 0.4
11	27	1,507	106				
12	28	1,510	105				
13	29	1,513	104				
14	30	1,516	106				
15	31	1,518	104	1,513	105.0	104.1	+ 0.9
16	Aug. 1	1,520	105				
17	2	1,522	103				
18	3	1,524	104				
19	4	1,526	102				
20	5	1,528	106	1,524	104.0	104.4	− 0.4
21	6	1,530	103				
22	7	1,532	106				
23	8	1,535	104				
24	9	1,539	105				
25	10	1,541	106	1,535	104.8	104.7	+ 0.1
26	11	1,544	104				
27	12	1,547	106				
28	13	1,550	105				
29	14	1,553	106				
30	15	1,556	103	1,550	104.8	105.1	− 0.3
31	16	1,559	102				
32	17	1,562	101				
33	18	1,565	107				
34	19	1,568	105				
35	20	1,571	106	1,565	104.2	105.5	− 1.3
36	21	1,574	106				
37	22	1,577	104				
38	23	1,579	105				
39	24	1,582	106				
40	25	1,585	106	1,579	105.4	105.8	− 0.4
41	26	1,588	104				
42	27	1,591	106				
43	28	1,593	108				
44	29	1,596	108				
45	30	1,599	107	1,593	106.6	106.2	+ 0.4

[1] Probable error of one of these mean observations = ±0°.5.

Table I.—COMBINATION SHAFT. ROCK TEMPERATURES—Continued.

No.	Date.	Depth observed.	Temperature observed.	Mean depth observed.	Mean temperature observed.[1]	Mean temperature calculated.	Error.
	1877.	*Feet.*	° *F.*	*Feet.*	° *F.*	° *F.*	° *F.*
46	Aug. 31	1, 603	106				
47	Sept. 1	1, 605	108				
48	2	1, 607	107				
49	3	1, 609	106				
50	4	1, 611	108	1, 607	107. 0	106. 5	+ 0. 5
51	5	1, 613	106				
52	6	1, 615	110				
53	7	1, 617	109				
54	10	1, 620	107				
55	11	1, 622	108	1, 617	108. 0	106. 8	+ 1. 2
56	12	1, 624	109				
57	13	1, 626	109				
58	14	1, 629	107				
59	15	1, 632	108				
60	16	1, 635	108	1, 629	108. 2	107. 1	+ 1. 1
61	17	1, 637	106				
62	18	1, 640	109				
63	19	1, 642	105				
64	20	1, 645	107				
65	21	1, 647	106	1, 642	106. 6	107. 4	− 0. 8
66	22	1, 649	108				
67	23	1, 651	105				
68	24	1, 654	110				
69	25	1, 656	109				
70	26	1, 658	107	1, 654	107. 8	107. 7	+ 0. 1
71	27	1, 661	108				
72	28	1, 663	110				
73	29	1, 665	107				
74	30	1, 668	109				
75	Oct. 1	1, 671	110	1, 665	108. 8	108. 0	+ 0. 8
76	2	1, 672	109				
77	3	1, 675	109				
78	4	1, 678	110				
79	5	1, 681	108				
80	6	1, 684	107	1, 678	108. 6	108. 3	+ 0. 3
81	7	1, 687	110				
82	8	1, 690	106				
83	9	1, 693	109				
84	10	1, 696	108				
85	11	1, 698	107	1, 693	108. 0	108. 7	− 0. 7
86	12	1, 700	109				
87	13	1, 703	110				
88	14	1, 706	110				
89	15	1, 709	108				
90	16	1, 711	110	1, 706	109. 4	109. 0	+ 0. 4
91	17	1, 714	108				
92	19	1, 717	109				
93	20	1, 720	107				
94	21	1, 723	110				
95	22	1, 726	108	1, 720	108. 4	109. 4	− 1. 0

[1] Probable error of one of these "mean" observations = ± 0°.5.

TABLE I.—COMBINATION SHAFT. ROCK TEMPERATURES—Continued.

No.	Date.	Depth observed.	Temperature observed.	Mean depth observed.	Mean temperature observed.[1]	Mean temperature calculated.	Error.
	1877.	*Feet.*	° *F.*	*Feet.*	° *F.*	° *F.*	° *F.*
96	Oct. 23	1,728	109				
97	24	1,730	110				
98	25	1,733	110				
99	26	1,736	110				
100	27	1,738	111	1,733	110.0	109.7	+ 0.3
101	28	1,740	110				
102	Nov. 22	1,744	110				
103	23	1,746	108				
104	24	1,748	109				
105	25	1,750	109	1,746	109.2	110.0	− 0.8
106	26	1,752	110				
107	27	1,754	107				
108	28	1,756	108				
109	30	1,758	110				
110	Dec. 1	1,760	110	1,756	109.0	110.3	− 1.3
111	2	1,762	109				
112	3	1,764	110				
113	4	1,766	108				
114	5	1,768	110				
115	6	1,770	111	1,766	109.6	110.5	− 0.9
116	7	1,773	112				
117	8	1,776	110				
118	9	1,779	112				
119	10	1,782	113				
120	11	1,785	112	1,779	111.8	110.8	+ 1.0
121	12	1,788	111				
122	13	1,790	112				
123	14	1,793	112				
124	15	1,796	110				
125	16	1,798	111	1,793	111.4	111.2	+ 0.2
126	26	1,800	113				
127	27	1,803	110				
128	28	1,806	112				
129	29	1,808	113				
130	30	1,810	112	1,805	112.0	111.5	+ 0.5
131	31	1,812	110				
	1878.						
132	Feb. 1	1,900	113				
133	7	1,924	114				
134	14	1,950	114				
135	Mar. 1	1,986	116	1,914	113.4	114.2	− 0.8
136	15	2,000	118				
137	Apr. 5	2,070	118				
138	27	2,135	127				
139	May 27	2,207	128				
140	June 10	2,230	112	2,128	120.6	119.6	+ 1.0

[1] Probable error of one of these "mean" observations = ± 0°.5.

Fig. 13.—COMBINATION SHAFT AND YELLOW JACKET SHAFT TEMPERATURES.

Yellow Jacket —·—·—·—· Combination (rock) - - - - - -

[The mean increments are represented by unbroken lines.]

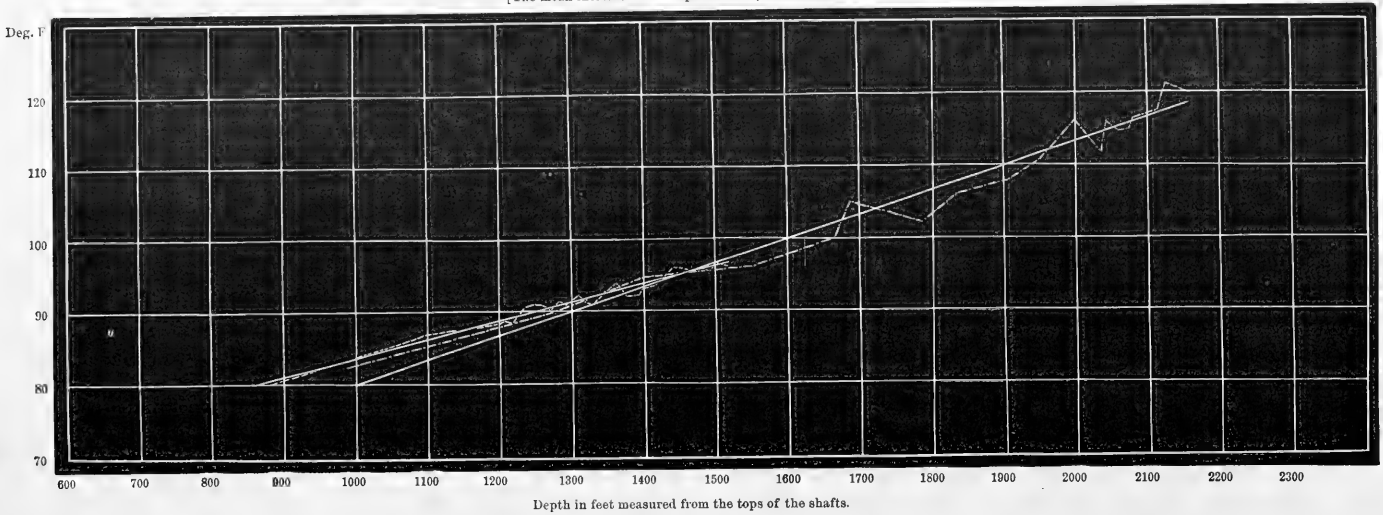

TABLE II.—YELLOW JACKET SHAFT.

[Observations taken by the official in charge, in drill-holes 3 feet deep; records kindly furnished by Capt. THOMAS TAYLOR.]

$a = 53.1$. $b = 0.0334 \pm 0.0009$.

No.	Date.	Depth of drill-hole.	Character of the rock.	Depth.	Temperature observed.[1]	Temperature calculated.	Error.
	1877.	*Inches.*		*Feet.*	° *F.*	° *F.*	° *F.*
1	Aug. 28	22	Wet	845	80.0	81.4	−1.4
2	Aug. 30	20	Wet	849	80.0	81.5	−1.5
3	Sept. 11	13	Wet	874	79.0	82.3	−3.3
4	Sept. 14	15	Dry	883	82.0	82.6	−0.6
5	Oct. 27	24	Dry	923	83.0	84.0	−1.0
6	Oct. 30	24	Dry	932	85.0	84.3	+0.7
7	Nov. 4	21	Dry	945	85.0	84.7	+0.3
8	Nov. 10	24	Wet	960	84.0	85.2	−1.2
9	Nov. 14	36	Dry	966	88.0	85.4	+2.6
10	Nov. 28	20	Wet	1,000	84.0	86.5	−2.5
11	Dec. 15	22	Wet	1,054	89.0	88.3	+0.7
12	Dec. 29	15	Wet	1,095	92.0	89.7	+2.3
	1878.						
13	Jan. 20	30	Wet	1,167	94.0	92.1	+1.9
14	Feb. 15	20	Dry	1,212	98.0	93.6	+4.4
15	Mar. 22	18	Dry	1,316	95.0	97.1	−2.1
16	Apr. 1	36	Wet	1,333	100.0	97.6	+2.4
17	May 27	24	Dry	1,451	104.0	101.7	+2.3
18	June 22	20	Wet	1,600	106.0	106.6	−0.6
19	Aug. 10	18	Wet	1,660	108.0	108.6	−0.6
20	Aug. 30	15	Wet	1,720	110.0	110.6	−0.6
21	Dec. 7	....	Wet	2,017	118.0	120.5	−2.5

[1] Probable error of an observation = ± 1°.4.

FIG. 14.—YELLOW JACKET SHAFT AND FORMAN SHAFT TEMPERATURES.

Yellow Jacket —·—·—·—· Forman (rock) - - - - - - -

[The mean increments are represented by unbroken lines.]

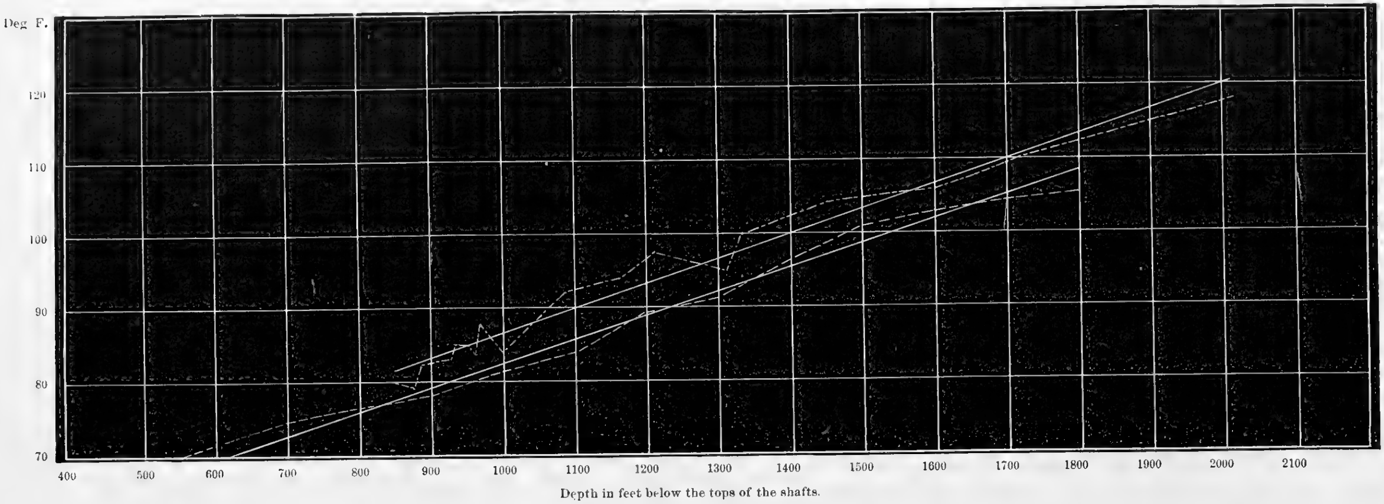

TABLE III.—FORMAN SHAFT. ROCK TEMPERATURES.

[From 100 to 1,800 feet.]

$a = 49.8.$ $b = 0.0326 \pm 0.0006.$

No.	Depth.	Temperature observed.[1]	Temperature calculated.	Error.
	Feet.	° *F.*	° *F.*	° *F.*
1	100	50.5	53.0	− 2.5
2	200	55.0	56.3	− 1.3
3	300	62.0	59.6	+ 2.4
4	400	60.0	62.8	− 2.8
5	500	68.0	66.1	+ 1.9
6	600	71.5	69.3	+ 2.2
7	700	74.8	72.6	+ 2.2
8	800	76.5	75.8	+ 0.7
9	900	78.0	79.1	− 1.1
10	1,000	81.5	82.4	− 0.9
11	1,100	84.0	85.6	− 1.6
12	1,200	89.3	88.9	+ 0.4
13	1,300	91.5	92.1	− 0.6
14	1,400	96.5	95.4	+ 1.1
15	1,500	101.0	98.6	+ 2.4
16	1,600	103.0	101.9	+ 1.1
17	1,700	104.5	105.2	− 0.7
18	1,800	105.5	108.4	− 2.9

[1] Probable error of an observation = ± 1°.3.

TABLE IV.—FORMAN SHAFT. ROCK TEMPERATURES.

[From 500 to 2,300 feet.]

$a = 53.2.$ $b = 0.0296 \pm 0.0002.$

No.	Depth.	Temperature observed.[2]	Temperature calculated.	Error.
	Feet.	° *F.*	° *F.*	° *F.*
5	500	68.0	68.1	− 0.1
6	600	71.5	71.0	+ 0.5
7	700	74.8	74.0	+ 0.8
8	800	76.5	76.9	− 0.4
9	900	78.0	79.9	− 1.9
10	1,000	81.5	82.9	− 1.4
11	1,100	84.0	85.8	− 1.8
12	1,200	89.3	88.8	+ 0.5
13	1,300	91.5	91.7	− 0.2
14	1,400	96.5	94.7	+ 1.8
15	1,500	101.0	97.6	+ 3.4
16	1,600	103.0	100.6	+ 2.4
17	1,700	104.5	103.6	+ 0.9
18	1,800	105.5	106.5	− 1.0
19	1,900	106.0	109.5	− 3.5
20	2,000	111.0	112.5	− 1.5
21	2,100	119.5	115.4	+ 4.1
22	2,200	116.0	118.4	− 2.4
23	2,300	121.0	121.2	− 0.2

[2] Probable error of an observation = ± 1°.4.

TABLE V.—FORMAN SHAFT. WATER TEMPERATURES.

$a = 45.8.$ $b = 0.0373 \pm 0.0010.$

No.	Depth.	Temperature observed.[3]	Temperature calculated.	Error.
	Feet.	° *F.*	° *F.*	° *F.*
1	400	62.0	60.8	+ 1.2
2	500	65.0	64.5	+ 0.5
3	600	70.0	68.2	+ 1.8
4	700	73.0	72.0	+ 1.0
5	800	75.0	75.7	− 0.7
6	900	77.5	79.4	− 1.9
7	1,000	80.5	83.2	− 2.7
8	1,100	83.0	86.9	− 3.9
9	1,200	91.0	90.6	+ 0.4
10	1,300	94.0	94.4	− 0.4
11	1,400	100.0	98.1	+ 1.9
12	1,500	104.0	101.8	+ 2.2
13	1,600	106.0	105.6	+ 0.4

[3] Probable error of an observation = ± 1°.3.

These temperatures were ascertained by drilling holes not less than three feet deep into the rock and inserting a Negretti & Zambra slow-acting thermometer (of the pattern adopted by the Underground Temperature Committee of the British Association and standardized at Kew) into the hole, closing the hole with clay, and leaving the thermometer for from 12 to 24 hours. Not less than three holes were tried at each point.

Fig. 15.—FORMAN SHAFT TEMPERATURES.

Rock — — — —　　　Water —·—·—·—.

[The mean increments are represented by unbroken lines.]

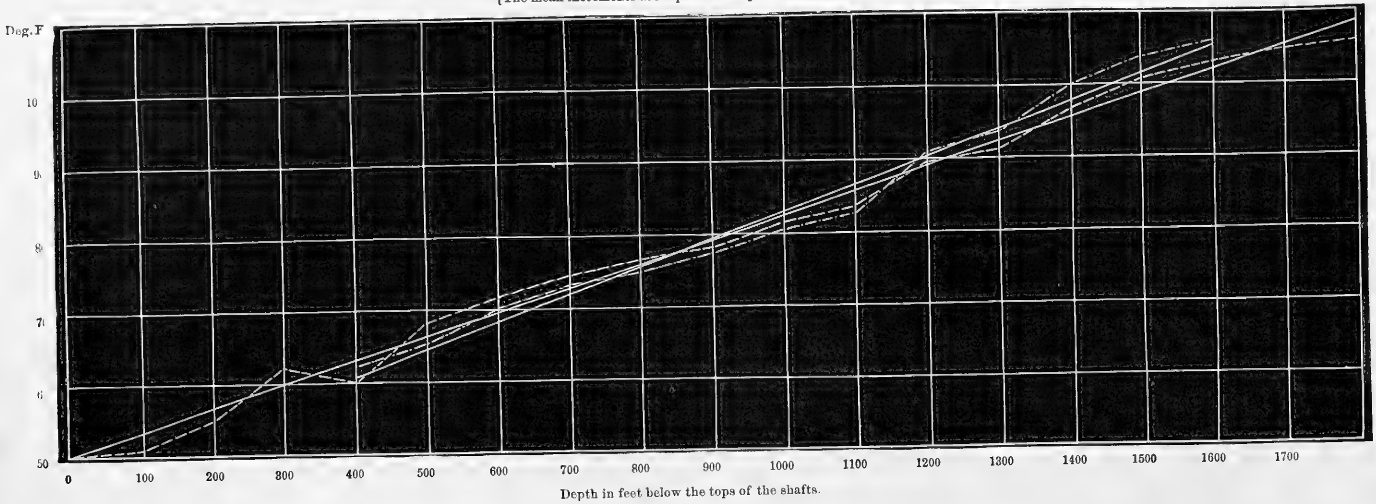

TABLE VI.—ROSE BRIDGE COLLIERIES, AT INCE, NEAR WIGAN.

[Observations given on the authority of John Arthur Phillips, esq. It is not stated whether the temperatures are those of the rock or the water. The original data for depth, in fathoms, are contained in column 2. Observations on Metalliferous Deposits and Subterranean Temperatures, by W. J. Henwood, p. 775.]

$a = 56.0$. $b = 0.0149 \pm 0.0004$.

No.	Depth.	Depth.	Temperature observed.[1]	Temperature calculated.	Error.
	Fathoms.	*Feet.*	° *F.*	° *F.*	° *F.*
1	80.5	483	64.5	63.2	+ 1.3
2	100.0	600	66.0	64.9	+ 1.1
3	279.0	1,674	78.0	80.9	− 2.9
4	302.5	1,815	80.0	83.0	− 3.0
5	315.0	1,890	83.0	84.1	− 1.1
6	331.5	1,989	85.0	85.6	− 0.6
7	335.5	2,013	86.0	86.0	± 0.0
8	339.5	2,037	87.0	86.3	+ 0.7
9	367.0	2,202	88.5	88.8	− 0.3
10	372.5	2,235	89.0	89.2	− 0.2
11	380.5	2,283	90.5	90.0	+ 0.5
12	387.5	2,325	91.5	90.6	+ 0.9
13	391.5	2,349	92.0	91.0	+ 1.0
14	400.0	2,400	93.0	91.7	+ 1.3
15	403.0	2,418	93.5	92.0	+ 1.5

[1] Probable error of an observation = ±1°.0.

Fig. 16.—ROSE BRIDGE COLLIERY AND FORMAN SHAFT TEMPERATURES

Rose Ridge — — — —　　Forman (rock) —·—·—·—·

[The mean increments are represented by unbroken lines.]

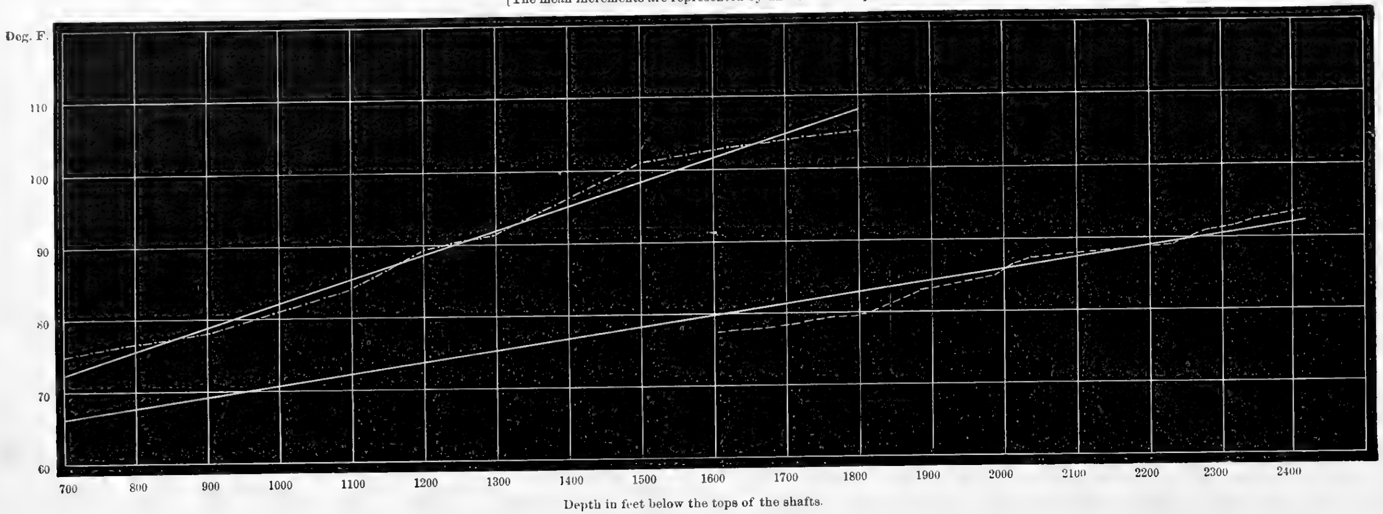

TABLE VII.—SPERENBERG.

[The observations were taken with the geothermometer, and the column of water was cut off on both sides (Zeitschrift für B.- H.- und S.-Wesen im preus. Staate, xx., 1872, p. 225). In the third and fourth columns the data are converted into terms of English units for convenience in comparing them with those obtained at WASHOE.]

Depth in Rhenish feet.	Rock temperature, Reaumur.	Depth in English feet.	Rock temperature, Fahrenheit.
100	10.16	103	55
300	14.60	309	65
400	14.80	412	65
500	15.16	515	66
700	17.06	721	70
900	18.50	927	74
1,100	20.80	1,133	79
1,300	21.10	1,339	80
1,500	22.80	1,545	83
1,700	24.20	1,751	87
1,900	25.90	1,957	90
2,100	28.00	2,163	95
2,300	28.50	2,369	96
2,500	29.70	2,575	99
2,700	30.50	2,781	101
3,390	36.15	3,492	113
4,042	38.25	4,163	118

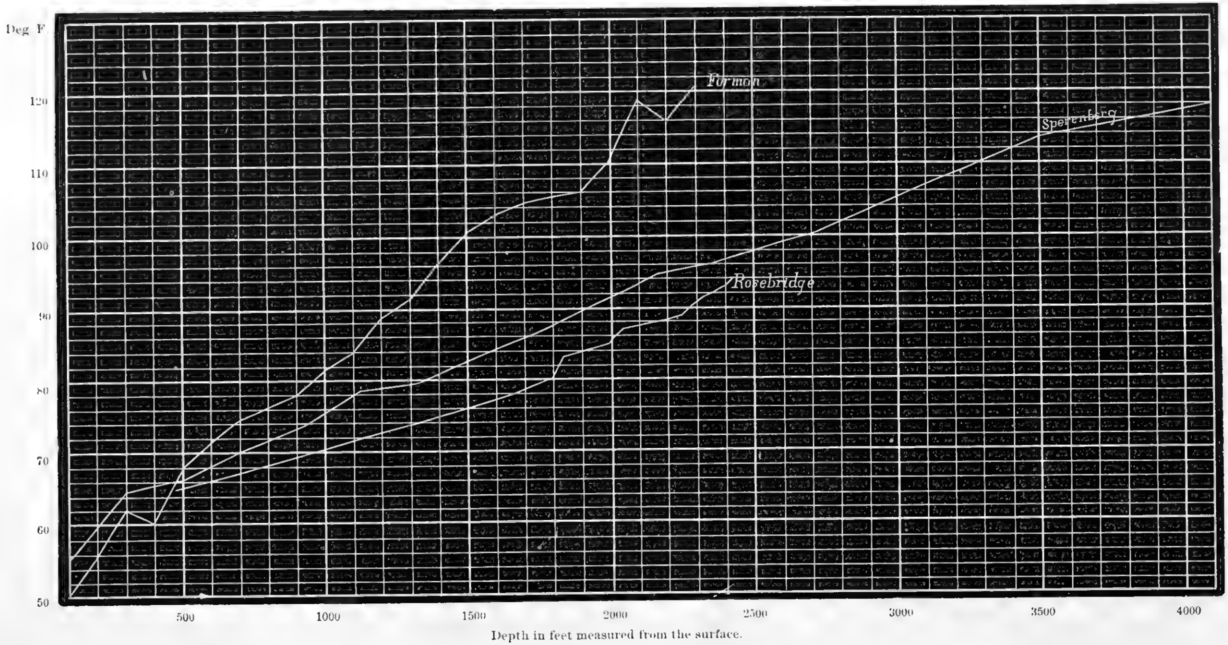

FIG. 17.—SPERENBERG BORING, FORMAN SHAFT AND ROSE BRIDGE COLLIERY TEMPERATURES.

TABLE VIII.—SUTRO TUNNEL.

[The temperatures are usually the average of four observations on different days of the month. Observations taken by the surveyor. Rock temperatures with Gall thermometer in regular drill-hole; water temperatures with common Kendall thermometer.]

Date.	Mean distance from east wall of Lode.	Mean temperature of water at face.	Date.	Mean distance from east wall of Lode.	Mean temperature of water at face.	Mean temperature of rock at face.
1875.	*Feet.*	*° F.*	1877.	*Feet.*	*° F.*	*° F.*
April	10,849	79	January	4,329	88	....
May	10,575	78	February	3,935	88	....
June	10,241	79	March	3,651	89	....
July	9,883	82	April	3,455	93	....
August	9,512	83	May	3,154	92	....
September	9,171	84	June	2,898	92	....
October	8,866	82	July	2,560	93	....
November	8,556	84	August	2,250	94	....
December	8,291	85	September	2,052	96	....
1876.			October	1,924	95	....
January	8,043	85	November	1,743	....	....
February	7,739	85	December	1,513	....	100
March	7,505	84	1878.			
April	7,175	85	January	1,275	....	102
May	6,794	84	February	1,048	108	108
June	6,513	84	March	818	....	110
July	6,262	84	April	577	....	111
August	5,988	85	May	342	....	110
September	5,651	86	June	128	....	110
October	5,326	86				
November	5,008	87				
December	4,687	87				

TABLE IX.—COMPARISON OF RESULTS.

1.....$t = a + b\,d$; $\left\{ \begin{array}{l} t \text{ in degrees Fahrenheit.} \\ d \text{ in feet from top of shaft.} \end{array} \right.$

Table.	Mine.	a	$b \times 10^3$	Remarks.
I	Combination shaft	66	25	Temperature of rock.
II	Yellow Jacket	53	33	Do.
III	Forman shaft, 100 to 1,800	50	33	Do.
IV	Forman shaft, 500 to 2,300	53	30	Do.
V	Forman shaft, 100 to 1,800	46	37	Temperature of water.
VI	Rose Bridge collieries	56	15	Not known.
VII	Sperenberg, 700 to 2,700 (Heinrich)[1]	59	17	

2.....$\tau = \alpha + \beta\,\delta$; $\left\{ \begin{array}{l} \tau \text{ in degrees centigrade.} \\ \delta \text{ in meters from top of shaft.} \end{array} \right.$

Table.	Mine.	α	$\beta \times 10^3$	Remarks.
I	Combination shaft	19	46	Temperature of rock.
II	Yellow Jacket	12	61	Do.
III	Forman shaft, 100 to 1,800	10	59	Do.
IV	Forman shaft, 500 to 2,300	12	54	Do.
V	Forman shaft, 100 to 1,800	8	68	Temperature of water.
VI	Rose Bridge collieries	13	27	Not known.
VII	Sperenberg, 700 to 2,700 (Heinrich)	15	31	

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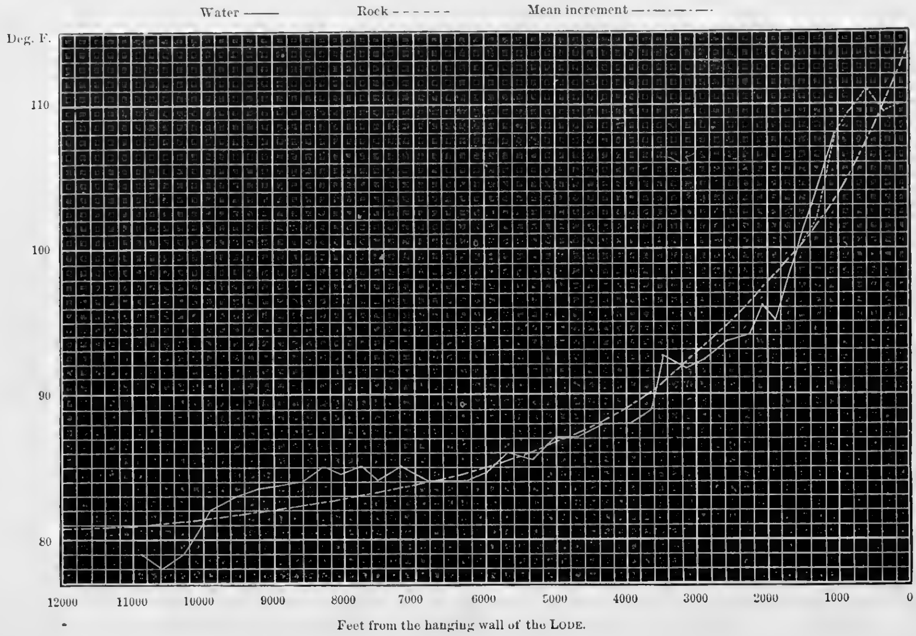
[1] Heinrich's equation as given by himself in Rhenish feet and degrees Reaumur is

$$t = 11.8277 + 0.0077828\,d.$$

Fig. 18.—SUTRO TUNNEL TEMPERATURES.



Reasons for some fluctuations.—A part of the fluctuations of the observations in the WASHOE DISTRICT can be reasonably accounted for. In the *Forman* shaft it will be observed that the water temperatures are somewhat lower than the rock temperatures above a depth of 1,160 feet. The upper portion of this shaft passes through decomposed, and in part disintegrated, augite-andesite. Near its under surface, however, this rock is somewhat fresher, and is there unusually fine-grained and rhyolitic in structure. It therefore offers some resistance to the rise of waters from below, and almost none to the descent of the slight atmospheric precipitation. The point at which the water grows hotter than the rock is exactly that at which the shaft passes from augite-andesite into the underlying hornblende-andesite. At 1,700 feet the shaft became so hot that it was necessary to shower cold water from the surface. The subsequent water temperatures were excluded from the calculation, and it is most likely that the rock temperatures were somewhat affected. This offers a probable explanation for the abnormally low temperatures of the rock immediately below this point. Mr. Forman informs me that, from the 2000-foot level on, the practice of showering water into the shaft was abandoned.

As may be seen from the section through the *Yellow Jacket* (Atlas-sheet VII.), this shaft passes through diabase and mica-diorite alternately, and such changes are likely to exaggerate the ordinary disturbing influences. That portion of the *Combination* shaft in which observations were taken is wholly in diabase, but there is evidence of disturbed conditions. The water in the face of the *Sutro Tunnel* opposite the *Combination* shaft was about 5° cooler than the rock in the shaft, while a reverse relation would have been expected. The shaft observations also fluctuate somewhat violently near this level, while for the interval from 1,900 to 2,100 feet the increment is sensibly the same as in the other shafts. It seems probable, therefore, that the high value of a and the low value of b resulting from the reduction of the observations is somewhat misleading, and that local variations of structure only cause them to differ essentially from those obtained for the *Yellow Jacket* and the *Forman* shafts.

Conditions in the Sutro Tunnel.—It will probably at once occur to the reader that the depth of the *Sutro Tunnel* below the surface is far from uniform.

The smallest depth, however, of that section of the tunnel, 10,000 feet long, for which the temperatures are plotted is above 1,000 feet, and for the last 5,500 feet of the tunnel the average depth below the surface is about 1,500 feet, with comparatively small surface variations. When it is considered that the annual variation of temperature commonly ceases to be perceptible at a depth of 100 feet, it appears that the irregularities of temperature in the *Sutro Tunnel* due to the character of the surface topography, above this last 5,500 feet at least, must be insensible. The variations from the exponential locus are, no doubt, due to the character of the rock, which, as is indicated in the section (Atlas-sheet VI.), shows alternate belts of greater and less decomposition. Rock temperatures would have been preferred to water temperatures had they been recorded, but such was not the case.

Conditions in the laterals.—Rock temperatures have been taken from time to time in the north and south lateral branches of the *Sutro Tunnel*, but in large part these branches pass close to mines which have been worked for years to a much lower level than that of the tunnel. The mean of the observations taken in the south branch as far as the *Imperial* ground is almost exactly the same as that of the observations in the north branch as far as the *Ophir*, 113° or 114°, thus confirming the fact, already well known, that within the limits indicated the mines are all hot, and, on the whole, pretty nearly equally so. The north branch near the *Ophir* is three or four degrees hotter than might have been anticipated from the observations in the main adit, and the *Alpha* and *Exchequer* claims are nearly as hot. Such variations are certainly to be expected. They may indicate local peculiarities of structure, such as the presence of diagonal fissures leading to the LODE, or very possibly the prevalence of slightly higher temperatures throughout the regions lying to the north and south of the main tunnel.

Regularity of the Forman curve.—A comparison of the diagrams shows that the observations in the *Forman* shaft reveal an increment not greatly more irregular than those observed at the Rose Bridge colliery, and at Sperenberg. In view of the local character of the abnormal temperatures near the COMSTOCK this fact is remarkable.

Results.—The five lines of temperatures near the LODE form a tolerably complete thermometric survey, and justify conclusions of a definite character. The *Forman* and the *Yellow Jacket* shafts show that the characteristic increment is very close to 1° F. for every 33 feet of vertical descent, and, since there is no evidence of curvature, this rate may be expected to continue for a long distance below the present workings. As the source of heat is approached the vertical increment must increase, and the true expression for the relation of depth and temperature is probably very similar to that found for the horizontal increment in the *Sutro Tunnel*. It appears hardly possible that were the source of heat within two miles of the surface no trace of curvature would be perceptible in the diagrams for a depth of 2,000 feet. The probabilities seem to be that the focus is several miles from the surface.

Equations referred to the datum level.—The equations for the shafts are referred to the surface at the points where they are sunk, and equal values of d do not, therefore, answer to the same level. The *Forman* shaft is 356 feet and the *Yellow Jacket* 343 feet below the datum level employed in surveys of the mines. Referred to that level, the equations become:

$$\textit{Forman Shaft:}\ t=38+0.033\ d$$
$$\textit{Yellow Jacket:}\ t=42+0.033\ d$$

where d is the depth below the datum level.

Correlation with the tunnel equation.—The difference between the values of a in these two equations is 4°. Now, the *Yellow Jacket* shaft is about 2,600 feet from the croppings of the LODE, and the *Forman* shaft is 950 feet farther, and the curve obtained from the *Sutro Tunnel* shows that such a difference should exist. Indeed, if in the equation

$$t=80+34\ \varepsilon^{0.00032x}$$

$-2,600$ and -950 are successively substituted for x the difference in the values of t obtained will be 4°.[1] This shows very clearly that the law of decrease of the temperature to the east of the LODE holds good for other sections than that taken on the line of the *Sutro Tunnel;* and this inference is strengthened by the similarity of the temperatures in the north and south

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[1] To give a to fractions of a degree would manifestly be absurd. If the fractions resulting from computation were to be retained the difference in the value of a calculated from the exponential equation would be the same as that derived from the observations at the shafts within half a degree.

laterals of the tunnel. On the other hand, these equations give for the *Sutro Tunnel* level (1,865 feet below the datum) temperatures five or six degrees higher than are found at the corresponding points in the adit. This agrees well with the supposition already suggested, that the isothermal surfaces rise somewhat towards the south; but the data are too uncertain, and the rock is too heterogeneous to warrant applications of the equations implying their absolute accuracy. It appears to me, under the conditions, extremely remarkable that the relations of temperature to depth and horizontal distance from the LODE are capable of even approximate mathematical expression.

Practical data.—Within the belt of country between 2,500 and 3,500 feet from the croppings, the relation of temperature of the rock to depth is expressed approximately by the equation

$$t = 40 + 0.033\, d,$$

d being measured from the datum level in feet; and this equation may be expected to hold good, with local fluctuations, for a long distance below the present workings. The equation gives for a temperature of 212° a depth of 5,200 feet. The water will be found commonly hotter than the rock, and its temperature also more variable. It is not unlikely to be struck at a boiling heat any time after the 4,000-foot level is passed, and will in all probability be struck short of 5,000 feet.

Inferences from the Sutro curve.—The curve obtained from the observations made in the *Sutro Tunnel* is clearly a conduction curve, and proves that the east country is heated from a surface at or near the LODE. If the LODE is supposed to have assumed its present temperature suddenly, the radius of curvature of this locus would be a function of the time, and if the coëfficient of conductivity of the rock, its initial temperature, etc., and all the conditions of radiation from the surface were known, the time which has elapsed since the LODE grew hot might be calculated. It is not likely, however, that the temperature of the LODE has always been constant or nearly so, and there is no means of inferring the constants, a definite knowledge of which would be necessary to a mathematical discussion of this problem.

But it is clear that as time goes on the radius of curvature of the conduction curve will increase, and that no illimitable time has elapsed since the LODE first assumed a temperature of above 110° F. on the 1,900-foot level.

Results independent of very accurate thermometers.—It is well known that the thermometer is not an instrument which gives positively uniform results, and that thermometric experiments aiming at a high degree of accuracy imply constant rerating of even the best instruments, which probably change more or less permanently at each fluctuation of temperature. The observations discussed in the foregoing pages were only in part taken with first-class thermometers, and some of them are very probably affected with errors of 1° or even 2° F. from this cause. This fact, however, does not at all impair the general validity of the results obtained. Suppose the graduation of the thermometers employed wholly arbitrary, and that the graduation of the instruments used at each shaft bore no relation to those used at any other, but that the calibration of each was good and permanent changes in volume were absent; the results obtained would still show that the increment of temperature from the surface downward was affected by no perceptible law other than that of direct proportionality to depth, and that in the tunnel the rise of temperature as the LODE was approached was best expressed by a geometric ratio. Or suppose that imperfection in calibration and the permanent effects of expansion induced any error for which a precedent can be found, say, even 3° F., between the highest and lowest readings in either of the shafts or the adit; the differences themselves are so large (from 30° to 60° F.) that the same general conclusions as to the great distance of the source of heat and the method of its communication to the walls of the LODE would follow. In short, the indications are so positive that no probable errors in the thermometers, however gross, could account for them or obscure them.

Conclusions.—The country rock, then, is heated from the LODE or the system of fissures closely associated with it, and the focus of this heat is at a vertical distance which can hardly be less than two miles from the surface, and is more probably four—in short, at a volcanic distance. Only fluid substances, gas or water, could serve as a vehicle to transport this heat to the upper portions of the Lode; and while gas is absent, the immense volumes of hot water form the most serious obstacles to mining. Water, then, has been the vehicle of the heat. The same results, therefore, as were arrived at in the first section of the chapter from geological and chemical arguments, are reached by discussion of the thermometric observations.

CHAPTER VIII.

THE LODE.

Condition of the Lode.—During the period in which the field-work for this report was done the condition of the COMSTOCK was not flourishing. The last remunerative ore from the neighborhood of the great *Consolidated Virginia* and *California* bonanza was extracted while the examination was going on, and no other body of similar importance had been discovered. In the course of the time covered by the stoping of the great bonanza several small bodies were discovered in the *Sierra* and *Union* ground. These, however, were speedily worked out. The old workings were, with few exceptions, inaccessible, and the exposures of the vein were meager and unsatisfactory. The study was therefore necessarily rather one of the conditions of the occurrence of the great LODE than of the vein phenomena in detail. Fortunately, the attention of previous investigators took the opposite direction, and the vein has been amply and ably described as far down as the large ore bodies extend. Aided by former descriptions and some few notes and recollections of visits made when several of the most important bonanzas were yielding largely, I am able to give a succinct account of the occurrence of ore on the COMSTOCK, and to show to what extent the facts and theories developed in the foregoing chapters throw light on the structure observed in the upper portion of the LODE, as well as upon the probable character of the regions below those as yet explored.

General outline.—The surface map, Atlas-sheet IV., shows a plan of the COMSTOCK as it would appear if the *débris* and talus were removed.[1] The main body of the LODE is a belt of quartz and vein matter 10,000 feet long and several hundred feet broad, showing slight undulations in its course,

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[1] The scale of the surface map is too small to show some of the minor irregularities in the walls which may be seen in some of Mr. King's horizontal sections, or the outlines of the horses.

but with a general strike of about north 15° east. At each extremity of this main fissure the LODE ramifies into diverging branches, of which there are two at the south end, and a greater number, probably more than are shown, at the northern extremity. These branches dwindle as the distance from the main body increases, and finally disappear, though it is not impossible that they might be traced somewhat farther than the map shows them. The whole system produces upon the eye the impression of a crack in slightly elastic material, due to a force acting near the middle and equalized at the extremities by dissemination over a large area. This impression is probably correct. The fissure has a comparatively constant dip of from 33° to 45°, though there are local irregularities of a trifling character.

Prismatic horse.—A very interesting and important feature of the COMSTOCK, observable in cross-section, is the forking of the vein at some distance below the croppings. The foot wall continues in typical cases unbroken to the surface, but a secondary fissure rises through the hanging wall in a more or less nearly vertical direction, leaving the foot wall at a depth of several hundred feet. A mass of country rock, which might be represented diagrammatically as a triangular prism, is thus included within the external walls of the vein. It is needless to say that very considerable modifications in the direction, position, and geometrical form of the secondary fissure are observable in different portions of the LODE.

Vein below the horse.—Excepting in the region above the junction of the east and west fissures, the vein in dip is of very uniform thickness; and does not show as often or as prominently as many lodes the tendency to open into chambers and pinch out again, which commonly accompanies a faulting of one wall relatively to the other. This fact is by no means due to the absence of a fault, but to its especial character. There is an unmistakable similarity between the configuration of the west wall and that of the eastern face of the range.

The walls.—The hanging wall of the COMSTOCK is diabase throughout the entire 10,000 feet of the main LODE, for some distance on the southeast branch, and along its northeast branch, as far as the explorations have been carried. The east wall is almost all in an extreme state of decomposition so far as the bisilicates are concerned, and the feldspars also are frequently replaced by alteration products. The foot or west wall of the main fissure is granular diorite for more than three-quarters of its length, but at the southern end it is chiefly composed of metamorphic slates. The foot wall is much less altered than the hanging. The northern branches, excepting the most easterly one, are inclosed in porphyritic diorites, though stringers of diabase also make their appearance in one or two spots on the fissure which extends toward the *Utah* shaft. The southern branches pass along a variety of contacts.

Black dike.—Accompanying the vein for about half its length is the narrow dike of younger diabase called "black dike." It is found only a little north of the middle of the main LODE, extending thence southward and following the southwest branch. It usually lies directly upon the foot wall, but occasionally passes a short distance behind it. In the higher levels it was so decomposed as to be unrecognizable as diabase.

Contents of the vein.—The contents of the vein are simple, on the whole, consisting of country rock in fragments varying in size from that of a grain of sand to horses thousands of feet in length, clay, quartz, and argentiferous minerals. The quantity of calcite, except in the *Justice*, is wholly insignificant, and gypsum, zeolites, etc., are rare. Some of the quartz is said to contain no silver or gold; but for the most part it carries both, though in varying quantities. That which lies upon or is inclosed in diorite carries gold, but little silver; very little of this, however, will pay the expense of extraction and treatment. The quartz associated with the hanging wall carries more silver, accompanied by gold of a value nearly equal to that of the silver.[1] The variation in the tenor of the quartz is extreme, as it usually is in silver veins; and it is only in certain spots that the quartz assays above the fifteen or twenty dollars necessary to warrant extraction at the present prices of labor and supplies; while occasionally the value per ton of comparatively small masses runs up to several thousand dollars. Masses of ore which will pay for extraction are called throughout the region west of the Rocky Mountains *bonanzas*, a Mexican mining term which avoids the ambiguity of the English term *ore*. The bonanzas, therefore, do not represent by any means all of the quartz which carries a perceptible amount of precious

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[1] See table of the proportions of gold and silver in Comstock bullion, p. 9.

metals, and are often surrounded by low-grade ores in great quantities. Though there are exceptions to the rule, large bodies of quartz commonly contain bonanzas. The occurrence of these bodies depends on very complex conditions, and no attempt can be made to account for their position until the sections of the LODE have been passed in review. With two very important exceptions they have all been found in the secondary fissure, not on that with a constant dip. Excepting the *Justice* body they have all occurred in contact with the east-country diabase.

Complex structure of the Comstock.—The ordinary conception of a vein is a simple crack in the earth's crust charged with ore and gangue. The COMSTOCK does not realize this conception even approximately. With the possible exception of the east-and-west veins near Silver City, the whole fissure system of the DISTRICT is referable to a single mechanical cause and the charging of the fissures is in all probability due to simultaneous lixiviation. The branches of the LODE to the north and south are structurally integral portions of the COMSTOCK, but the LODE considered as a great ore deposit is limited to the contact of the diabase with the underlying rocks.

Cross-section through the C. & C.—The most interesting vertical cross-section of the LODE is that through the *C. & C.*, *Consolidated Virginia*, and *Andes* shafts; and fortunately this was pretty thoroughly accessible at the time of examination. The foot wall is diorite, and the hanging wall substantially diabase, while the surface is capped with earlier hornblende-andesite. The secondary fissure at this point was not simple but multiform, splitting the wedge of country rock into sheets or sharper wedges. The intervening space is filled with quartz, none of which has been stoped on the plane of this section, though remunerative ore has been extracted in the *Andes* at a short distance from it, and a very important ore body occurred near the surface some 500 feet to the north. The quartz contains numerous fragments of country rock, too small to be shown in the drawing; and some of the horse is so silicified as to be regarded in mining as quartz. At 400 feet from the surface the different fissures unite, and the main fissure is supposed to continue without interruption to the bottom of the *Consolidated Virginia* shaft, where it is a mere crack. Why the vein has not been prospected for an interval of about 1,200 feet I cannot say. The great bonanza which has yielded over one-third of the product of the whole LODE stands in a vertical position and extends 500 feet from the fissure. Below it large masses of diorite are embedded in indeterminable vein-matter and diabase.

In the funnel-shaped mass directly under the croppings a notable feature is the variation in the character of the quartz. This is hard and firm where it lies upon the west wall, and so far from it as the general structure indicates that the quartz sheets are parallel to the line of the main fissure. East of the horse, on the other hand, the quartz is in great part crushed to a condition like that of commercial salt. The horse-matter in this portion of the section is also accompanied by heavy clays. The ore near the croppings in this region was heavily charged with galena, blende, and pyrite, differing in this respect from the great bonanza in the same vertical plane, and from the principal ore bodies of the LODE.

The "great bonanza."—The bonanza consisted of a group of three bodies, one of them far larger than the others, and one of very small dimensions. The cross-section under discussion and the longitudinal vertical projection, Atlas-sheet X., give a better idea of the geometrical form and the position of this important group than any description could do.[1] It was composed of crushed quartz, including fragments of country-rock, and carried a few hard, narrow, vein-like seams of very rich black ores, consisting of stephanite and similar minerals, while nearly the whole mass of "sugar-quartz" was impregnated to a moderate extent with argentite and gold, the latter probably in a free state. The immense volume of these soft ores more than compensated for their moderate tenor,[2] and much the greater part of the entire yield of the bonanza was derived from them. They carried a moderate amount of pyrite. A great part of the space stoped out consisted of fragments of country-rock, impregnated, however, with ore, and assaying well. These fragments were highly decomposed, but perfectly recognizable by their green color and traces of porphyritic structure. They were not rounded, and I never saw traces of the concentric structure which any process of replacement must have imparted to them. On the contrary, they were as sharply defined as if freshly broken. Comb structure was not visible

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[1] Mr. Church gives excellent illustrations of the form of this body on different levels, but the black rock west of the bonanza is not black dike.

[2] The ore of the great bonanza averaged about $80 per ton, but this included the rich stringers.

in the bonanza on a large scale, but where masses of country-rock were favorably placed, the space between them often showed this peculiarity, indicating that the fragments had acted as centers of crystallization for the quartz. The same appearance was noticed by Mr. King in the earlier bonanzas. Clays were by no means a prominent feature of this body, though not absent. The endless sheets of clay following and intersecting the ore bodies which were so striking in the upper levels throughout the LODE seem to have disappeared below the junction of the fissures. To the east of the bonanza, especially in the region exposed by the north branch of the *Sutro Tunnel*, the rock is very heavily charged with pyrite, as well as greatly decomposed; and the sulphuret is clearly formed within the augite crystals of the diabase. The dioritic masses east of and below the bonanza are shattered and somewhat decomposed, but not to the same extent as the augitic rock The material laid down as "vein-matter" on this and the other sections is crushed rock, so highly altered that its original character cannot be determined with certainty. The color underlying the conventional markings which designate vein-matter indicates what, in my opinion, is its probable lithological origin.

Inferences from the C. & C. section.—It is so difficult to retain detailed descriptions in the memory, that it seems advisable, in the interest of the reader, to draw such inferences from each section as are justifiable, without waiting till they have all been passed in review. The occurrence of the secondary fissures on the COMSTOCK appeared to Baron v. Richthofen clear evidence that the surface had not undergone great erosion since the formation of the vein. Mr. King concurred in this opinion, and it also appears to me essentially a surface phenomenon; for had the east wall near the present top of the fissure been backed up by thousands of feet of rock, it is difficult to see how it could possibly have yielded in the manner shown by the section. The secondary fissures must, too, have been caused by faulting action, for in no other way can a tendency to rupture in a vertical direction be accounted for. That the east country throughout the mines, and prominently in this neighborhood, shows numerous signs of faulting, has already been explained at length, as well as that the sheeted structure is not ascribable to eruptive bedding.

Sugar-quartz.—The microscope further shows that the sugar-quartz is composed of crushed crystals,[1] and this can also be demonstrated macroscopically. In interstices between fragments of country rock, bunches of quartz crystals are not uncommon, and these though fractured are sometimes held together by the support of the surrounding material. In such cases the same crack can sometimes be observed running through a considerable number of crystals, proving, if necessary, that they have not yielded to an internal stress, but to an external force. Though the whole country is greatly broken up, so that the average size of the blocks of country rock showing no fissures is not much above the size of a man's fist, it is nowhere reduced to the fineness of sugar-quartz. This need cause no surprise, however, for miners and mill men are well aware that, in spite of its hardness, quartz is very readily crushed, far more readily than volcanic rocks, or even than limestone. The occurrence of sugar-quartz, then, is an evidence of movement, and this can have taken place only in one direction, that of the dip of the fissure; for even if it were conceivable that the whole country in this neighborhood might be compressed latterly, the behavior of the quartz in the upper levels would prove the supposition inapplicable. The quartz-sheets which are parallel to the fissure are solid, or, at most, according to Mr. King, show a slaty structure; while the masses which are not parallel to the fissure are crushed. In some of the bonanzas in other portions of the COMSTOCK, Mr. King noticed a parallelism to the LODE even in the crushed masses, and such a phenomenon is also said to have been observed in the great bonanza of this section.

Period of the fault.—Since the secondary or east fissure was filled with quartz, the faulting action to which the existence of this fissure is due must have preceded the deposition of ore on the COMSTOCK; and since the ore was crushed by a movement in the direction of the dip of the main fissure, faulting must also have succeeded the deposition of ore. The faulting action studied in Chapter IV. must therefore have embraced the whole or nearly the whole of the period during which the deposition of ore was taking place,

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[1] The finest portions of the sugar-quartz mounted in balsam and examined in polarized light under the microscope are unmistakably anisotropic, and while portions of crystal-faces are occasionally visible, most of the surfaces are conchoidal fractures. I have met with no evidence that any of the solid quartz of the COMSTOCK has resulted from the consolidation of sugar-quartz, either by pressure or any other agency.

though movements may have occurred only at long intervals It is possible that the seams of rich ore in the great bonanza represent a deposition posterior to the final cessation of movement.

Tenor of the ore.—The variation in the tenor of ore is probably ascribable to two causes. The general poverty and the auriferous character of the quartz associated with the diorite are probably due to the composition of that rock, which in this locality nowhere secretes argentiferous ores. On the other hand, the fluctuations in the composition of the ore associated with diabase are most likely due to a combination of chemical and dynamical causes. Whatever may have been the actual solubility of the silica and the argentiferous compounds of the diabase, under the conditions which prevailed when the solutions were formed, it is in the highest degree unlikely that it was the same. When, by a renewed movement of the hanging wall, fresh material was exposed to solution, either the silica or the silver would dissolve with greater relative rapidity than after prolonged exposure to the solvent action; and the ore deposited would vary correspondingly. It is also by no means impossible that some of the richer ores have been redeposited, forming at the expense of surrounding bodies of lower grade.

Indistinctness of the east wall.—The east wall is very indistinct on this and on most of the other sections. This is in accordance with the lateral-secretion hypothesis. As has been seen, the fragments of country-rock certainly act as centers of crystallization, and, had the solutions risen from great depths along the fissure, quartz must also have crystallized from both walls equally; but if the solutions percolated from the east into the fissure, this structure would certainly not have resulted unless they passed the wall very gradually and gently.

Clays.—The clays of the COMSTOCK appear to be for the most part mere attrition mixtures of decomposed but not necessarily of kaolinized rock, as has been explained in Chapter VI. In this section it is observable that the horses near the croppings end downwards in clay sheets, and that the clays are most abundant where horse matter lies across the general direction of movement.

Quartz deposited in openings.—The substitution hypothesis of ore deposition receives, as has been seen, no support either from observation or theory.

It appears to me necessary, therefore, to suppose that quartz and ore have been deposited in openings. The space occupied by the bonanza can of course never have been an uninterrupted cavern, but it would seem to have been a space loosely filled by fragments of country rock, which are now represented by the included horse matter. Though the country-rock is so greatly fractured, a space of this kind is by no means impossible. If a large opening were to be made anywhere in the diabase, fragments would immediately fall from the sides and roof. The latter would assume the shape of a dome, and though a complete arch of blocks would not form, a portion of the weight of the overlying country would be distributed laterally, and the diminished pressure would most likely be insufficient to crush the displaced fragments. The lenticular mass of diorite below the bonanza does not appear to be in place. It was probably partly separated from the west wall at the diabase eruption, and since that time it seems to me to have moved downwards. Owing to the irregularity in the walls consequent upon its presence, and to the difference between its resistance and that of the diabase to lamination by faulting, it left a rent in the hanging wall, which has afforded an opportunity for the deposition of quartz in the manner just explained.

Cross-section through the Tunnel.—The next section south of the *C. & C.* is that through the *Sutro Tunnel* and the *Savage* shaft. It fails to cross any ore but, as may be seen from the longitudinal vertical projection, it nevertheless passes through nearly the lowest point of a fan-like group of bonanzas, the "Virginia group," as it is often called, extending from the *Chollar* to the *Gould & Curry.* On this plane the secondary fissure leaves the west wall at a lower point than in any other portion of the LODE, and all of the bonanzas were found in the secondary fissure. Throughout this portion of the LODE the east and west fissures display the same general characteristics as at and near the *Andes.* The west quartz was hard, according to Mr. King, while the eastern quartz, as I have myself been able to observe, is crushed. The great horse body is split by quartz-masses, which are not continuous, however, thinning out in the strike and being replaced by others. Clay seams are very heavy and intersect as well as follow the horses. The ore was not "base," and much of it was extraordinarily rich. The bonanzas were very thin perpendicularly to the plane of the LODE as compared with that previously described, and hence occupy a much greater space on the vertical longitudinal projection. In detail the structure of these bodies was excessively complicated, as may be seen from Mr. King's report. It is not in my power to add anything to his description, to which the reader is referred for more detailed information.

Virginia group of ore bodies.—The Virginia group of bonanzas lies in an undulation of the west wall, the general shape of which may be clearly traced on the surface map; but by inspection of the horizontal section on the *Sutro Tunnel* level it will be perceived that this depression has flattened so as almost to disappear at a vertical distance of about 1,900 feet from the datum point. Before the walls were disturbed in their relative positions, a solid mass of diabase lay in this local depression. The fact that the depression is limited to the neighborhood of the surface must have brought an extraordinary strain to bear upon the tongue of east country rock lying within it when the fault took place. The lines of secondary fracture, instead of running nearly parallel to the LODE, appear also to have crossed the continuous prismatic horse so often referred to, and to have reached the foot wall at the extremities of the undulation. The mass thus separated would be canted eastwards by the same force which effected the separation, and between it and the main body of the east country there would form a crescentic opening, the points of which would lie at the croppings on the west wall, while its greatest width would also be on the west wall at the bottom of the tongue of east country. From the west wall vertically, or in the direction of the secondary fracture, the opening would everywhere taper, ending in a mere line at the surface or more probably somewhat below the surface, since the crushing stress in an east-and-west direction would be powerful. This opening once formed would be immediately blocked by fragments of rock, and could never close.

Such I conceive to have been the nature of the case in the region of the Virginia group, modified in detail by more or less important irregularities of structure; and it will be observed from the Tunnel section that the west quartz tapers from the surface downward, while the east quartz thickens; showing that the horse has revolved slightly on a horizontal north-and-south axis, remaining firmly in contact with the east wall at the top and with the west wall at the bottom. By inspection of the longitudinal vertical projection and of the mine maps, it will also be perceived that the ore bodies lay within such a space as is suggested by consideration of the probable results of faulting.

The occurrence of the rocks in the *Sutro Tunnel* has already been sufficiently discussed in Chapter V. The various belts of decomposition indicated have all been located as veins upon the surface; but there is nothing in this section to indicate any hope of ore away from the COMSTOCK, except upon the Occidental lode.

Cross-section through the H. & N.—The *Hale & Norcross* section passes through the edge of the largest bonanza of the Virginia group. Its thinness, compared with the *Consolidated Virginia* and *California* bonanza, is striking, but would be somewhat less so were the plane of the section nearer the axis of the body. The structure of the horse is much less regular than on the *Sutro* section, but it is again noticeable that the western quartz diminishes in width as the depth increases, while the openings at the east increase. The horse is intersected by a nearly vertical quartz body. In the *Chollar* these two eastern fissures come together. The black dike makes its appearance in this section, and is found running into the *Savage*, but no farther north, nor is it known to reach the surface at any point. The andesite contact is laid down from inferences drawn chiefly from observations made at the *Savage*, 700 feet farther north, the *Santa Fé* adit being closed. Most of the lower workings of the *Hale & Norcross* were also inaccessible at the time of the examination, and it is not impossible that the vein is drawn somewhat wider than a careful examination would justify.

Cross-section through the Jacket.—In the *Imperial* ground the diorite swings to the west, leaving metamorphic slates with an easterly dip as the foot wall in the Gold Hill mines.

But a small portion of the *Yellow Jacket* workings was accessible at the time of the investigation; but a preliminary examination of the lower levels had been effected before the Gold Hill mines were flooded, and an excellent collection, kept by the company while sinking the new shaft, supplemented by visits to the accessible tank stations, furnished all the necessary information concerning the eastern portion of the section. The old workings had been carefully examined by Mr. King's party, and the information recorded by him, with additional facts from the surface, and from a few levels below the bottom of the old shaft, make the section fairly satisfactory.

Several masses of micaceous diorite crossing the new shaft are represented as embedded in diabase. The evidence already adduced of the relative age of these two rocks precludes the supposition that these bodies can be intrusive, and the only tenable supposition seems to be that they are fragments detached and moved into their present position by the diabase eruption. That such an event is quite possible is evident, the wonder being that it is not of more frequent occurrence on the COMSTOCK.

Fissure dipping west.—A very peculiar phenomenon is the occurrence of an ore body in the *Yellow Jacket* dipping west and ending abruptly on the west wall. The following is suggested as a possible solution. The earlier hornblende-andesite cap is in this region of considerable thickness, and its under and upper surfaces seem to be nearly parallel, while the diabase contact slopes at an angle of some 33°. The direction of the faulting movement was at least as nearly vertical as that of this contact. To this movement the tenacity of the andesite offered a resistance, but as it contained no parting in the direction of motion it yielded in the direction of least resistance, or nearly at right angles to the surface. This action gave rise to the fissure dipping westward. As the faulting movement continued, a second eastern fracture formed exactly as in the Virginia mines.

Cross-section through the Belcher.—The *Belcher* section is made out from fewer data than most of the others, in spite of the fact that the ore-bearing levels were open to inspection. No galleries have been run into the east wall on this plane, and there are no workings where the croppings should appear. The quartz is continuous on the slope of the main fissure above its junction with the secondary fracture, but how far is not known. I believe, however, that the fissure might be followed to the surface, though it is improbable that ore in any quantity would be found. From the sketch map, Fig. 1, it appears that the evidences of solfataric action run high up Crown Point ravine, and back of the *Belcher;* and the decomposition seems almost necessarily to indicate a structural connection between the surface and the deep-seated fissures. The secondary fissure appears to represent the east fissure of the *Yellow Jacket*, the west fissure here coinciding with the slope of the Lode.

The fault at the Belcher.—There is much less evidence of faulting at this section than on any of the preceding. The topography does not show a logarithmic character; the lamination of the surface rocks is not perceptible, nor is there much evidence of such a structure in the mine; and far more of the ore was solid or composed of bunches of large interlocked quartz crystals, with spaces between them, than in the Virginia mines. There is some crushed quartz, however, and the character of the bonanza, which was largely made up of angular fragments of country-rock, seems to indicate faulting, though of a less violent and extensive character than that which occurred on the flank of Mount Davidson. The bonanzas hitherto described appear to have filled spaces due to secondary fracturing, while that in the *Belcher* seems to have occupied an opening due to changes in dip, combined with a relative movement of the walls, concave surfaces being brought into opposition. An inspection of the section can hardly fail to produce this impression and, if it be a fact, it furnishes another proof of the comparative gentleness of the faulting action in this locality. Since the dislocating force is manifestly dissipated at the ends of the Lode by distribution over a large area, it is likely to grow less intense as the extremities are approached. The diminution indicated at the south end of the main Lode is greater than at the north end.

Small stringers of good ore have been met on the 3,000-foot level of the *Belcher*, the deepest level yet reached.

Cross-section through the Forman shaft.—The section through the *Baltimore* and *Forman* shafts is more valuable as a study of the succession of the rocks than for any positive information it furnishes regarding the Lode. The contacts in this portion of the country are much more numerous than near Virginia, and one of these, seemingly continuous with the main Comstock fissure, has been sufficiently opened to admit the deposition of quartz. The dynamical action must have been very slight, however, for there are no certain evidences, either in the shape of croppings or of lines of profound decomposition, that fissures from the surface connect with this contact in depth. But croppings reappear just below the *Justice*, and the surface and subterranean phenomena together render it, to my mind, altogether probable that the fissure is continuous, as shown upon the surface map.

The evidence of the structure of the country on this section is, for the most part, far less detailed than that obtained for some of the others; but it is sufficient to justify considerable confidence in the general features shown. The *Forman* shaft leaves nothing to be desired, thanks to the thoroughly scientific spirit in which the management has preserved accurately labeled specimens from all levels, as well as temperature observations. A very important point proved by the shaft is that the diabase does not extend so far south as this line, for had it done so it must have been encountered between the hornblende-andesite and the quartz-porphyry. The *Caledonia* works were also open to inspection, and were carefully examined. The three other shafts were closed, but the information afforded by the dumps, in connection with the maps of the workings and the statements of employés as to the drifts from which the different divisions of the dump-piles came, and correlated with the data obtained on the surface and in the mines still open, gave ample evidence as to the order of occurrence of the rocks.

Diabase nowhere appears on this section, but is found overlying quartz-porphyry at the *Overman*, a short distance to the north, and a small partial section is given to illustrate this occurrence.

Cross-section through the Union shaft.—To the north of the main LODE, as to the south of it, the evidences of dynamical and of chemical action grow slighter, though much less rapidly. From the section through the *Union* shaft, for example, it appears that on the main northerly branch no secondary fissure has formed, and since the LODE is here divided at the surface into at least three stringers, a sufficient intensity in the faulting action to produce a well-marked secondary fissure could scarcely be anticipated. The south branch of Seven-Mile Cañon has cut deeply into the surface here presented. If the eroded ground were restored some traces of a logarithmic surface would be visible. The lower workings from the *Union* shaft are entirely accessible, and prove that the diabase contact is not on the fissure which has been chiefly explored to the north of this plane, but diverges from the strike of the main LODE towards the northeast. A line of heavy croppings exists in this general direction, and probably marks the contact. A comparison of this section with the surface map and with the horizontal section on the *Sutro Tunnel* level shows that the contact between the diabase and the diorite being steeper than the dip of the northern branch of the LODE, the fork of the vein is met much farther north on the lower levels than at the surface. The disturbing influence of the sharp bend in the diabase-diorite contact upon the regularity of the faulting action is visible in the larger amount of crushed rock, and the apparently displaced diorite masses on this section. Most of the diorite east of the northerly fissure and nearly all of that on the lower levels is porphyritic. A small ore body occurred near the croppings on the northerly branch. Mr. King describes the ore there found as "fragmentary masses of blocky quartz, impregnated with native gold, closely resembling the California auriferous quartz." The little ore bodies on the 2300 and 2400-foot levels are more like the ordinary COMSTOCK ores. The evidences of solfataric action are very strong on the lower levels of this section; indeed, the decomposition is so profound as to make lithological determinations a matter of the utmost difficulty.

Cross-section through the Sierra Nevada.—The *Sierra Nevada* section shows evidences of very powerful dynamical action, yet of but a small amount of faulting; for the dip of the north fissure is here so irregular that no movement whatever could occur in the ordinary direction without extensive fracturing. The occurrence of limestone on this section has already been noticed. The diorite beneath it is mainly granular, and that resting upon it is for the most part porphyritic, though no sharp line can be drawn for any considerable distance between these varieties. It appears to me that this included sheet of stratified rock was largely instrumental, by its weakening effect, in determining the course of the north fissure. Beneath the limestone is a small stringer of diabase, no doubt connected somewhere with the main body to the east, but at what point is uncertain. It is accompanied by a minute quantity of ore, not unlike that of the COMSTOCK bonanzas, but it would be difficult to gather five pounds of it, and there is no likelihood of any ore body of importance being found here. The same stringer of diabase, or a similar one, occurs further north in *Utah* ground, on the north fissure. The main body of diabase seems to have been struck on the 1450 level of the *Sierra Nevada* by a drill hole, the cores of which were fortunately preserved. The drift itself was inaccessible, and could not have been opened at any moderate cost.

The east-and-west fault.—There are clear evidences of a slight downward movement to the north of the *Sierra Nevada*, or an equivalent rise of the region to the south. It is impossible to state definitely that this was not independent of the great fault, but after considerable study of the case it has seemed to me unlikely, on the whole, that the two movements were unconnected. Everything shows that the eruptive rocks of the DISTRICT are exceedingly rigid, and cannot be flexed perceptibly without breaking. At the same time there is, as has been seen, strong proof that the faulting diminishes rapidly to the north and south, beyond the points at which the main LODE ramifies. In part the strain was weakened by distribution over various fissures, but this would have been insufficient to effect adjustment in the absence of flexibility. This argument would therefore point to the probability of east-and-west fractures as a means of relief, and it is to this action that the little slips in the *Sierra Nevada* appear to me attributable.

Cross-section through the Utah.—In the *Utah* the north fissure again straightens, so as to exhibit approximately the usual dip of the COMSTOCK, and though the fault was slight it left a trace of a secondary fracture. Diabase appears in several levels, but only as an irregular dike, backed by micaceous diorite, which also shows extensively on the surface in this neighborhood. As nearly as can be made out, this diabase comes in on a cross-fissure from the southeast and not on the branch of the LODE. The evidences of solfataric action are not great in this mine, much of the rock being even fresher than that to be found on the surface at any point in the DISTRICT. In the lowest levels, however, there are belts of somewhat decomposed rock.

Horizontal section.—It was intended to make horizontal sections of the COMSTOCK on three levels, but this proved wholly impracticable on account of the inaccessibility of the older workings. Fortunately it was possible to explore nearly all of the *Sutro Tunnel* level, 1,900 feet below the croppings. The result is recorded in Atlas-sheets VIII. and IX., where the inaccessible drifts are shown in hair lines; while the projection of the principal workings on other levels, of which use was made in drawing inferences as to the conditions existing on the 1900-foot level, is shown in dotted lines. The care with which the determinations were made is shown by the abundance of the marks indicating the points from which specimens were collected, and slides ground. This very laborious collection was necessitated chiefly by the extreme state of decomposition of the rocks, which here almost wholly effaces their distinguishing characteristics. It was also necessary to prove the presence or absence of any rock which could properly be brought under the definition of propylite.

Ore bodies occur at the diabase contact.—It appears from this section that the east wall of the COMSTOCK, from the *Overman* to the *Sierra Nevada*, is diabase, while the west wall is diorite for only a part of the distance. By comparison with the vertical sections and the vertical projection of the LODE it will be seen that all the ore bodies of any importance, except that in the *Justice*, are at or close to the diabase; while the Gold Hill bonanzas rest upon metamorphic rocks. The forking of the vein at the *Overman* is well exhibited on this level, with its cause, the divergence of the black dike from the main diabase mass. To the north it is evident that the north fissure is on the strike of the LODE, and that its formation was probably facilitated by the presence of the limestone body in the *Sierra Nevada* ground.

Faulting.—The evidence with regard to faulting offered by this level is interesting. The course of the LODE is very closely the same as the line of the croppings, with the exception of the undulation shown at the surface opposite the Virginia group of bonanzas. The disappearance of this undulation was discussed in connection with the vertical section through the *Sutro Tunnel.* The effect of the compression produced by the sharp bend of the diabase contact to the eastward at the north end, in conjunction with the southeasterly dip, is seen in the great mass of crushed rock in the northern mines. This crushed rock has been denominated vein matter, in accordance with local mining usage, because it is decomposed past certain lithological determination; it is not laid down as forming a part of the vein, however, because it is not a loose aggregation of fragments considerably removed from their original position, but consists of huge rock masses fissured in every direction.

Close contact of the walls.—Considering the extent of the vein and the indubitable evidences of an extensive fault, it is at first sight very remarkable that the walls are almost everywhere in such close contact, and that the only large opening due to mere relative displacement of the walls is that occupied by the Gold Hill bonanza. If the theory of the fault propounded in Chapter IV. is correct, however, this state of things follows as a necessary consequence, for the vein represents only a single parting, and the relative motion between its walls is the relative motion of two successive sheets. The actual amount of displacement must depend on the thickness of the sheets, which on the COMSTOCK is certainly not above twenty-five feet. This would answer to a relative movement of the actual walls of something like a hundred feet. The opening of the vein in Gold Hill is probably in part attributable to the character of the foot wall, which, being stratified at an angle to the LODE, would be, as all experience shows, less rigid and less easily split into sheets. The dip of the west wall in Gold Hill is also considerably smaller than in Virginia, about 10° less, and this fact must have had a tendency to ease the pressure in the southern mines.

Influence on the path of rising waters.—On account of the small relative movement of the walls of the LODE these are sometimes found nearly or quite in contact with one another over considerable areas; and at points where the walls are perceptibly, but not distantly, separated the intervening space is often closely packed with clay and rock fragments. The vein is therefore not an open water channel throughout, and it is highly probable that on some straight or sinuous line it may be impenetrable to liquids from one end to the other. With the east country rock the case is different. As has been noticed frequently in the foregoing pages, it shows an endless number of partings parallel to the LODE and innumerable fractures across the sheets. Few of these partings show any clay, and as capillary fissures can never be stopped except by plastic material, there is little obstruction to the circulation of water in the country rock. This condition of things has most likely had not a little to do with the deposition of ore. The waters, rising from a depth which the heat relations show must be measured in miles, were prevented from following the LODE fissure and were forced to permeate the country rock, reaching the open spaces of the vein laterally, and there depositing the quartz and ore minerals dissolved.

Partial section on the 2500-foot level.—The northern mines were accessible on the

2500-foot level for a considerable distance, and a horizontal section of these workings is presented. It shows, in connection with the parallel section 600 feet above, the growing tendency of the diabase contact to dip towards the southeast and the great increase of crushed rock with increasing depth. All preparations had been made to lay down the geology of the Gold Hill mines at the corresponding level, when a flood rendered the workings inaccessible. The map, however, at least indicates the continuity of the vein in depth and parallelism of structure between this and the *Sutro Tunnel* levels.

Vertical projection of bonanzas.—The longitudinal vertical projection needs no explanation, supplementing in an evident manner the other Atlas-sheets. The disposition of the various bonanzas which it shows has been mentioned in connection with the cross-sections of the LODE.[1]

Mine maps.—The entire official mine maps are also presented, and will enable those specially interested in the LODE to follow out many details of structure. The notes on these maps as to walls, clay seams, etc., represent the deliberate judgment of the surveyors and superintendents, and I have found them, where accessible, for the most part, correct. They are left as they stood on the originals, because the greater number of the localities where they occur are inaccessible, and as a record of opinion of those technically engaged in mining they have a distinct value, which would be lost if partially replaced by my own determinations. Not all the galleries appear on the maps, for, though the main workings have been carefully plotted from the earliest times, unimportant drifts are often run without the coöperation of the surveyor, and these sometimes escape record. The surveyed galleries, shafts, and winzes aggregate about 155 miles, and the unrecorded ones probably 30 miles additional.[2]

Claim-map.—The claim-map of the WASHOE DISTRICT forms a proper complement to the mine maps. It shows the claims up to 1881 and distinguishes

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[1] In preparing all of the geological sections of the LODE, I was assisted by Mr. R. H. Stretch, who is responsible only for the mapping, the geological determinations being my own. My determinations, however, were greatly facilitated by Mr. Stretch's familiarity with the old workings, now for the most part inaccessible, and by his zealous assistance in gathering data as to structure and lithology. The longitudinal vertical projection of the LODE is entirely Mr. Stretch's work.

[2] The official surveyors of the COMSTOCK have been Messrs. I. E. James, R. H. Stretch, Marlette & Hunt, T. D. Parkinson, Browne, Hoffmann & Craven, and L. F. J. Wrinkle. The contract for the maps was made with Messrs. Hoffmann & Craven.

claims for which patents have been issued, those on which applications for a patent have been made, those determined by U. S. survey, but on which no applications for patents have been made, and finally claims the boundaries of which have merely been determined by private survey. An index to the claims, showing the position of each on the map, will be found at the end of the volume.[1]

Conclusions.—Collectively, the various observations made, if they are correct and the inferences from them sound, throw considerable light on the history of the LODE. After the eruption of the diorite the first event of importance, so far as the vein is concerned, was the outburst of diabase, which involved a rupture and dislocation of the earlier diorite, leaving a smooth contact between the two rocks at an angle of about 45°. The contact was afterwards slightly opened to admit the younger diabase or black dike. Eruptions of earlier hornblende-andesite and of augite-andesite afterwards occurred, which probably caused fractures and dislocation in the eastern portion of the diabase, but produced no traceable action on the COMSTOCK fissure. The country was subsequently so eroded as to reduce the surface of these four rocks to a gently sloping plain, with an inclination of a little more than two degrees to the west. After the commencement of the dry period (dry, that is to say, so far as this region was concerned) a great movement began which may possibly have been a sinking of the hanging wall, but was more probably a rise of the foot wall. The center of action appears to have been near Mount Davidson. This dislocation involved an enormous friction, one result of which was a separation of the foot wall and the hanging wall into sheets parallel to the fissure for a long distance from it. A secondary effect of the same force was the formation of innumerable cracks in these sheets nearly perpendicular to their partings. The edge of the east country necessarily assumed the form of a wedge, and was broken completely through at a point a few hundred feet below that at which the primary fissure reached the surface. Openings were formed along the COMSTOCK as a result of the movement of the walls, but under a variety of circumstances. In Gold Hill a space was left by the non-conformity of the wall surfaces brought into opposition. In the Virginia group a slight

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[1] The claim-map was prepared by Messrs. Hoffmann & Craven. Some additions and corrections, however, were made by Mr. Wrinkle.

irregularity in the dip of the foot wall prevented the mass broken from the edge of the east country from following the main body of diabase to its final position; while in the *Consolidated Virginia* and the neighboring mines, at a depth of between 1,000 and 2,000 feet, a projecting mass upon the foot wall gave rise to a local rent in the hanging wall. Besides these more important openings, numerous clefts formed in the prismatic horse which had been broken off from the hanging wall, and between the horse and the main body of the east country. Large quantities of rock were ground to dust in the course of the faulting, especially at and near the great horse, where the mechanical action was least regular.

Floods of heated waters now rose from a depth of two or more miles, certainly carrying carbonic and sulphhydric acids, and possibly other active reagents, in solution. The water followed the course of the main fissure as closely as circumstances permitted, but was deflected to a great extent into the fractured mass of the east country, where decomposition resulted. Silica and metallic salts were set free from the mineral constituents of the rock, and were carried into the comparatively open spaces near the main fissure, where they were redeposited. The proportion of silica to ore minerals varied greatly with time and local circumstances, which if they are capable of full explanation certainly have not received it in this report. Some of the causes of the variations, however, can be indicated without difficulty. The lithological character of the rock upon which the waters acted was evidently of prime importance, determining both metallic contents and gangue; so that the deposits of Cedar Hill, those of the *Justice* mine, and the bonanzas of the main Lode, all show distinctive characters. The duration of the exposure of particular rock masses to solvent action no doubt had much to do with the tenor of the resulting ore. It is likely, for example, that silica under the conditions then prevailing, is more readily soluble than silver compounds. If so, the water first passing over a mass of rock would deposit low-grade quartz in the vein, and subsequently, as the supply of soluble silica diminished, a better quality. It seems clear that fresh movements occurred from time to time, and that fresh rock surfaces were thus exposed. This would have brought about alternations in richness, such as have sometimes been noticed in the Lode. Pressure, too, if not temperature, may have varied from time to time, and so may the quantity of active reagents in the rising waters. On the whole, the earlier deposits of quartz seem to have been of lower grade than the later ones, but the phenomena are so complicated that no considerable practical value attaches to this observation.

The ore was deposited on the walls and fragments of rock as in more regular veins, but the currents percolating from the east and decomposing the rock through which they passed, gave the east wall a somewhat indefinite character. This indefiniteness was increased by the dynamical action which followed the deposition of quartz, and probably also accompanied it. After most of the quartz was precipitated, renewed movements occurred, crushing the deposits in great part to so-called "sugar quartz." It was the quartz bodies standing at a considerable angle to the west wall, and therefore crossing the fissure planes, which were most extensively comminuted. More attrition products were of course also formed at the same time.

The solutions which so powerfully attacked the polyhedral fragments of diabase were of course not without effect on the pulverized rock masses which were abundant, particularly in and near the secondary fracture, or "east vein." The clays are the result. In a simple vein, attrition mixtures and clays are apt to occur only on the two walls. On the COMSTOCK such a regular formation is found on the west wall, but seldom on the east. There is no necessary connection between walls and clays in spite of their frequent association, some typical veins showing nothing of the kind. The clays of the COMSTOCK show little kaolin.

Probabilities.—The first condition for a deposit of ore is the formation of an opening, and on the COMSTOCK such spaces appear to have formed in three distinct ways, already explained. The secondary fracture has been worked out, and except in Gold Hill considerable nonconformity of the walls is not to be looked for. There it is as likely to occur at greater depths as above; indeed, the fact of its occurrence in the *Crown Point* and *Belcher*, at a mean depth of, say, 1,700 feet from the *Gould & Curry* croppings, leads almost necessarily to the conclusion that there must be other nonconformities at greater depths, unless the rocks change to other species. Openings of the type of that which contained the *Consolidated Virginia* and *California* bonanza may occur at any point on the vein, and wholly without warning from above, as was the case with that body. The want of indications of such an opening from above is due simply to the fact that from the nature of the case the accompanying subsidiary phenomena are on lower levels than the opening. At least one other type of opening may occur, which is as likely to carry ore as those just mentioned. Where large bodies of rock are broken and dislocated, interstitial spaces of considerable size may readily form within the mass. An enormous volume of such material exists in the lower levels of the north end mines, and nothing would be less surprising than the discovery of one or more ore bodies in that locality. Attendant upon the ore bodies and somewhat below them to the east, the hanging wall will probably be more heavily charged with pyrite than the average rock of the east country, as has been the case with former bonanzas.

Of the actual precipitation of ore and gangue from solution little is known. It is very natural to connect it with surface influences, and hence to suppose that ore must be limited to certain depths. Such an hypothesis is frequently held by mining men, but experience does not confirm it; for though there are shallow deposits, there are many deep ones. The gold veins of California and Australia show no tendency to give out in depth, when affected by no other unfavorable conditions, such as a change of rock; and the mines of Přibram, in Bohemia (the only ones, I believe, which are deeper than those on the Comstock), were never so rich and profitable as they have been since the 3,000-foot level was passed.

The western limit of the diabase is the only ground in which important ore bodies ever have been or are ever likely to be found in the Comstock mines, and exploration should, in my judgment, be confined to the neighborhood of this contact. Money spent elsewhere will almost certainly be wasted. As long as the east country continues to show an extensive body of diabase, there is no reason for discouragement. Should this rock ever narrow to a mere dike between diorite walls, the outlook would be gloomy; but it is highly probable that such a change occurs, if at all, only at a point far below the limit which technical difficulties will set to exploration.

The whole contact between diabase and the underlying rocks is worthy of careful exploration. Evidences of disturbance and decomposition are to be regarded as indications of the possible neighborhood of ore, and regions exhibiting these characteristics should be thoroughly cross-cut; while, where the rock is comparatively firm and fresh, drifts or winzes should be pushed on to more promising ground. The country northeast of the *Ophir* is particularly favorable. As may be seen from the horizontal sections, it presents a large extent of unprospected contact between diabase and diorite directly adjoining a region of broken and highly altered rock where ore in small quantities has already been found. Ore is not unlikely to be met with in this unexplored area at depths of less than 2,000 feet, and therefore under comparatively favorable conditions as to heat and water. The mines near the *Union* shaft are also likely to find ore towards the bottom of the mass of shattered rock in which the 1,900 and 2,500-foot levels are excavated. In the *Best & Belcher* ground, too, there are signs of great disturbance, though the decomposition is less intense than in the mines north of the *Ophir*. A drift from the lowest levels of the *Consolidated Virginia* would show whether the indications on this claim improve with depth.

CHAPTER IX.

ON THE THERMAL EFFECT OF THE ACTION OF AQUEOUS VAPOR ON FELDSPATHIC ROCKS.

BY CARL BARUS.

Mr. Church,[1] in his report on the geology of the COMSTOCK LODE, has endeavored to account for the abnormally rapid increase of the temperature of this DISTRICT with increasing depth[2] by ascribing it to chemical action—more immediately to the decomposition (kaolinization) of the feldspathic rocks in consequence of the presence of moisture. This theory, however, notwithstanding the ingenuity with which it has been discussed by its author, is based on an assumption that has scarcely a single experimental datum to support it; nor is the fundamental hypothesis upon which Mr. Church bases his argument, namely, that the process of kaolinization is one from which we may, *a priori*, expect the production of heat (as Mr. Becker has already pointed out) by any means of a kind to be readily admitted.

General plan.—It appeared very desirable, therefore, insomuch as from theoretical grounds alone there is abundant room for difference of opinion, to put the matter to a direct physical test. At the outstart, and with the time and means available in camp, qualitative experimentation only could judiciously be attempted, the necessarily complicated quantitative study being reserved for more favorable opportunities; if, indeed, the preliminary investigation should furnish results of sufficient interest to warrant further research.

The thermal effect of kaolinization (abbreviated T. E. K.) may be defined as the quantity of heat produced by the action of aqueous vapor on

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[1] The Comstock Lode, its formation and history, by John A. Church, 1879.

[2] This volume, Chapter VII.

the unit mass of feldspathic rock in the unit of time. T. E. K. may, therefore, *a priori*, be either positive, zero, or negative. It must be regarded, moreover, as a function of the time during which the action has been going on, of the temperature and of the quantity of feldspar contained in a given sample of rock.

The problem presented is none other than the measurement of very small increments of temperature with all the accuracy attainable. For such a purpose either thermometric or electrical means are applicable. The former requiring specially constructed apparatus, had at once to be discarded. It is a question, moreover, whether the thermometric method of research will not, under all circumstances, offer obstacles of a very serious character. In the measurement of small increments at the boiling point it becomes a matter of great importance to keep the mercury column throughout at a temperature as nearly as possible equal to that of the bulb—a condition which can be realized only with great difficulty, when a division of the stem into very small fractions of a degree is also required.[1] Electrically, there are two methods applicable The first, however, based on the relation between temperature and resistance, would have necessitated the measurement of increments of the latter quantity amounting to scarcely 0.0005 per cent. of the whole, in order to arrive at the accuracy desired. Though even this is feasible in the laboratory, I despaired of being able to reach such nicety with the means at my disposal. In view of these facts, it was finally determined to try how far a thermo-electric method of research might be successful in answering the question.

Processes of this kind, in which the effect observed is due to chemical action, are usually accelerated by the application of heat. In other words, the assumption is warranted that the thermal effect of the action of aqueous vapor on feldspar (T. E. K.) will increase, and will therefore be more easily detected as the temperature of the vapor increases; provided, of course, that this temperature is not chosen so high as to dissociate the products of de-

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[1] A greater difficulty still would probably be encountered from the fact that the reservoir of a thermometer subjected to large differences of temperature is by no means constant in volume, but subject to variations dependent upon the glass chosen. (Phenomena of "after-action.")

composition resulting in a normal case. Believing, therefore, that the phenomena of kaolinization are reproduced at all temperatures below a certain limit, and that the difference in effect is merely quantitative, the rock in the experiments here described was subjected to steam at the boiling point of water on the COMSTOCK.[1] Besides this, it was intended to modify the method of research sufficiently to trace the action of superheated steam also. This must, however, be reserved for a future report.

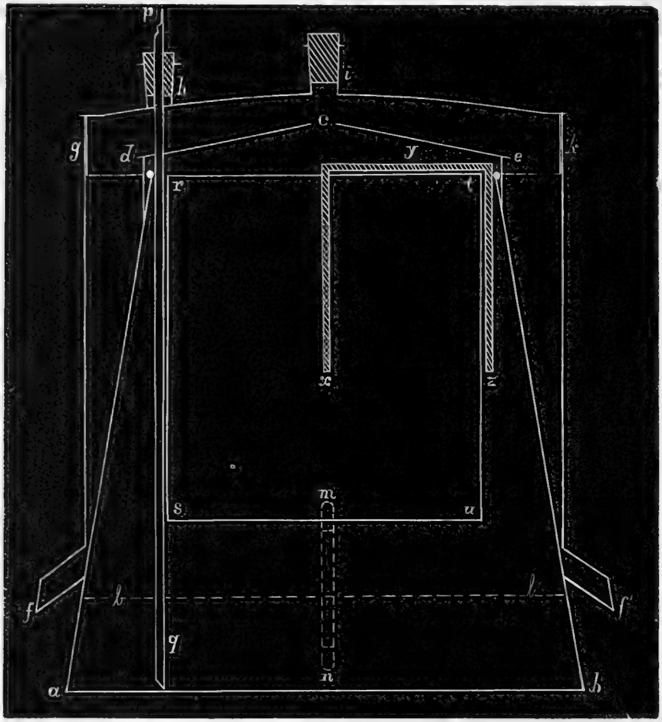

FIG. 19.—Boiler (scale one-fifth).

Apparatus.—The apparatus (a boiler) in which the rock was subjected to the action of steam is shown in longitudinal section, on a scale of one-fifth,

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[1] About 93° C.

in Fig. 19. As will be seen, the well-known contrivance for determining the boiling point of thermometers was made the pattern of construction. Steam is generated in the interior conical compartment $a\ b\ e\ c\ d$ of heavy tinned sheet iron, 18 inches in diameter at the bottom and 12 inches at the top, and between 18 and 20 inches high. The top, $d\ c\ e$, also conical,[1] and provided with a hole at c for the escape of steam, can be removed, and fits like a lid over the walls of this compartment. The whole is surrounded by the cylindrical mantle, $f\ g\ i\ k\ f'$, of the same material. The top, $g\ i\ k$, of this can also be removed, has the form of an ordinary lid, and is provided with tubulures for the insertion of corks, etc., at h and i. The exterior compartment communicates with the air by the tubulures f and f'.

In the interior of the inner compartment, and held in position by a suitable tripod (not shown in the cut), is the cylindrical chamber $r\ s\ u\ t$, 11 inches in diameter and 12 inches high, and provided—like a sieve—with a bottom of wire gauze strengthened by radial supports of thick brass wire. $P\ q$, finally, is a feed pipe for resupplying the boiler with water lost by evaporation.

The rock to be tested was broken into small fragments, from the size of a hazel-nut down to that of a pin-head, but excluding dust, and placed in the chamber $r\ s\ u\ t$. Previously, however, the thermo-element $x\ y\ z$ (described on the next page) had been fixed in position, supported by suitable cross-bars of wood covered with thick sheet rubber. In putting the rock into the chamber care was taken to pack it sufficiently tight to prevent currents of steam from possibly passing through the mass. Steam reached the interior by a process of diffusion, thoroughly saturating the whole. Of this I had frequent occasion to convince myself. Water having been poured into the boiler to a level $l\ l$, approximately, and heated to ebullition, the steam completely enveloped the rock chamber, permeating the material in its interior. Passing through the hole c, and again around the greater part of the apparatus, it finally escaped at f and f' into the air.

As a source of heat, two small kerosene stoves were found excellent. By means of the four broad flames thus obtained, the heat could be regu-

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[1] Thus serving a second purpose, namely, to prevent steam condensed on the top of the boiler from dripping into the rock below.

lated as desired and kept constant during the whole time of experimentation. Oil could be supplied without interfering with the flames. Trimming of wicks was seldom necessary, and, there being four flames, gave rise to no serious disturbance. To diminish the heat lost by radiation as much as possible, the whole apparatus, with the exception of the bottom, was covered to a thickness of about three-quarters of an inch with cotton batting, wrapped in layers and surrounded externally by heavy paper. Finally, the water lost by evaporation was replaced drop by drop by means of a pneumatic arrangement placed upon the boiler, but not shown in the figure. The number of drops fed in a given time was so regulated by the aid of a small faucet as to keep the level *l l* of the water in the boiler, as indicated by the gauge *m n*, approximately at a constant height. The ebullition was not allowed to become sufficiently intense to produce an increase of pressure in the interior.

To recapitulate: By the aid of a fairly constant source of heat, the ebullition from a water level of constant height could be maintained at a nearly constant intensity. It was believed, therefore, that a stationary thermal condition would soon set in and continue indefinitely. Errors due to fluctuation of the barometric column, this being as likely to produce positive as negative effects, could be excluded by proper methods of reduction.

Thermo-element.—To measure the small increments of temperature, a thermopile composed of three bismuth-silver elements was first used. Though this acted well, there was danger, in consequence of the amount of sulphur in the rocks ($Fe\ S^2$), of complete destruction of the silver terminals during the course of the experiment. This metal was therefore discarded, and platinum, which is not thus affected, chosen in its stead. The bismuth was cast in the shape of three adjacent sides of a rectangle, the length and width chosen being such as to allow the two ends to occupy the positions x and z shown in Fig. 19. Of course care was taken to insulate the whole thoroughly from the walls of the boiler, this being accomplished by surrounding the element on all sides by strips of thick sheet rubber. The parts of the element were kept from touching each other by pieces of glass tubing suitably placed. The terminals—which, to prevent confusion, are not indicated in the figure—were themselves insulated by a covering of rubber hose of small caliber.

They passed out of the boiler through tubulures (also omitted in the figure) placed conveniently on its sides, the hose and wire being secured by small perforated corks. Of course no attention was paid to the purity of the metal employed. The silver and bismuth were fastened together by melting a little globule on the end of the silver wire, and then applying it, while still hot, to the end of a bismuth bar. The soldering thus produced was very perfect. The platinum and bismuth had, however, to be soldered together by ordinary means.

Method of measurement.—The relation between the electromotive force e, due to the temperatures T and t $(T > t)$ of the ends of the thermo-element, can be expressed with the aid of two constants, a and b, thus:

$$e = (T - t)\,[a + b(T + t)].$$

But as $T - t$ in this case is a very small quantity (a few hundredths of a degree),

$$\varDelta t = T - t = \frac{e}{a + 2bT},$$

where T is the temperature of ebullition of the water as given by the aid of the barometer. Knowing, therefore, a, b, and the barometric height we are able to find $\varDelta t$, or the difference of temperature between the interior and the exterior of the rock chamber (x and z in Fig. 19).

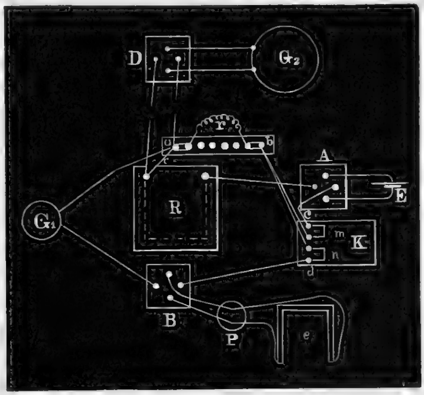

FIG. 20.—Disposition of apparatus.

For the measurement of e a "zero" method was employed. In Fig. 20 a diagram of the connections as actually made is given, for the purpose of calling attention to a few details of importance in measurements of this kind. The platinum terminals of the thermo-element e are soldered to copper circuit wires at P, the points of junction being immersed in a reservoir filled with petroleum. Before each observation this liquid was stirred. The copper wires pass through the commutator *B*, and thence the one through a double key *K* to the point *b*, the other through the galvanometer G_1 to the point *a*, thus completing the first branch. The smaller resistance *r* forms the second branch, also terminating at the points *a* and *b*. For the convenient insertion of this resistance a number of small holes were bored in a thick piece of wood and filled with mercury. The points *a* and *b* are connected with the extreme holes of the series by means of strips of thick copper foil. Finally, the terminals of a zinc sulphate Daniell *E* pass through the commutator *A*, thence the one through the key *K* and directly to *b*, the other through a large rheostat *R* (from 1 to 10,000 ohms), and by a thick wire, *C*, to *a*, completing the third branch.

When the current in G_1 is zero

$$e = E\,\frac{r}{R+r}, \text{ or, more simply, } = E\,\frac{r}{R},$$

where *e* is the electromotive force at *e*, *E* at *E* in the figure; where, furthermore, *R* is the resistance at *R*, *r* at *r* in the figure, and where *r* is negligible in comparison with *R*.

Having thus described the general method, it will be pertinent to mention a few of the more important details. By means of *K* two circuits conveying currents due to *E* and *e*, respectively, are closed. It is, however, necessary that they should be so closed as to act simultaneously (differentially) on the galvanometer G_1; for if the current due to the electromotive force *e* were to act alone serious disturbances might be the result. This can be accomplished by the following simple contrivance in the construction of the key. Fig. 21 gives a section through the line of mercury cups *c d*, Fig. 20. Pieces of thick copper wire, bent as shown, are fastened to a thin piece of board, capable of revolving partially about a horizontal axis parallel to the line *c d*. In this way the pieces *m* and *n* can be dipped into the mercury cups under their extremities or lifted out of them together. The board is, moreover, provided with a spring so arranged as to keep *m* and *n* out of the cups, and the circuit therefore remains open, unless closed by the ob-

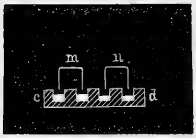

FIG. 21.—Section of key.

server. The cups corresponding to m, and conveying the current due to the Daniell E, are, however, filled with mercury to a level a little higher than the rest. Hence, under all circumstances the circuit containing E, and not passing through G_1, is closed first. A moment after, however, that containing e and G_1 is also completed, but it will be obvious that the effect from e and E, if the directions of these electromotive forces are properly chosen, will act differentially on G_1, as was desired.

The electromotive force e, obtained as above, is never wholly due to the thermo-element e alone, but contains also a disturbing electromotive force, ε, resulting from the accidental distribution of temperature in the connections. For a short period of time (that of an observation) ε may be considered as nearly constant, or at least varying linearly. In order to eliminate the latter, very largely at least, Dr. Strouhal and myself, in analogous experiments, inserted the two commutators A and B. In a series of corresponding positions of the commutators, alternately opposite, direct measurement would give

$$\frac{+e+\varepsilon}{+E}=a_1$$

$$\frac{-e+\varepsilon(1+\alpha)}{-E}=a_2$$

$$\frac{+e+\varepsilon(1+2\alpha)}{+E}=a_3$$

$$\frac{-e+\varepsilon(1+3\alpha)}{-E}=a_4$$

$$\frac{+e+\varepsilon(1+4\alpha)}{+E}=a_5$$

$$\cdots\cdots\cdots$$

where α is a constant. If now an odd number of observations be made, and if M_1 be the mean of the odd right-hand members, M_2 the mean of the even right-hand members,

$$\frac{e}{E}=\frac{1}{2}(M_1+M_2).$$

In the present investigation, the electromotive forces measured being exceedingly small, at least five commutations of both A and B were made for each value of $\varDelta t$ cited.

The galvanometer G_1 was one of low resistance, consisting of a few hundred turns of wire around an astatic needle on silk fiber. The instrument was quite delicate, and with the aid of proper methods of interpolation would easily have enabled the measurement of increments as small as a few ten-thousandths of a degree centigrade. Unfortunately, the silk was too thick, and the zero point of the instrument, as a consequence, too variable; while, on the other hand, the strong winds of the region and the frail foundation of the house itself rendered this accuracy unattainable, and we were obliged to content ourselves with measurements accurate to a few thousandths of a degree. Readings were made with a mirror and scale.

Thus far E has been considered constant. As this is not the case, its variations were measured by the aid of a second galvanometer, G_2 (Fig. 20), made by Mr. Grunow, and described elsewhere.[1] This instrument was placed at a distance from the boiler, in the cellar, where the atmospheric condition was tolerably uniform, and for convenience provided with a commutator of its own, D. It will easily be seen that by breaking the circuit at B and C and closing K, E will be in a simple circuit, including G_2, and that its value may be measured in terms of R, which is also included.

The value of the constants a and b in the equation on page 295 was determined by putting the ends of the thermo-element c in adjoining jars, containing water at different temperatures.[2] Ten or more observations were usually made, from which a and b were calculated by the method of least squares.

I cannot but consider this method of measuring differences of temperature as theoretically very perfect. First of all, discrepancies due to Peltier's phenomena are avoided, while the constants a and b are used precisely in the same way in which they were obtained. Moreover methods of interpolation are particularly applicable; even a method of multiplication might be thus employed. There can be no doubt that under more favorable circumstances the minimum difference of temperature measurable with certainty would be much smaller than I have been compelled to consider it.

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[1] This volume, page 327.

[2] Not having a reliable barometer, all temperatures are expressed in terms of the interval between zero and 100° C. of the best instrument at hand, this interval being arbitrarily assumed as correct. On this assumption the stems of the thermometers used were calibrated.

Material experimented upon.—The rock selected by Mr. Becker for these experiments was the freshest diabase encountered in the mines. The feldspars show scarcely a trace of decomposition, and a large part of the augite is unaltered. It was collected in the *Sutro Tunnel*, close to the hanging wall of the LODE in the *Savage* claim. The same rock is described in Chapter III., slide 18, and its analysis is given in the table following page 151

Results.—The results are reported chronologically, but with all corrections, including those based on subsequent experiments. Temperatures are given throughout in degrees centigrade, electromotive forces in volts.

From an inspection of the tables containing the results for the variation of the electromotive forces of bismuth-silver and bismuth-platinum with temperature, it will be seen that the relation is in both cases so nearly linear that it may at once be assumed as such. One constant, a, only, therefore, results from the calculation. Tables I. and II. contain the data for the calculation of the thermo-electric constant a for the triple element bismuth-silver, together with the results obtained. T is the temperature of the warmer, t of the colder end of the element, e the electromotive force corresponding to the temperatures of the respective observations observed or calculated as specified, $\delta(e)$ finally the difference between observed and calculated results. Two sets of observations were made in order to ascertain to what extent a fixed value for a could be presumed—the bismuth bars being cast and not pressed. In the calculations preference was given to values of e corresponding to greater differences of temperature.

TABLE I.

No.	t.	T.	$e \times 10^3$ observed.	$e \times 10^3$ calculated.	$\delta(e) \times 10^5$.	
1	6.1	75.1	15.61	15.63	−2	
2	6.3	68.7	14.13	14.13	+0	
3	6.4	63.8	12.89	13.00	−11	$a = 226.5 : 10^6$.
4	6.7	57.0	11.41	11.39	+2	
5	6.9	50.5	9.92	9.88	+4	
6	7.1	45.0	8.64	8.59	+5	
7	7.2	39.5	7.32	7.32	±0	
8	7.6	34.9	6.25	6.18	+7	
9	7.8	30.4	5.18	5.12	+6	
10	8.3	25.2	3.84	3.83	+1	

TABLE II.

No.	t.	T.	$e \times 10^3$ observed.	$e \times 10^3$ calculated.	$\delta(e) \times 10^5$.	
1	11.0	73.7	14.22	14.22	±0	
2	11.3	64.2	11.96	12.00	−4	
3	11.5	58.7	10.70	10.70	±0	
4	11.8	52.8	9.30	9.30	±0	$a = 226.7 : 10^6$.
5	12.2	47.8	8.10	8.07	+3	
6	12.3	42.1	6.78	6.76	+2	
7	12.5	36.9	5.52	5.53	−1	
8	12.8	32.2	4.43	4.40	+3	
9	13.0	27.2	3.19	3.22	−3	
10	12.8	16.4	0.87	0.82	+5	

Table III. contains the successive values of Δt, or the difference of temperature between the interior and exterior of the rock-chamber. It also shows the date of each observation and the number of hours which had elapsed since ebullition first set in. Corrections for the variation of a and the electromotive force of the normal element E have been applied. During the time covered by the first six observations the water lost by evaporation was supplied somewhat intermittently; subsequently, however, as well as throughout all succeeding experiments, it was fed into the boiler drop by drop, so that the feeding process may be considered as practically continuous. Δt is positive, this sign having been chosen to indicate that the space exterior to the rock-chamber—or the end of the thermo-element in steam—is the hotter.

TABLE III.

No.	Date.	Hours.	Δt.	No.	Date.	Hours.	Δt.
	h.				*h.*		
1	Dec. 10, 6	6	0.059	14	Dec. 14, 18	42	0.064
2	Dec. 10, 20	20	0.068	15	Dec. 14, 23	47	0.063
3	Dec. 11, 8	32	0.054	16	Dec. 15, 8	56	0.062
4	Dec. 11, 18	42	0.074	17	Dec. 15, 14	62	0.060
5	Dec. 12, 12	60	0.055	18	Dec. 15, 20	68	0.059
6	Dec. 12, 22	70	0.071	19	Dec. 15, 24	72	0.059
7	Dec. 13, 6	6	0.065	20	Dec. 16, 4	76	0.060
8	Dec. 13, 10	10	0.065	21	Dec. 16, 8	80	0.060
9	Dec. 13, 14	14	0.062	22	Dec. 16, 12	84	0.058
10	Dec. 13, 18	18	0.068	23	Dec. 16, 18	90	0.060
11	Dec. 14, 3	27	0.063	24	Dec. 16, 24	96	0.057
12	Dec. 14, 8	32	0.063	25	Dec. 17, 4	100	0.059
13	Dec. 14, 13	37	0.062	26	Dec. 17, 8	104	0.057

Table IV. finally gives the data obtained for the calculation of *a* after the experiments in Table III. had been completed, together with the results of calculation. The nomenclature is the same as before.

TABLE IV.

No.	t.	T.	$e \times 10^3$ observed.	$e \times 10^3$ calculated.	$\delta(e) \times 10^5$.	
1	10.0	74.8	14.12	14.18	-6	
2	10.0	66.7	12.36	12.42	-6	
3	10.3	60.7	11.04	11.04	± 0	
4	10.4	55.8	9.95	9.95	± 0	$a = 219{\cdot}1 : 10^6$.
5	10.5	49.5	8.59	8.55	$+4$	
6	10.7	44.3	7.39	7.36	$+3$	
7	10.8	40.1	6.47	6.42	$+5$	
8	11.0	33.3	4.97	4.89	$+8$	
9	11.2	25.8	3.27	3.20	$+7$	
10	11.8	20.0	1.88	1.80	$+8$	

If the values of *a* in Tables I. and II are compared with that in Table IV., a difference of about 3 per cent. will be found. This may be due partly to a change in the internal structure of the bismuth bars, partly to the fact that both bismuth and silver were attacked by the sulphur fumes generated in consequence of the presence of iron pyrites in the rock. In the case of bismuth this action merely produced a thin, colored coating of sulphide on the exterior. The silver, however, was so deeply corroded that its use had to be abandoned, and in subsequent experiments this metal was replaced by platinum.

The data for Δt show a difference of temperature between the interior and exterior of the rock-chamber, which is much greater than was anticipated. Moreover, the consecutive values of this quantity gradually decrease, indicating thereby an apparent increase of the temperature of the rock itself.

Tables V. and VII. contain the data obtained in the determination of *a* respectively before and after the measurements of Δt made during the intermediate week. In Table VI. these measurements are given, together with the date, barometric height, and water-level, *l* (in inches from the bottom as zero), corresponding to each Δt. The figures for barometric height were obtained from a small aneroid. No reliance can therefore be placed on the values as absolute, though the fluctuations are probably represented with tolerable faithfulness. Besides these data, the number of hours which had elapsed since ebullition first set in are also given.

TABLE V.

No.	t.	T.	$e \times 10^3$ observed.	$e \times 10^3$ calculated.	$\delta(e) \times 10^5$.	
1	12.6	79.7	14.51	14.51	±0	$a=216.3:10^6$.
2	15.5	65.6	10.79	10.84	−5	
3	18.4	61.1	9.28	9.24	+4	
4	12.7	53.9	8.98	8.91	+7	
5	18.3	53.0	7.46	7.51	−5	
6	13.0	46.4	7.22	7.22	±0	
7	13.1	42.9	6.39	6.45	−6	
8	15.6	39.8	5.23	5.24	−1	
9	13.4	32.9	4.28	4.22	+6	
10	15.3	31.9	3.52	3.46	+6	

TABLE VI.

No.	Date.	Hrs.	Δt.	Bar. H't.	l.	No.	Date.	Hrs.	Δt.	Bar. H't.	l.
1	Dec. 25, 23^h....	23	0.098	23.30	......	12	Dec. 28, 23^h...	95	0.067	23.12	4.9
2	Dec. 26, 3^h....	27	0.093	23.30	......	13	Dec. 29, 5^h....	101	0.067	23.17	4.9
3	Dec. 26, 9^h....	33	0.088	....	......	14	Dec. 29, 14^h...	110	0.061	23.24	4.8
4	Dec. 26, 14^h....	38	0.088	....	......	15	Dec. 29, 24^h....	120	0.062	23.30	4.4
5	Dec. 26, 22^h....	46	0.083	23.24	4.9	16	Dec. 30, 9^h....	129	0.062	23.35	4.2
6	Dec. 27, 3^h....	51	0.082	23.15	4.2	17	Dec. 30, 18^h....	138	0.062	23.36	4.4
7	Dec. 27, 9^h....	57	0.078	23.10	4.9	18	Dec 30, 24^h....	144	0.058	23.40	5.2
8	Dec. 27, 14^h....	62	0.077	23.06	4.8	19	Dec. 31, 9^h....	153	0.060	23.30	4.4
9	Dec. 27, 23^h ...	71	0.072	23.15	5.0	20	Dec. 31, 17^h....	161	0.055	23.35	4.0
10	Dec. 28, 10^h...	82	0.068	23.23	4.7	21	Jan. 1, 9^h....	177	0.048	23.25	4.4
11	Dec. 28, 14^h ..	86	0.066	23.19	4.5						

TABLE VII.

No.	t.	T.	$e \times 10^3$ observed.	$e \times 10^3$ calculated.	$\delta(e) \times 10^5$.	
1	14.1	72.0	12.32	12.39	−7	$a=213.9:10^6$.
2	14.1	65.8	11.13	10.06	+7	
3	14.1	60.1	9.92	9.84	+8	
4	14.1	54.1	8.56	8.56	±0	
5	14.3	50.3	7.66	7.70	−4	
6	14.3	45.0	6.54	6.57	−3	
7	14.3	40.9	5.64	5.69	−5	
8	14.3	36.1	4.66	4.66	±0	
9	14.3	30.9	3.57	3.55	+2	
10	13.9	38.1	5.18	5.18	±0	

A large difference between the temperatures of the interior and exterior of the cylinder, the former being the smaller, but increasing more rapidly than before, is again apparent.

Table VIII. records an uninterrupted series of observations made by Mr. Becker on the variation of Δt during an interval of three weeks

Table IX. contains the final check of the value of a.

TABLE VIII.

No.	Date.	Hrs.	Bar. H't.	Δt.	l.	No.	Date.	Hrs.	Bar. H't.	Δt.	l.
1	Jan. 4, 21^h	3	23.25	0.024	......	26	Jan. 15, 7^h	253	22.83	0.062	4.5
2	Jan. 5, 5^h	11	23.25	0.033	4.2	27	Jan. 15, 21^h	267	....	0.063	4.6
3	Jan. 5, 21^h	27	....	0.033	4.7	28	Jan. 16, 7^h	277	22.94	0.067	5.0
4	Jan. 6, 7^h	37	23.15	0.044	4.4	29	Jan. 16, 21^h	291	....	0.068	4.6
5	Jan. 6, 16^h	46	....	0.042	4.8	30	Jan. 17, 7^h	301	23.29	0.063	4.7
6	Jan. 6, 21^h	51	....	0.042	4.8	31	Jan. 17, 21^h	315	....	0.064	4.9
7	Jan. 7, 7^h	61	23.18	0.042	4.0	32	Jan. 18, 10^h	328	23.36	0.068	5.2
8	Jan. 7, 17^h	71	....	0.041	4.8	33	Jan. 18, 21^h	339	....	0.066	4.8
9	Jan. 7, 21^h	75	....	0.044	4.3	34	Jan. 19, 20^h	362	23.30	0.063	4.5
10	Jan. 8, 7^h	85	23.21	0.044	3.8	35	Jan. 20, 7^h	373	23.36	0.021	4.6
11	Jan. 8, 15^h	93	....	0.043	4.8	36	Jan. 21, 8^h	398	23.50	0.016	4.8
12	Jan. 8, 20^h	98	....	0.042	5.3	37	Jan. 21, 22^h	412	....	0.043	......
13	Jan. 9, 7^h	109	23.18	0.045	4.0	38	Jan. 22, 7^h	421	....	0.048	......
14	Jan. 9, 17^h	119	....	0.041	4.2	39	Jan. 22, 22^h	436	....	0.031	......
15	Jan. 9, 21^h	123	....	0.039	4.6	40	Jan. 23, 7^h	445	23.30	0.034	5.2
16	Jan. 10, 7^h	133	23.15	0.042	4.5	41	Jan. 23, 21^h	459	....	0.081	......
17	Jan. 10, 19^h	145	....	0.041	4.5	42	Jan. 24, 7^h	469	22.96	0.046	4.7
18	Jan. 11, 13^h	163	....	0.040	4.3	43	Jan. 24, 21^h	483	....	0.048	......
19	Jan. 11, 20^h	171	....	0.050	4.7	44	Jan. 25, 8^h	494	22.81	0.076	4.4
20	Jan. 12, 7^h	181	23.20	0.049	4.5	45	Jan. 25, 21^h	507	....	0.051	......
21	Jan. 12, 17^h	191	....	0.057	4.7	46	Jan. 26, 7^h	517	22.92	0.149	4.6
22	Jan. 12, 21^h	195	....	0.055	4.5	47	Jan. 26, 21^h	531	....	0.150	......
23	Jan. 13, 8^h	206	23.12	0.060	4.6	48	Jan. 27, 7^h	541	23.15	0.094	4.5
24	Jan. 14, 7^h	229	22.90	0.067	4.5	49	Jan. 27, 15^h	549	....	0.126	......
25	Jan. 14, 17^h	239	....	0.063	4.9						

TABLE IX.

No.	t.	T.	$e \times 10^3$ observed.	$e \times 10^3$ calculated.	$\delta(e) \times 10^5$.	
1	12.8	64.6	10.87	10.89	-2	
2	12.9	59.5	9.79	9.80	-1	
3	12.9	54.4	8.78	8.73	$+5$	$a = 210.3 : 10^6$.
4	13.0	50.1	7.74	7.80	-6	
5	13.1	44.7	6.65	6.65	± 0	
6	13.1	40.7	5.81	5.81	± 0	
7	12.8	32.2	4.13	4.08	$+5$	
8	13.1	30.1	3.62	3.57	$+5$	
9	12.7	25.8	2.75	2.76	-1	
10	12.7	22.1	2.02	1.98	$+4$	

In the foregoing determinations of a, the temperature t was chosen to coincide as nearly as possible with that of the room. Though this arrangement furnished important practical advantages (t varying but slightly), only that part of the thermo-element lying near the hot end was really in action. It was therefore thought desirable to reverse the element, so that the end which was formerly in hot water would now be in cold, and *vice versâ.* Table X. contains the results thus obtained.

TABLE X.

No.	t.	T.	$e \times 10^3$ observed.	$e \times 10^3$ calculated.	$\delta(e) \times 10^5$.	
1	13.3	63.6	10.51	10.51	±0	$a = 208.9 : 10^6$.
2	13.4	57.4	9.23	9.19	+4	
3	13.5	45.0	6.54	6.58	−4	
4	13.5	40.6	5.65	5.66	−1	
5	13.5	35.9	4.69	4.68	+1	
6	13.5	30.7	3.60	3.59	+1	

The difference between the values of a in Tables IX. and X. lies within the range of unavoidable errors.

In Table VIII. there is a difference of temperatures between the interior and exterior of the rock-chamber analogous to that in preceding tables. The former is, as usual, smaller, but in this case the temperature of the rock apparently *decreases* as the action continues.

Between the observations No. 34 and No. 38 there appeared disturbances of a kind which seemed to indicate that a break had occurred somewhere in the insulation. Subsequent inspection showed that the parts of the rubber hose around the platinum terminals, which were in contact both with air and steam, had swollen to a spongy mass of many times their former bulk. It is not improbable that the wire during the disturbances mentioned had been more or less perfectly in contact with the walls of the boiler, the doughy rubber protection having either given way or offering imperfect insulation. Though this was partially remedied, yet the last week's observations are nevertheless to be regarded as somewhat suspicious, and were consequently omitted in the calculations below.

Discussion.—In the following discussion the observations in Tables III. and VI., and the first two weeks in Table VIII., are to be considered. Together these data correspond to an interval of four weeks. In the endeavor to reach the most probable conclusion to be derived from the large number of observations, the end in view will be attained most speedily, and perhaps most satisfactorily, by assuming for the relation between the variables some approximate form, and calculating the constants by the method of least squares. In the present case there is as much reason to adopt a linear form of function as any other, and this would have the advantage of greater simplicity. Denoting the number of hours which have elapsed since the beginning of the experiment by u, let

$$\varDelta t = \alpha + \beta u. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

In this equation the constant α is without great interest. It simply denotes the value of $\varDelta t$ when u is zero, but is largely influenced by the normal difference of temperature between the interior and exterior of the rock-chamber, *i. e.*, the difference which may be recognized by an inspection of the foregoing tables, and of Table XIV. β, however, is of importance, representing the increment of temperature of the rock per hour in consequence of the T. E. K. It will be noticed that β is either negative, positive, or zero, according as the process of kaolinization produces or absorbs heat perceptibly, or is without appreciable thermal effect. In making the calculation for β I had hoped to be able to derive this constant from the four weeks' observations, as a whole. The problem is difficult, however, insomuch as the results obtained do not form one continuous series. The problem is not, in other words, that of a single straight line as in equation (1), but one involving three straight lines, for all of which, however, the value of β is the same. Expressing the whole interval during which the observations were made (four weeks) by π[1], and regarding the values of $\varDelta t$ in Table III. as being ordinates of the component line whose extreme abscissæ are 0 and $\frac{\pi}{4}$, those in Table VI. as belonging to the line between $\frac{\pi}{4}$ and $\frac{\pi}{2}$, and those in Table VIII. to the line between $\frac{\pi}{2}$ and π; then the whole line between 0 and π, expressed as a special case of Fourier's series, would be represented by the equation

$$\varDelta t = A_1 \sin u + A_2 \sin 2u + \quad . \quad . \quad . \quad . \quad . \quad . \quad + A_m \sin m u + . \quad . \quad .$$

where

$$A_m = \frac{2}{\pi} \left\{ \int_0^{\frac{\pi}{4}} (\alpha_1 + \beta \varphi) \sin m \varphi \, d \varphi + \int_{\frac{\pi}{4}}^{\frac{\pi}{2}} (\alpha_2 + \beta \varphi) \sin m \varphi \, d \varphi \right.$$
$$\left. + \int_{\frac{\pi}{2}}^{\pi} (\alpha_3 + \beta \varphi) \sin m \varphi \, d \varphi \right\},$$

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[1] The assumption furnishes the constant for the reduction of the observations.

and α_1, α_2, α_3 are the intercepts of the component lines on the axis of ordinates. This finally leads to

$$\varDelta t = \frac{2}{\pi} \sum_{o}^{\infty} \frac{1}{m} \left\{ \alpha_1 (1 - \cos m\pi) - \beta \frac{\pi}{4} \left(\cos m\frac{\pi}{4} + \cos m\frac{\pi}{2} + 2\cos m\pi \right) \right\} \sin mu,$$

an equation which, though linear with respect to α_1 and β and capable of further simplification, cannot be practically utilized.

In view of this fact, it was decided to calculate the constants α_1 and β for each set of observations separately. Tables XI., XII., and XIII. give the results, these tables corresponding to III., VI., and VIII., respectively.

TABLE XI.

No.	*u.*	Δt obs.	Δt calc.	Diff.	No.	*u.*	Δt obs.	Δt calc.	Diff.
7	6	0. 065	0. 065	±0	17	62	0. 060	0. 061	−1
8	10	0. 065	0. 065	±0	18	68	0. 059	0. 060	−2
9	14	0. 062	0. 065	−3	19	72	0. 059	0. 060	−1
10	18	0. 068	0. 064	+4	20	76	0. 060	0. 060	±0
11	27	0. 063	0. 064	−1.	21	80	0. 060	0. 059	+1
12	32	0. 063	0. 063	±0	22	84	0. 058	0. 059	−1
13	37	0. 062	0. 063	−1	23	90	0. 060	0. 058	+1
14	42	0. 064	0. 062	+1	24	96	0. 057	0. 058	−1
15	47	0. 063	0. 062	+1	25	100	0. 059	0. 058	+1
16	56	0. 062	0. 061	+1	26	104	0. 057	0. 057	±0

$\alpha = +0.064$;
$\beta = -0.000082 \pm 0.000007$.

TABLE XII.

No.	*u.*	Δt obs.	Δt calc.	Diff.	No.	*u.*	Δt obs.	Δt calc.	Diff.
1	23	0. 098	0. 090	+8	11	86	0. 066	0. 072	−7
2	27	0. 093	0. 088	+5	12	95	0. 067	0. 070	−3
3	33	0. 088	0. 087	+1	13	101	0. 067	0. 068	−1
4	38	0. 088	0. 085	+2	14	110	0. 061	0. 066	−5
5	46	0. 083	0. 083	±0	15	120	0. 062	0. 063	−1
6	51	0. 082	0. 082	±0	16	129	0. 062	0. 061	+1
7	57	0. 078	0. 080	−3	17	138	0. 062	0. 058	+4
8	62	0. 077	0. 079	−2	18	144	0. 058	0. 057	+1
9	71	0. 072	0. 076	−4	19	153	0. 060	0. 054	+6
10	82	0. 068	0. 074	−6	20	161	0. 055	0. 052	+3
					21	177	0. 048	0. 048	±0

$\alpha = +0.096$;
$\beta = -0.000271 \pm 0.000013$.

TABLE XIII.

No.	u.	Δt obs.	Δt calc.	Diff.	No.	u.	Δt obs.	Δt calc.	Diff.
1	3	0.024	0.033	−9	18	163	0.040	0.050	−10
2	11	0.033	0.034	−1	19	171	0.050	0.051	− 1
3	27	0.033	0.036	−2	20	181	0.049	0,052	− 3
4	37	0.044	0.037	+7	21	191	0.057	0.053	+ 4
5	46	0.042	0.038	+5	22	195	0.055	0.053	+ 2
6	51	0.042	0.038	+4	23	206	0.060	0.055	+ 6
7	61	0.042	0.039	+3	24	229	0.067	0.057	+10
8	71	0.041	0.040	+1	25	239	0.063	0.058	+ 5
9	75	0.044	0.041	+3	26	253	0.062	0.060	+ 3
10	85	0.044	0.042	+2	27	267	0.063	0.061	+ 2
11	93	0.043	0.043	±0	28	277	0.067	0.062	+ 5
12	98	0.042	0.043	−1	29	291	0.068	0.064	+ 4
13	109	0.044	0.044	±0	30	301	0.063	0.065	− 2
14	119	0.041	0.045	−4	31	315	0.064	0.066	− 2
15	123	0.039	0.046	−7	32	328	0.068	0.068	+ 1
16	133	0.042	0.047	−5	33	339	0.066	0.069	− 3
17	145	0.042	0.048	−6	34	362	0.063	0.071	− 8

$a = +0.033$;

$\beta = +0.000106 \pm 0.000006$.

The constants β in these tables are, however, of inconvenient magnitude, and it will be more expedient to represent these quantities on the scale of a year. Let ΔT, then, denote the apparent increase of the temperature of the rock in the apparatus per year, the variation being supposed to have continued during the whole of this time in the same manner as during the time of observation. Then from Tables XI. and XII., which, together, comprehend an interval of two weeks,

$$\Delta T = +1^\circ.5 \pm 0^\circ.1;$$

and from Table XIII., corresponding to the same interval,

$$\Delta T = -0^\circ.9 \pm 0^\circ.1.$$

These figures express the final result of the investigation. They indicate that, as far as these experiments go, it would be about equally correct to assume a positive or a negative thermal effect from the action of aqueous vapor on the rock; and that for the present, at least, a thermal effect may be assumed to be absent.

By comparing corresponding values of a in the tables above, it becomes evident that the changes in the values of Δt cannot in any way be referred to the thermo-element; nor is there, in the results taken as a whole, an effect due to the variation of the barometric pressure or to the water level apparent.

A series of experiments made with the rock-chamber empty, the rest of the apparatus remaining, however, as before, gave the following results:

TABLE XIV.

No.	Date.	Hrs.	Δt.	No.	Date.	Hrs.	Δt.
1	Dec. 17, $11^{h}.5$	0.0	0.020	1	Dec. 17, $15^{h}.0$	0.0	0.019
2	Dec. 17, $12^{h}.0$	0.5	0.022	2	Dec. 17, $15^{h}.5$	0.5	0.020
3	Dec. 17, $12^{h}.5$	1.0	0.024	3	Dec. 17, $16^{h}.0$	1.0	0.029
4	Dec. 17, $13^{h}.5$	2.0	0.028	4	Dec. 17, $17^{h}.0$	2.0	0.031

The interval of time covered by these experiments is, of course, too small to justify any confidence in the constants which might be derived from them. They are, however, sufficient to show that Δt undergoes changes analogous to those noted in the preceding pages. It probably follows, therefore, that the final results may be regarded as giving an estimate of the degree of accuracy attainable by the method in its present shape. The chief source of error is the fact that the apparatus does not maintain the constancy of temperature necessary. It is apparently impossible by means of it to heat the large mass of rock to the same temperature throughout. Furthermore, the thermometer employed is neither in sufficiently intimate contact with the rock, nor are the junctures placed in circumstances as nearly identical as is desirable. Finally, I am inclined to infer that a stationary thermal condition was not reached in the experiments. Although this supposition accounts for only a part of the anomalies met with, it will nevertheless be necessary in future researches to extend the time of each set of observations considerably beyond the duration of the above experiments. I omit a detailed discussion of these matters, however, as a further study of the subject is intended.

CHAPTER X.

ON THE ELECTRICAL ACTIVITY OF ORE BODIES.

BY CARL BARUS.

GENERAL STATEMENT.

In 1830 R. W. Fox communicated to the Royal Society a paper which contained the results of a careful experimental study of the possible electric activity of ore bodies. From this time until 1844 the matter was discussed with some enthusiasm by Fox and Henwood, in England, and by von Strombeck and Reich, in Germany. After the publication of Reich's second paper (1844), however, further research seems to have been altogether abandoned; at least I have not, with some pains, been able to find anything that has a bearing on the subject.[1] This is all the more remarkable, as the general line of investigation had already taken a promising direction. It would also have been supposed that Thalen's[2] work would have given the matter a fresh impetus.

With the present investigation (undertaken at the suggestion of Mr. Becker[3]) the question of a relation between local currents and ore bodies is, as it were, resuscitated, so that a general review of the development which it had attained previous to its abandonment seems pertinent.

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[1] See, also, "Revue des Progrès récentes de l'Exploitation des Mines, etc., par M. Haton de la Goupillière, Ingen. en chef des Mines, Professeur, etc.," in the Annales des Mines, T. XVI., p. 6, 1879.

[2] R. Thalen; v. de la Goupillière, *l. c.:* "On trace des lignes d'égale intensité, qui dans le voisinage d'un gîte prennent une forme caractéristique consistant en deux systémes de courbes fermées, concentriques, autour de deux foyers assez nettement indiqués."

[3] Cf.: First Annual Report of the U. S. Geolog. Survey, p. 46, 1880.

BRIEF REVIEW OF THE WORK OF PREVIOUS INVESTIGATORS.

Fox,[1] in his original experiments, secured electric contact with the vein by wedging copper plates against it. These were put in connection with a galvanometer by copper wire. Earth currents, if present, entered the wire at one end, passing through the galvanometer and finally back into the earth at the other.

As a general result of his investigation Fox found that the intensity and direction of the currents bore no relation to the cardinal points, but could be explained by a consideration of the distribution of ores.[2] Between two points of a continuous vein on the same level no current was observable; but when the points tapped were on different levels, or when there intervened between them an area of barren rock (horse), or when two apparently distinct veins were connected, the effect was invariably decisive. At times the currents were so powerful as to throw the needle of his by no means delicate galvanometer ($3\frac{1}{4}$-inch needle in twenty-five turns of wire) several times around the circle. After enumerating a number of facts with reference to the relative position of the veins, Fox remarks that "many of the phenomena referred to bear a striking resemblance to common galvanic combinations, and the discovery of electricity in veins seems to complete the resemblance." In other parts of this paper, however, he expresses the opinion that "mineral veins and internal heat are connected with electric action," and, moreover, anticipates greater effects with increasing heat and depth.

The experiments of v. Strombeck[3] were made at Werlau and Holzappel on a large vein, in which quartz, blende, galena, copper-pyrites, and tetrahedrite occurred in irregular distribution, and are distinguished by the care with which all known sources of error were avoided. Contact was secured by drilling into the vein holes 2 to 3 inches in depth, into which the ends of the wire, spirally wrapped and held in position by a cork, were inserted. In

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[1] R. W. Fox, "On the electro-magnetic properties of metalliferous veins in the mines of Cornwall." Phil. Trans., II., p. 399, 1830.

[2] Galena, copper, and iron pyrites were the minerals met with.

[3] A. v. Strombeck, "Ueber die von Herrn Fox angestellten Untersuchungen in Bezug auf die electro-magnetischen Aeusserungen der Metallgänge." Karsten's Archiv., VI., 431, 1833.

other respects the method of research was identical with that of Fox. v. Strombeck made a large number of experiments, but was unable to detect any traces of electric excitation, and, consequently, concludes that Fox's results are not applicable to veins generally, and that even in Cornwall the matter requires further consideration.

In 1834 Fox again resumed his experiments, with special reference to the objections which had been raised against the validity of his results.[1] It having been mooted that the currents observed might in some way owe their origin to the copper contact-plates, he showed that by replacing these by plates of zinc the results remained unaltered. This was the case even when terminals of copper and zinc were used simultaneously. It was, moreover, immaterial whether the contact was produced by plates or whether the ends of the wire only were pressed against the vein. By inserting a copper-zinc couple into his circuit Fox found that its effect was in some cases nearly, in others decidedly, overbalanced by the lode currents. Finally, in the interval of four years which had elapsed between these and his former experiments the direction of the currents had remained unchanged.

In a subsequent paper Fox[2] endeavors to classify minerals with reference to their electrical properties. A table of conductivities is contained in his original paper.

In the Skeers lead mine, near Middleton, Fox[3] obtained but feeble currents; at the Coldberry mine, in the same locality, they were absent altogether. Lead mines do not in general give evidence of electrical action comparable to that of copper mines—a circumstance which Fox refers to the positions of their ores in his scale.

Henwood's[4] experiments were made on a larger scale (at times as much as 600 fathoms of copper wire were employed), but otherwise in a way

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[1] R. W. Fox, "Account of some experiments on the electricity of the copper vein in Huel Jewel mine." Rep. Br. Assoc., 1834, p. 572.

[2] R. W. Fox, "Note on the electric relations of certain metals and metalliferous minerals." Phil. Trans., I., p. 39, 1835.

[3] R. W. Fox, "Report on some experiments on the electricity of metallic veins, etc." Rep. Br. Assoc., p. 133, 1837.

[4] W. J. Henwood, "Sur les courants électriques observés dans les filons de Cornouailles." Annales des Mines, [3], XI., p. 585, 1837.

analogous to that of Fox. They contain a thorough corroboration of the results of the latter. He, moreover, insists that currents are only obtained in the case where the points tapped are in vein matter, being most decisive for copper pyrites, vitreous and black copper ore, galena and blende; that between points in barren rock electric action is altogether absent. After a number of theoretical considerations—to which the paper is largely devoted—he concludes that the currents are probably of thermo-electric origin, and that they are certainly purely local.

Some time after, all of Fox's experiments were again repeated and the results confirmed throughout by Reich.[1] Although the heating of one of the points of contact in the case where both were applied to the same vein produced a decided thermo-electric effect, quantitatively this was so small as to furnish grounds against Henwood's hypothesis. Reich is convinced that Fox's currents are hydro-electric phenomena. When a point in ore was connected with one in rock, the currents were not only much smaller—probably on account of the greater resistance in this case—but if plates of copper and zinc were used together as terminals, a commutation of these invariably produced a corresponding change in the direction of the current.

In Fox's last paper[2] on the subject, the effect of the contact plates is again carefully considered. But even with one terminal of zinc, the other of copper, "the current continued to deflect the needle from 50° to 60°, notwithstanding that any action between the copper * * * * and the zinc * * * * if it had existed would have been in the opposite direction and have tended more or less to counteract the influence of the actual current." The galvanometer referred to consisted of forty-eight turns of brass wire wrapped around a 2-inch needle, on a pivot. The lode current in a case observed was found to remain constant for a period of eight months. Toward the end of the paper mention is made of experiments in which one or both terminals were in rock. In this case the results were similar to those of

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[1] F. Reich, "Notiz über elektrische Ströme auf Erzgängen." Pogg. Ann., XLVIII., p. 287, 1839.

[2] R. W. Fox, "Some experiments on subterranean electricity, made at Pennance mine near Falmouth." Phil. Mag., [3], XXIII., pp. 457 and 491, 1843.

Reich, "there being still a tendency to deflection." The exchange of terminals of different metals also produced a change in the direction of the current.

In the next year Reich[1] published his second paper, undertaken with the especial object of studying more closely the currents probably existing in the rocks surrounding the vein. His idea was that lode currents are produced by the contact of the different ores in the deposit, the rock which separates them more or less completely one from another performing the function of the liquid of an ordinary galvanic couple. As Fox's method of obtaining contacts with the earth was inapplicable, Reich had holes (12 inches deep) drilled in the rock, into which dilute sulphuric acid was poured. Strips of copper foil plunged into the acid and connected with the ends of a copper wire completed the circuit. Currents were obtained when at least one point was near ore; they were completely absent when both points were in barren rock. Though the deflections of the needle ranged from 2° to 30°, they seemed to obey no general law. The results are, moreover, difficult of interpretation, because the needle does not discriminate between high and low grade, or between base and noble minerals,[2] the deflection being a function of both the quality and the quantity of the electrically active material. Reich's mode of operation was derived from a consideration of the currents of a galvanic cell in action. The paper[3] is interesting and the reader's attention is especially called to it. I shall have occasion to consider it again below.

The reader is finally referred to the Proceedings Roy. Soc. Lond., III., p. 123, 1832, and IV., p. 317, 1841, which were not at my disposal.

Remarks on the foregoing.—From 1830 until 1844, therefore, the papers in hand offer little more than a criticism of Fox's original investigation. In 1844, with the publication of Reich's second paper, in which the idea that if local currents due to ore bodies are present at all they must be discoverable in the rocks, was the basis of research, a second step may be considered

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[1] F. Reich, "Versuche über die Aufsuchung von Erzen mittelst des Schweiger'schen Multiplicators." Berg- u.- hüttenmänn'sche Ztg., [3], pp. 342–346, 386–390, 1844.

[2] The term "mineral" wherever used throughout this chapter is intended to refer to those of the heavy metals only—to those in short in which we may expect to find metallic properties.

[3] See, also, B. v. Cotta, "Erzlagerstätten," Vol. I.

as having been made. It is to be regretted that in none of the papers is there even an attempt toward fully describing the phenomena quantitatively. Generally, conclusions are drawn from the deflection of a galvanometer needle without sufficient consideration of the very probable variation of the resistance of different circuits. The experiments are, moreover, made individually, not in series or with reference to any definite, preorganized plan. Insomuch, however, as most of the work was done when methods of electric measurement were still in their infancy, these matters are not to be mentioned to the disparagement of the authors. In fact, the reader is surprised at the broad view usually taken, at the cautiousness with which hypotheses are stated, and at the number of details and chances of error which are considered.

HYPOTHESIS UNDERLYING THE PRESENT INVESTIGATION.

There can be little doubt that the hypothesis which ascribes to ore-currents a hydro-electric origin is perfectly correct. Fox and Reich themselves found in the case of terminals of copper and zinc used together, the points tapped being in rock, that currents resulted, the direction of which changed with an exchange of the terminals. I have actually measured the electromotive force in action under these circumstances (see page 322), and found it of the same order as that produced by combining these metals with a liquid in the form of a galvanic element. If, then, there are also ores which possess the electric properties of metals—and that this is the case Fox[1] went to some trouble to show—the possibility of ore-currents due to hydro-electric action follows as an immediate consequence. These currents will in general have an origin analogous to those technically known as "local currents" in batteries, while at times they may even be due to the occurrence of a complete natural battery. Thermo-electric hypotheses are unnatural, insomuch as with the temperatures met with, even in the COMSTOCK, it would be necessary to assume values for thermo-electric power which, in comparison with those of known substances, are abnormally large. Such

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[1] R. W. Fox, Phil. Trans., 1., p. 39, 1835.

a speculation is, therefore, remote, artificial, and forced, and, in cases where there is a better hypothesis, deserves only very secondary consideration.

Suppose now that, in connection with an ore body, with reference to which experiments are being conducted, electric action actually does occur. In the consideration of these currents we are at once confronted by the important fact that insomuch as electric action has been going on for an indefinite period of time the currents must have become constant both in intensity and direction, and that therefore the equipotential surfaces corresponding to this flow will have fixed and probably well-definable positions.

In view of the fact that with most geological readers the consideration of electric phenomena will be merely an incidental matter, it may be well to be more explicit than would otherwise be necessary. By far the greater number of electrical phenomena can be explained by regarding electricity as in the nature of an incompressible fluid. The analogy is, in fact, very complete, and extends even into further detail than need be noticed here. We speak of a liquid as having a tendency to flow from a higher to a lower level; of electricity, as flowing from an equipotential of greater to one of less value. In the former case the "levels" are approximately spheroidal surfaces—"geoids"—parallel to the normal surface of the earth; in the latter they may be closed, or may extend to infinity; they may be quite simple or exceedingly complex. In order to exhibit the topography of a country in detail, it may be represented graphically by the aid of a series of equidistant earth levels. In electricity an analogous problem is similarly solved, those surfaces being chosen for which the potential value from surface to surface increases by a definite amount.[1] If a reservoir, the water in which is constantly at a level, p, be joined by a pipe with one in which the water-level is constantly q (both p and q being measured vertically upwards from some fixed datum, and $p > q$), the quantity of liquid traversing any right section of the pipe in the unit of time would *cæt. par.* be dependent on the dimensions of the latter and upon $p - q$. If a point on an equipotential of the value p be connected by a thin wire with a point on one of the value q, analogous remarks may be made with reference to the quantity of electricity (I) flowing

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[1] Neither level nor potential imply the presence of matter or of electricity, respectively, at a given point.

through any right section of the wire in the unit of time. Now it is upon I that the deflection of a magnetic needle surrounded by a coil of wire, the plane of the windings being vertical and parallel to the needle, *cæt. par.*, depends; whence it follows, even if the same arrangement of coil and needle were used throughout, that the deflection just mentioned would contain an incidental element; in other words, that it depends upon the means which have been adopted to effect the connection between the equipotentials p and q.

Returning to the problem in hand, it will be found that the mere measurement of deflections would be of but little avail. An effort must be made to determine the values of p and q at the points tapped by the ends of a wire. These quantities, moreover, are particularly significant, insomuch as the potential at any given point in the vicinity of the ore body depends principally upon the character and distribution of the electrically active ore-matter, and of the rock surrounding it, or wholly on conditions fixed by nature. Hence, instead of seeking for the ore body itself, an attempt will be made to add to the few clews available to the prospector by investigating some characteristic variation of the potential at consecutive, similarly disposed points, as indicating proximity to it. But what has been said of p and q applies equally well to $p-q$, which latter quantity is, moreover, easily measurable, either directly (electrometrically, or by certain galvanometric methods) or indirectly, by the determination of the magnitude of deflection of the needle described above, under known conditions. $p-q$ is technically called electromotive force.

To an observer the equipotentials are accessible for measurement either on the surface or in those places where drifts penetrate them. Let α, ν, τ, Fig. 22, be a line lying either upon or within the surface of the earth. Suppose the electromotive forces be measured between a point α, and consecutive points β, γ, δ . . . μ, ν, ξ, ... σ, τ, υ, . . . taken at convenient, approximately equal, distances apart. The points μ, ν, ξ . . . are supposed to

FIG. 22.

be near the ore body, whereas α, β, γ . . . and σ, τ, υ . . are remote from it. As I shall frequently have occasion to refer to the point α in contradistinction to the remaining points $\beta, \gamma, \delta, \ldots \sigma, \tau, \upsilon \ldots$, I will throughout this chapter refer to the former under the name permanent contact (*P. C.*), while to any of the others the name temporary contact (*T. C.*) will be applied. Then will the electromotive force (e) between *P. C.* and any *T. C.* in general vary with the distance (χ) between these points. This relation will usually be so complex as not to be easily expressible by mathematical means, but it can nevertheless be indicated symbolically by

$$e = f(\chi).$$

If, however, χ is supposed to increase from zero (in which case *P. C.* and *T. C.* coincide) to the value it has for some remote point, υ, then as a field of electrical activity is encountered in the neighborhood of μ, ν, ξ, $f(\chi)$ must pass through a single maximum or minimum, or a number of them. It is therefore toward a characteristic variation of this kind that we must look in endeavoring to define a position of greatest proximity to the ore body. Analogously, though less generally, it may be stated that the increment of potential due to successive increments of distance $\alpha\,\beta$, $\beta\,\gamma$, $\gamma\,\delta$, etc., will be small except in the neighborhood of the ore body. This is probably the idea which Reich had in mind, and which he must have come upon had he followed out the line of his argument to its consequences.

I will add here that local difficulties did not permit me actually to pass linearly through an ore-region. I had to content myself, therefore, with a progress from the latter into barren rock.

EXPERIMENTS MADE IN SOME OF THE MINES ON THE COMSTOCK.

Method.—Experiments were commenced in the *Consolidated Virginia*, *California* and *Ophir* mines, the line at times extending into *Union* and *Mexican* ground.

From the work of previous investigators I was naturally led to expect currents due to electromotive forces of considerable magnitude, and as a consequence, was satisfied with a method of obtaining contact with the vein in which the electromotive force due to the terminals alone was not greater than a few hundredths of a volt Bright steel gads, to the tops of which pieces of thick copper had been firmly fastened, were especially convenient for this purpose, as they could be driven into the vein or again withdrawn from it expeditiously. These gads were from 8 to 10 inches long and about one inch in diameter at the head, from which they tapered gradually to a point. As it would be repeatedly necessary to use them in places where the earth was naturally moist, the question arose whether it might not be desirable in all the experiments to moisten the rock around the gads at once. Accordingly, two sets of experiments, the results of which are contained in Tables I. and II., were made, the former above the surface, the latter below.

Two suitable positions in rock free from mineral[1] matter having been selected, the gads were driven and the circuit completed. Measurements of resistance and electromotive force were then made. The gads were now exchanged and the measurements repeated, and so on. The relative position of the gads to an observer facing them is indicated in the second column of the tables. Resistance (*W*) in ohms and electromotive force (ε) in volts are given in the third and fourth columns, respectively. The last column shows the direction of the current, arbitrarily called "+" when flowing in one way, "—" when flowing in the opposite.

TABLE I.—*Experiments made on south side of Bullion Ravine.*

[Gads driven into quartz seams between walls of diorite, about 10 feet apart. Seams naturally somewhat moist.]

Gads dry.					Gads wet.				
No.	Position of the gads.	W.	ϵ.	Direction of the current.	No.	Position of the gads.	W.	ϵ.	Direction of the current.
1	I, II	7600	0. 03	+	1	II, I	1560	0. 01	+
2	II, I	6300	0. 09	+	2	I, II	1260	0. 02	+
3	I, II	4300	0. 01	—	3	II, I	1280	0. 02	+
4	II, I	4500	0. 06	+	4	I, II	1200	0. 01	+
5	I, II	3700	0. 00	—	5	II, I	1210	0. 01	—
6	II, I	3400	0. 01	+	6	I, II	1200	0. 01	—
7	I, II	3200	0. 00	+	7	II, I	1230	0. 01	+
					8	I, II	1240	0. 01	—
					9	II, I	1240	0. 04	+

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[1] See note, page 313.

TABLE II.—*Experiments in the Con. Virginia and California, 1750-foot level.*

[Gads driven into rock, as free from mineral matter as possible, about 8 feet apart.]

Gads dry.					Gads wet.					
No.	Position of the gads.	W.	ε.	Direction of the current.	No.	Position of the gads.	W.	ε.	Direction of the current.	Date.
1	II, I	6000	0.04	+	1	II, I	550	0.03	—	Sept. 24, 1880.
2	I, II	3700	0.04	+	2	I, II	500	0.03	—	Sept. 24, 1880.
3	II, I	2800	0.02	+	3	II, I	450	0.01	—	Sept. 24, 1880.
4	I, II	2200	0.02	+	4	I, II	400	0.02	—	Sept. 24, 1880.
5	II, I	1870	0.02	—	5	II, I	380	0.01	—	Sept. 24, 1880.
6	I, II	1380	0.01	+	6	II, I	390	0.01	+	Sept. 25, 1880.
7	II, I	1030	0.03	+	7	I, II	270	0.03	+	Sept. 25, 1880.
8	I, II	1060	0.01	—	8	II, I	280	0.01	+	Sept. 25, 1880.
					9	I, II	260	0.03	—	Sept. 25, 1880.
					10	II, I	270	0.01	—	Sept. 25, 1880.

The results are highly in favor of wet gads. By their use a very marked diminution of resistance is effected without increasing the values of ε. The direction in which ε acts follows no observable law, probably being conditioned by the electrical difference of the gads and by effects of polarization due to the introduction of a Daniell.

Analogous experiments were also made with copper and zinc. These metals were used in the form of strips cut from sheets. Each strip was bent around the small end of a slightly conical stick of wood about one foot in length. The plug was then firmly driven into a hole previously drilled for the purpose, in such a way as to force the metal into thorough contact with the rock Table III. gives the results, the notation being the same as that used in Table I.

TABLE III.—*Experiments in the Con. Virginia and California, 1750-foot level.*

[Plugs about 10 feet apart in moist clay seams, repeatedly exchanged as indicated.]

Copper plugs, wet.			Zinc plugs, wet.		
No.	Position of plugs.	ε.	No.	Position of plugs.	ε.
1	I, II	+0.02	1	I, II	+0.02
2	II, I	+0.02	2	II, I	+0.02
3	I, II	+0.01	3	I, II	+0.03
4	II, I	+0.02	4	II, I	+0.01
5	I, II	+0.02	5	I, II	—0.01
6	II, I	+0.02	6	II, I	—0.01
7	I, II	+0.01	7	I, II	+0.00
8	II, I	+0.02	8	II, I	+0.01
9	I, II	+0.01	9	I, II	+0.01
10	II, I	+0.02	10	I, II	+0.00

Steel plugs are therefore not greatly inferior to those of copper or zinc in cases where a few hundredths of a volt are believed to be of minor importance; whereas, on the other hand, their use for the purpose in view is attended with much convenience. It was found, however, that great care had to be taken in keeping them bright, as otherwise the electrical difference between the gads themselves was apt to rise to many times the value given above. It was also necessary to maintain a thorough contact between the ends of the metallic circuit and the gads.

Great difficulty was encountered in avoiding leaks in the copper wire connecting the plugs with the galvanometer. At first wire covered with a double thickness of cotton and waxed was employed, but proved to be wholly inadequate. Even gutta-percha wire scarcely offered as complete an insulation as was desired, in the hot and damp atmosphere of the COMSTOCK, when laid in long lines without special precautions. After testing a number of devices, it was finally found sufficient to suspend the wire from silk or waxed cotton threads, care being taken to prevent it from anywhere touching either rock or timbers. This plan of swinging the line was adhered to throughout, in spite of the loss of time frequently occasioned thereby. In short, the rule was finally adopted of arranging all the connections just as though the experiments contemplated were to be made with frictional electricity.

The galvanometer used in these experiments was an ordinary instrument with an astatic needle, capable of measuring intensities as small as 0.0001 in Weber's electromagnetic scale (*mg. mm. sec.*) with certainty. Readings were made directly, the needle swinging over a graduated arc.

For the measurement of electromotive forces a method of compensation was first employed. But in the course of the investigation it was found absolutely necessary to abandon all complications and to reduce the method of research to the utmost simplicity. This will be evident to the reader when he remembers that the heat of the mines is such as to cause profuse perspiration, and thus seriously interfere with manipulation; that it was desirable to make the first observations near or on the vein—hence in the busiest part of the mine—so that expeditious operation was extremely important; that, finally, the time during which exposure to high temperatures can be endured with safety is itself necessarily limited. A simple method, analogous to one of consecutive substitution of two elements in the same circuit of large resistance, was therefore adopted. If e and E denote the lode electromotive force and the electromotive force of a normal element, respectively, i and I the intensities due to the action of e and $E \pm e$ in the same circuit, we shall have, approximately,[1]

$$\frac{e}{E \pm e} = \frac{i}{I}, \text{ or } e = E\,\frac{i}{I \mp i}.$$

Intensities were measured by the aid of the galvanometer above described, the instrument having been carefully calibrated at the outstart—an operation which was frequently repeated during the course of the experiments. i and I could both be determined in the same circuit without inserting auxiliary resistances.

Results.—By way of example, some of the results obtained in the mines of the COMSTOCK will now be cited. The plan has been indicated in a foregoing paragraph (page 316–7). It will be remembered that a permanent contact placed conveniently in one end of the network of drifts, is successively connected with points in positions of sufficient interest to justify measurement. In the tables, unless otherwise stated, *P. C.* is to be understood as coinciding with point I. The second column contains the distance, in feet, of the points tapped below the level of the mouth of the shaft as a datum. "Distance" and "bearing" refer to the imaginary lines connecting *P. C.* (I) with the remaining points of the series. An exception is, however, made in Table VI., where the data contained in corresponding columns give the horizontal distance and bearing of the lines joining consecutive points e, the lode electromotive force, is expressed in volts, and is taken as positive when it acts in the direction *P. C.* ⟶ Earth ⟶ *T. C.*

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[1] Approximately, because, in the case when the lode electromotive force acts alone, we have not a true circuit, in the ordinary sense. Between the holes, both in the earth and in the wire, the direction of the current is the same. But since the resistance of the rock, passing from the hole into the earth, diminishes rapidly (see page 359), the former may be considered, with a degree of accuracy sufficient for the purpose, as acting through the same resistance as does the normal element, subsequently inserted.

TABLE IV.—*Experiments made in the Ophir mine.*

[Steel gads.]

No.	Level.	Points.	Distance	Bearing.	*e.*	Remarks.
	Feet.		*Feet.*			
1	2, 000	I	0	....	±0. 00	In quartz seam; barren.
2	2, 000	II	116	S. 55° E.	+0. 02	In clay seam.
3	2, 000	III	170	S. 20° E.	+0. 01	In quartz seam; old stope; low-grade ore.
4	2, 000	IV	415	S. 42° E.	+0. 02	In quartz seam; new stope; ore.
5	2, 000	III, IV	260	S. 55° E.	+0. 01	
6	2, 300	I	0	....	....	In clay seam.
7	2, 300	II	230	N. 19° E.	+0. 04	In small quartz seam; barren.
8	2, 300	III	370	N. 19° E.	+0. 01	In small quartz seam; low-grade ore.
9	2, 300	IV	415	N. 29° E.	+0. 05	Do.
10	2, 300	V	470	N. 38° E.	+0. 02	In quartzose clay.

TABLE V.—*Experiments in the Consolidated Virginia and California mines.*

[Steel gads.]

1	1, 750	I	0	Points nearly vertically above one another.	+0. 00	All points in the vein; ledge very broad; low-grade ore in quartz gangue.
2	1, 750	II	20		+0. 09	
3	1, 750	III	60		+0. 01	
4	1, 750	IV	100		+0. 08	

TABLE VI.—*Experiments in the Ophir and Mexican mines.*

[Copper terminals.]

1	2, 000	I	0	....	+0. 00	In small quartz seam; barren.
2	2, 300	II	0	....	+0. 02	Do.
3	2, 300	III	100	S. 19° W.	+0. 03	Do.
4	2, 300	IV	100	S. 19° W.	+0. 04	Do.
5	2, 300	V	100	S. 19° W.	+0. 04	In large quartz seam; low-grade ore.
6	2, 300	VI	80	N. 29° E.	+0. 03	Do.
7	2, 300	VII	85	N. 38° E.	+0. 04	In quartzose clay.

Discussion.—From a comparison of Tables I. and II. with Tables IV., V., and VI. it appears at once that the electromotive forces due purely to chemical difference and polarization of the terminals are of the same order as the data expressing the electric activity of the LODE. The latter therefore can serve no other purpose than that of affording information as to the magnitude of the forces to be determined. To assure myself as to the certainty of this conclusion, I made a measurement of the electromotive force (ε) obtained by using terminals of copper and zinc conjointly, and found, as a mean of three experiments,

$$\varepsilon = 0.82.$$

In consequence of polarization, the current speedily diminished in strength, so that all the phenomena are identical with those which would be obtained in the laboratory. The effect of polarization in distorting the true value of the lode currents was frequently noticed, but it would be superfluous to repeat the data here.

It is necessary therefore, in order to obtain satisfactory results, to apply all the refinements that have been developed for problems of this character. In making an attempt of this kind in the mines on the COMSTOCK, however, unusually great difficulties would be encountered. At the outstart, the fact that the observer is compelled to operate with wet hands must be considered as prejudicial to delicate physical experimentation. But there is a more fundamental difficulty. It will be remembered that the ore of the COMSTOCK LODE is argentite accompanied by gold, probably in the metallic state, finely disseminated in quartz. At the time of the experiments the mines without exception were working in comparatively barren parts of the vein, so that there was actually more mineral possibly possessing electrical properties (iron pyrites, etc.) in the rocks than ore in the ore-stopes. In such a case the term "ore body" is scarcely applicable at all.

The result of circumstances of this kind, regarded from an electrical point of view, can be expressed as follows: Either there will be no electric action at all, since each little granule of ore or pyrite may be considered as surrounded by an insulating envelope of either quartz or country rock—whether the latter be considered as an insulator or an electrolyte is immaterial—or the whole DISTRICT, vein and rock, is to be regarded as the field of electric action. In the latter case an equal difficulty occurs, insomuch as within the limited space open to the observer the variation of potential will be inappreciable. In short, from the peculiar distribution of mineral matter, electric excitation is not local in comparison with the space accessible for experimentation.

The unusual difficulty with which a correct interpretation of results would be attended, not to mention the loss of time occasioned by the fact that, in consequence of the heat, experimentation cannot be long continued, finally induced me to abandon the matter at the COMSTOCK altogether—at least until definite results could be obtained in a more favorable locality.

EXPERIMENTS MADE AT THE RICHMOND MINE, EUREKA DISTRICT, NEVADA.

Opportunities for investigation.—In determining to make the study of local currents a part of the work to be done under his charge, Mr. Becker[1] had selected both the COMSTOCK LODE and the Eureka district as available localities, in which to test the applicability of an electrical method as an aid to prospecting. The former is a fissure vein, in which the ore, comparatively free from base material, is scattered irregularly through a quartz gangue. At Ruby Hill, Eureka, the ore is principally plumbic carbonate and sulphide and oxide of iron—the whole containing more or less silver and gold—occurring, moreover, in huge, apparently isolated masses in limestone. In most of the cases fissures containing vein matter and connecting the chambers have been traced. The facilities offered for the prosecution of the investigation by the Eureka deposits were therefore, to all appearances, unusually great. The immense ore bodies in sight were furthermore at a mean distance of not more than 400 feet from the surface, and a series of electric surveys could easily be carried out over, through, and under them. Finally, it appeared not at all improbable, insomuch as the ore bodies in places extend to within 100 feet from the surface, and are in fact to some extent above the mean surface of the surrounding country,[2] that local electrical currents might actually be detected on the surface itself. In consideration of this encouraging prospect due pains were taken to work up all the experimental details with corresponding care.

Arrangement of terminals.—Above all things it was necessary to devise some method of obtaining electric contact between the ends of the metallic circuit and the rocks, which would be free from the difficulties met with in the COMSTOCK. Metallic plates, etc., used alone, are objectionable (see page 358); but it is clear that through the intervention of a suitable liquid, effects of polarization, etc., can be avoided. The following contrivance, based on

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[1] *Cf.* First Annual Report U. S. Geolog. Survey, p. 46, 1880.

[2] Being in Ruby Hill, an elevation of some hundreds of feet above the extensive plain partially surrounding it.

the well-known fact of the excellence of amalgamated zinc in a zinc sulphate solution, for the purpose in question, was finally adopted.

Into a large cork *a*,[1] Fig. 23 (longitudinal section), is inserted a strip of amalgamated zinc, *ef*, about one-half inch broad, to the top of which, *e*, a gutta-percha-covered copper wire, *hik*, is soldered. Throughout the greater part of its length it rests against a stick of wood, *cd*, cylindrical above at *c*, which end is to be thrust through a perforation in the cork *a*, but wedge-shaped below, *d*. At *i* the wire and stick are firmly tied together. A smaller cork, *b*, secures the lower end of both zinc and stick. The whole is surrounded by a piece of beef-gut, *gg* (free from salt), tied to the corks *a* and *b*, as shown in the cut.

Into the bag (6 to 10 inches long) thus formed is poured a solution of zinc sulphate, the wooden plug *l* being for this purpose removed and a small funnel inserted. On replacing the plug the terminal is ready for use. The object of the stick is to obviate accidents due to breakage of the zinc, this material becoming very brittle by amalgamation.

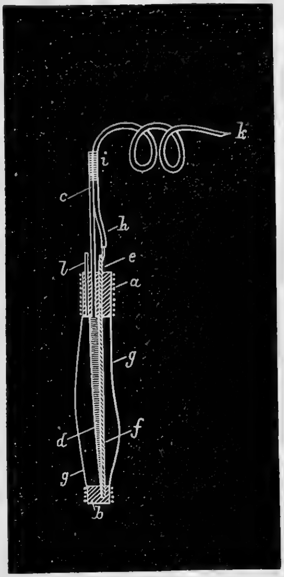

FIG. 23.—Terminal, longitudinal section.

Fig. 24 represents the terminal in place. A suitable hole, 6 to 9 inches deep and 1 to $1\frac{1}{2}$ inches in diameter, is drilled into the rock or vein, at an angle of about 30° with the vertical, and filled with a solution of sodic sulphate or water; whereupon the bag is introduced as shown in the figure. The dotted line *mn* indicates the level of the outer liquid.[2] Solution of sodic sulphate was at first used, because it increases the conductivity and is not acted upon appreciably by the rock (limestone). It was found, however, that ordinary water, which had previously been placed in contact with zinc for some time, so as to precipitate all dissolved matter which might act upon

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[1] 1 to $1\frac{1}{2}$ inches in diameter.

[2] The solution poured into the hole will be referred to throughout this description as the "outer liquid."

it, was preferable (see page 357). When not in use the bags were kept in a glass vessel containing a zinc sulphate solution; during the observations, however, they were transported from place to place in jars containing water.[1]

The electromotive force between two similar bags placed in the same external liquid was seldom found to be greater than 0.005 volt, usually much less, and tolerably constant (see page 362); whereas the electromotive force of polarization, due to the action of a Daniell under circumstances actually met with in the mines, a number of data being in hand, was in no case as large as 0.001 volt and in the experiments cited falls below this limit. For comparison the bags in a particular instance were filled with water instead of zinc sulphate, when an electromotive force of polarization of 0.020 volt was obtained.

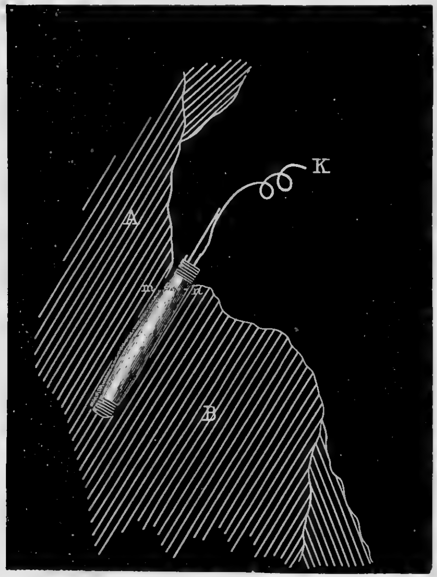

Fig. 24.—Terminal in position.

Wire.—Gutta-percha-covered wire No. 19, of excellent quality (Tillotson & Co., New York), was used almost exclusively, the whole circuit nevertheless being suspended in air from threads, as in the Comstock. In the long circuit on the 600-foot level it was necessary, however, to employ cotton-covered wire for part of the line, the supply of the other being insufficient. This could be done without disadvantage, as follows: A hollow cylinder of gutta-percha, stripped from the end of a wire covered with this substance, was bent in the form of a loop, Fig. 25, and kept bent by a thread passed through its

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[1] It was desirable during the observation to have the outside of the bag as free from zinc sulphate solution as possible.

interior and tied. The cotton-covered wire used (*a b* in figure) was passed through this loop, suspended by the other end of the thread.

A case in which gutta-percha-covered wire trailed on the ground a distance of about 1,000 feet, was made the subject of measurement. A leak was quite perceptible; the insulation offered, however, was about 1,000,000 ohms.

In extending the line from point to point, according to Reich's very convenient plan, the wire is wrapped on a light wooden reel, but in such a way that the inner end also remains accessible. The outer end being in connection with the measuring apparatus, enough wire is uncoiled to reach the desired hole, and a connection (contact-bag) between this and the inner end of the wire is then made. In the damp atmosphere the reel soon became saturated with moisture, and, in spite of the insulation of the wire, care had to be taken to insulate the former also.

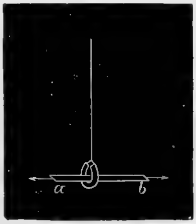

FIG. 25.—Suspension.

Galvanometer.—For the measurement of intensity I was fortunate in securing a magnificent instrument, made for me after the Wiedemann pattern, by Mr. Wm. Grunow, of New York. This instrument is exceedingly convenient for the purpose, as by an adjustment of the coils the sensitiveness can be varied over a very wide range. Readings were made with telescope, mirror, and scale. In the adjustment adopted currents as small as $\frac{20}{10^8}$ webers could be detected with certainty.

Measurement of electromotive force.—The simple method of consecutive substitution for the measurement of electromotive forces $\left(e = E\frac{i}{I \mp i}\right)$—insomuch as while there were no reasons for abandoning it there were a great many in its favor—was adopted here as on the COMSTOCK. The coils of Grunow's galvanometer could easily be so placed as to enable the observer to measure with sufficient accuracy both the lode current and that due to the latter and the normal electromotive force conjointly, without making any change at the instrument or inserting auxiliary resistances. By means of an inclosed mercury commutator the current in the galvanometer could be reversed and the deflection thus doubled. All intensities (i and I) were determined as a mean of five consecutive commutations—not that it was desirable or necessary to increase the accuracy by such a process, but because it appeared essential not to hurry the measurements and to test the constancy of the current as appearing in the five data obtained Errors from condensation of moisture on the commutator were avoided by excluding the latter entirely from time to time, the measurements being made by simply connecting the wires with clamp-screws.[1]

As a matter of especial importance it will be necessary to consider a scheme of operations by which discrepancies due to extraneous causes can be eliminated as completely as possible. In the experiments the following order of observations was adopted and rigidly adhered to throughout:

1. Measurement of the apparent intensity of the lode current (i').
2. The same, with the terminals exchanged (i'').
3. Measurement of the current produced by the normal element and lode conjointly (I).
4. With the battery left in place the circuit is broken at the temporary contact; no deflection must ensue (E supposed to be acting *with* the lode electromotive force).

If a mean of the intensities derived from the first and second operations $[i = \frac{1}{2}(i'' + i')]$ be taken, the intensity of the current (i) due to the lode only will be obtained. That due to differences in the amalgamated zincs is thus eliminated. In by far the greater number of experiments three exchanges were made, so that the first and third positions of the terminals were identical. Analogously, then,

$$i = \tfrac{1}{2}\left(i'' + \frac{i' + i'''}{2}\right).$$

The fourth operation in this scheme insures the perfect insulation of the circuit between the $T.\ C.$ and the galvanometer. The part between the latter and $P.\ C.$—the two being always placed in close proximity, this

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[1] The commutator used was made of wood boiled in linseed oil, and supported on three conical feet of wood boiled in wax and resin. The holes, moreover, were coated with a thick layer of wax (see page 354). Whole sets of observations had to be discarded on account of the insufficient insulation of an earlier apparatus.

partial circuit, moreover, remaining fixed—is tested once for all before commencing the experiments.

It is often desirable, before inserting the Daniell, to determine whether the circuit is in order and without a break. This may be easily accomplished by touching with the finger a copper part of it, so that a secondary circuit, *T. C.*, wire, galvanometer, wire, body, earth, *T. C.*, or *P. C.*, wire - - - body, earth, *P. C.*, is produced, respectively. The electromotive force acting in this case is that of zinc-copper, but in consequence of the very large resistance of the finger contact the current, though distinctly perceptible, is too weak to produce any appreciable polarization.

In spite of all these safeguards, however, a close inspection of the recorded values still revealed discrepancies which had not been avoided. Accordingly the method of procedure was further improved by the following additions: To eliminate as much as possible the effect due to the terminal bags, a variation was introduced by which the results from different bags could be compared. Four of these, *A*, *B*, *C*, and *D*, were generally employed, which, when combined, two and two, in the manner shown in the diagram, gave three separate and distinct values for the lode electromotive force *e*. The electromotive force between any two bags, *A* and *B*, is represented by $A|B$, between *A* and *C* by $A|C$, etc.

Holes.	P. C.	T. C.	Electromotive force.	P. C.	T. C.	Electromotive force.	P. C.	T. C.	Electromotive force.
First series ...	*A*	*B*	$e \pm A\|B$	*B*	*A*	$e \mp A\|B$	*A*	*B*	$e \pm A\|B$
Second series ..	*A*	*C*	$e \pm A\|C$	*C*	*A*	$e \mp A\|C$	*A*	*C*	$e \pm A\|C$
Third series ...	*A*	*D*	$e \pm A\|D$	*D*	*A*	$e \mp A\|D$	*A*	*D*	$e \pm A\|D$
	Original position.			First exchange.			Second exchange.		

After the second exchange, the bags again have their original position with reference to the holes. The corresponding measurements, therefore, check one another, while from their mean any linear variation of their own electromotive force is eliminated. Each series gives a value for *e*. With this method of triple measurement the series was completed by determining all the electromotive forces between *P. C.* and each of the *T. C.*'s, starting with the one nearest *P. C.* and ending with the most remote. After this the whole set was again repeated, starting, however, with the extreme

T. C. and finishing with the one nearest *P. C.* The two sets, therefore, form a symmetrical series, and from the means of all the values corresponding to any particular *T. C.* any change which may have taken place in the hole *P. C.* (see page 360), as well as in the electromotive force of the Daniell, may be regarded as practically eliminated. A comparison of the two sets, moreover, affords a good criterion of the constancy of the currents as well as of the trustworthiness of the results obtained in general.

Resistance.—Besides the electromotive force, the resistance of the different circuits was also measured, being an item of interest. The values usually ranged between 2,000 and 3,000 ohms, though at times they went as high as 20,000, or as low as 700 ohms. Almost the whole resistance of the circuit is encountered by the current in passing from the wire into the rock, and from the latter back again into the former. In other words, the resistance of the layers of rock immediately surrounding *P. C.* and *T. C.* is so large that in comparison with it that of the rest of the circuit (never greater than 20 ohms) can be completely neglected The total resistance is, therefore, essentially the sum of two terms, corresponding to the holes, respectively. Suppose now that in a circuit *P. C.* (*T. C.*) these partial resistances are w and r, respectively; in a circuit *P. C.* (*T. C.*)′, w and r', respectively; if it is found, experimentally, that

$$\left.\begin{array}{l} w+r=a,\\ w+r'=b,\\ r+r'=c, \end{array}\right\}, \text{and if } s=a+b+c, \text{ then } \left\{\begin{array}{l} r=\frac{s}{2}-b,\\ r'=\frac{s}{2}-a,\\ w=\frac{s}{2}-c. \end{array}\right.$$

These points have been described in considerable detail, being of such importance that without them the results reached would be illusory. I was twice obliged to discard whole sets of experiments because one or the other of the disturbances set forth had found their way into the results in the most insidious manner. It is true that Fox actually used uncovered wire; but it must be remembered that the currents obtained by him were abnormally large. Moreover, I am convinced that the currents found by Fox, when connecting two different points in rock, were entirely due to, and that those of Reich were very largely distorted by, discrepancies of the kind discussed in this paragraph.

Relative position of the ore bodies.—Before proceeding further, it will be necessary to give the reader a general idea of the disposition of the ore bodies of the Richmond mine. It will be convenient, and fully sufficient for the present purposes, to consider them with reference to a horizontal and a vertical projection. The former will be given with the different sets of observations which are to follow. For the latter I am indebted to Mr. R. Rickard, superintendent of the Richmond Mining Company, without whose cordial coöperation it would have been impossible, in the time allotted, to carry out these experiments. To Mr. Rickard are also due the following details and sketch

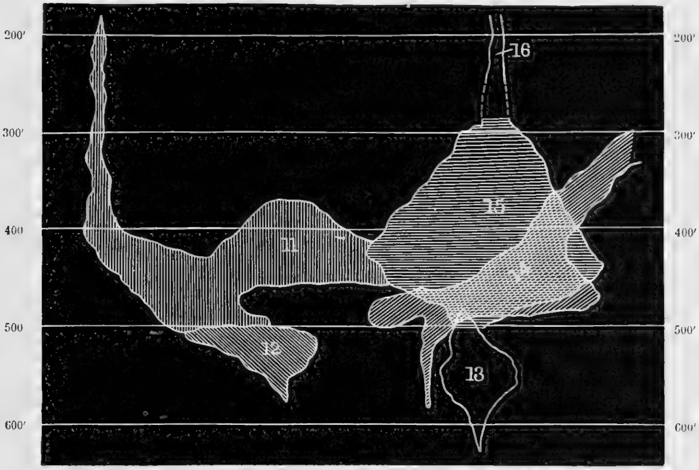

FIG. 26.—Vertical section through ore bodies.

In Fig. 26 the horizontals passing across the diagram represent the levels in feet below the shaft-mouth as a datum. Different ore bodies are differently shaded, the attached numbers depending upon the date of their discovery. The sketch is intended to illustrate the relative positions of the ore bodies one to another only, as seen from the extreme north.

Chamber No. 11 begins on the 200-foot level and continues to the 500-foot level.

No. 12 is a continuation of No. 11, beginning on the 500-foot level and ending 70 feet below this level.

No. 16 commences 50 feet above and runs 70 feet below the 200-foot level; the bottom of the present workings.

No. 15 commences on the 300-foot level and continues to the 500-foot level.

No. 14 begins 50 feet above the 400-foot level and continues to within 50 feet of the 600-foot level.

No. 13 begins at the 500-foot level and continues 50 feet below the 600-foot level.

Chambers Nos 13, 14, and 15 are all connected and form one ore body. No. 16 will undoubtedly connect also with these three, so that in fact Nos. 13, 14, 15, and 16 are but lobes of one and the same huge deposit.

The greatest horizontal extent of these bodies is between the 400 and 500-foot levels, the plan showing the following dimensions:

N. to *S.*	520 feet.
E. to *W.*	600 feet.

No. 7 extends from the 400-foot level to 50 feet below this level.

No. 10 begins 20 feet above and ends 50 feet below the 400-foot level, and is exhausted. No. 13 also is partially exhausted.

East of the group of ore bodies of the Richmond Company are those of the Eureka Consolidated Company, which are also of unusually large dimensions, the ore being the same in every respect.

Experiments on the 500 and 400-foot levels.—These series of measurements were made with the intention of observing the variation of potential met with in passing through the ore body, the line of electric survey beginning and terminating in points as far distant from it as was practicable.

The plan of the position of the drifts on the 500 and 400-foot levels relatively to the ore chambers, so far as is necessary for the present purposes, is given in Fig. 27, on a scale of $\frac{1}{3000}$. Starting with the shaft at *m*, the drifts are represented by broad black lines. The main drift on the 400-foot level, passing from a point between VIII. and IX. on that level in an approximately semicircular path toward the shaft, has, as well as other workings, been partially or wholly omitted. Instead of giving an outline of the horizontal projection of the ore bodies themselves, it was thought preferable to represent rather the position and extent of the actual workings. On the map, chamber No. 11 is designated by *ab*, No. 12 by *CD*, Nos. 13 and 14 by *rS*, and No. 15 by *tg*. The position of chambers Nos. 7 and 10 is only indicated. Smaller patches of ore also occur at *n*, between the 500 and 600-foot levels, and at *P*, above and below the 500-foot level.

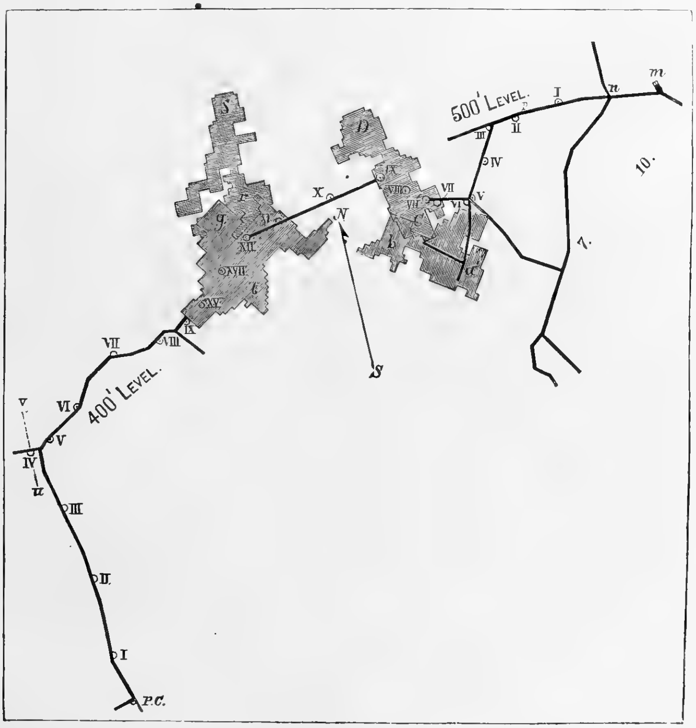

FIG. 27.—Plan of the 400′ and 500′ levels. Scale $\frac{1}{3000}$.

uv, on the 400-foot level, marks the position of a line of contact between shale and limestone. It may be remarked that the shale of the west country intersects the 400-foot level on a line approximately parallel to the drift between *P. C.* and No. IV.

Unfortunately, local circumstances rendered it absolutely impossible to make this survey in a single continuous series, however desirable such a method of procedure would have been. But the object was accomplished indirectly by selecting a permanent contact both on the 400 and on the 500-foot levels, and carrying the two lines of measurement onward to the same intermediate point. The differences of potential thus obtained from two fixed points, respectively, can then be converted by a simple method of reduction into those which would have been obtained had all the electromotive forces been measured from one and the same *P. C.*

On the 500-foot level the permanent contact was placed in chamber No. 12, in calcareous earth stained with iron, its position coinciding nearly with the letter *C* in the plan of this chamber (Fig. 27, *C. D.*). The points selected as *T. C.'s* are designated on the map by small circles, to which Roman numerals are annexed, and extend from I., near the shaft *m* on the 500-foot level, in a more or less broken line to XV., in chamber No. 15, about 30 feet below the 400-foot level. The following table will describe them more completely. Column 2 in Table VII. contains the points, some of which, to prevent confusion, were omitted on the map; column 3, the depth of each below the mouth of the shaft, taken as zero. "Distance" refers to the length of the lines joining consecutive points for which data are given.[1] The figures under "bearing" are to be similarly understood. (S. 81° W. refers to the line I.–III.; S. 26° W., to III.–V.; N. 67° W., to V.–IX., etc.) It appeared unnecessary to give more than the bearings of the main lines of direction on which the points approximately lie. The figures included under "resistance" are the means of two determinations of this quantity made for each of the points. They express the sum of the resistances of the rock surrounding *P. C.* and the *T. C.* specified. The original results were always greater than those made at a subsequent time; this from the fact that the rock in the neighborhood of *P. C.* and *T. C.* became, during the progress of the experiments, gradually more saturated with moisture.

---

[1] The points for which no data are given are distributed through various parts of chambers 12 and 15, in positions for which it was difficult to make measurements.

TABLE VII.

No.	Points.	Level.	Distance.	Bearing.	Resistance.	Remarks.	
		Feet.	*Feet.*		*Ohms.*		
1	P. C.	500	....	....	....	Ferruginous, calcareous earth, in chamber 12.	
2	I	500	0	Origin.	3620	Hard, fissured limestone.	
3	II	500	84	....	1480	Limestone, compact, porous, moist.	
4	III	500	39	S. 81° W.	1550	Do.	
5	IV	500	55	....	1660	Do.	
6	V	500	69	S. 26° W.	1670	Do.	
7	VI	500	13	....	970	Limestone, very porous, near contact of chamber 12.	
8	VII	500	47	....	2090	Ferruginous earth.	
9	VII′	500	....	....	850	Red ocher, near bunch of ore.....	Chamber No. 12.
10	VIII	500	....	....	1520	Ferruginous earth	
11	IX	500	101	N. 67° W.	1590	Pocket of lead carbonate ore in limestone.	
12	X	500	101	....	5560	Hard, impervious limestone and calcspar.	
13	XI	500	94	....	3720	Hard, solid limestone.	
14	XI′	490	....	....	2240	Ferruginous earth, with galena	Chamber No. 15.
15	XII	480	88	S. 80° W.	3590	Black iron ore, loose dry	
16	XIII	460	....	....	2620	Ferruginous earth, with galena	
17	XIV	450	....	....	1990	Ferruginous earth, without galena..............	
18	XVI	450	....	....	1140	Large breast of lead carbonate ore..............	
19	XVII	440	....	....	6260	Ferruginous earth, very dry	
20	XV	430	123	S. 37° W.	990	Large breast of lead carbonate ore..............	

The results of the measurements of electromotive force between *P. C.* in chamber 12 and the consecutive *T. C.'s* are given in Table VIII. The general method of obtaining them has already been described (see page 329). Intensities (i) are given in absolute electromagnetic units (*C. G. S.*); electromotive forces (e) in volts, and these are arbitrarily considered positive when the potential of *T. C.* is the greater, or when the lode current flows

$$T.\ C. \longrightarrow \left\{ \begin{matrix} wire \\ earth \end{matrix} \right\} \longrightarrow P.\ C.$$

It will be remembered that, throughout, four terminal bags, *A*, *B*, *C*, *D*, were used. The results obtained with *AB* are given in Series I., where, moreover, i' is the intensity observed with the bags *A* and *B* in any particular position (say *A* in hole *P. C.*, and *B* in *T. C.*); i'' the intensity observed when the bags are exchanged (*B* in hole *P. C.*, and *A* in hole *T. C.*); finally, i''', the observed intensity when the bags again have their original position. e is the corrected lode electromotive force between *P. C.* and the *T. C.* specified. Series II. contains the corresponding results with the bags *A* and *C*; Series III., with *A* and *D*.

Finally, Series I., II., and III. were obtained in surveying from point

I. to XV., series IV., V., and VI., on the other hand, on returning from XV. back to I

In these experiments a solution of sodic sulphate was used as an outer liquid.

TABLE VIII.

FIRST SERIES.

No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$	No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$
1	I	+ 16	− 10	+ 13	+ 1	11	X	± 0	− 25	....	− 7
2	II	+ 41	− 26	....	+ 1	12	XI	− 35	+ 5	....	− 6
3	III	− 61	+ 56	....	± 0	13	XI′	+ 41	− 46	....	± 0
4	IV	+ 46	− 41	....	± 0	14	XII	− 49	+ 5	....	− 8
5	V	− 33	+ 71	− 30	+ 3	15	XIII	− 25	− 25	....	− 6
6	VI	+ 89	− 66	+ 102	+ 2	16	XIV	− 5	− 12	....	− 2
7	VII	+ 59	− 39	+ 56	+ 2	17	XVI	+ 35	+ 10	....	+ 3
8	VII′	+ 7	− 57	+ 10	− 2	18	XVII	− 0	− 3	....	− 1
9	VIII	+ 35	− 41	....	± 0	19	XV	+ 112	+ 95	+ 121	+ 11
10	IX	− 117	− 41	....	− 13						

SECOND SERIES.

1	I	+ 8	− 12	....	− 1	11	X	+ 2	− 28	....	− 7
2	II	+ 30	− 26	....	± 0	12	XI	− 38	+ 25	....	− 3
3	III	− 53	+ 33	....	− 2	13	XI′	+ 49	− 56	....	− 1
4	IV	+ 39	− 46	....	− 1	14	XII	− 43	+ 12	....	− 6
5	V	− 31	+ 61	− 33	+ 2	15	XIII	− 16	− 33	....	− 6
6	VI	+ 71	− 33	+ 102	+ 3	16	XIV	− 13	± 0	....	− 1
7	VII	+ 39	− 26	+ 43	+ 2	17	XVI	+ 53	− 10	....	+ 2
8	VII′	± 0	− 57	− 5	− 3	18	XVII	− 3	− 2	....	− 1
9	VIII	+ 36	− 49	....	− 1	19	XV	+ 82	+ 118	+ 110	+ 11
10	IX	− 120	− 38	....	− 13						

THIRD SERIES.

1	I	+ 12	− 13	+ 15	± 0	11	X	− 5	− 25	....	− 8
2	II	+ 38	− 34	....	± 0	12	XI	− 26	− 8	....	− 6
3	III	− 33	+ 33	....	± 0	13	XI′	+ 44	− 49	....	− 0
4	IV	+ 33	− 31	....	± 0	14	XII	− 51	+ 11	....	− 7
5	V	− 11	+ 46	− 11	+ 3	15	XIII	− 20	− 28	....	− 6
6	VI	+ 97	− 62	+ 105	+ 2	16	XIV	− 8	− 11	....	− 2
7	VII	+ 54	− 34	+ 57	+ 2	17	XVI	+ 36	+ 10	....	+ 3
8	VII′	+ 10	− 59	+ 5	− 2	18	XVII	− 0	− 3	....	− 1
9	VIII	+ 26	− 46	....	− 1	19	XV	+ 103	+ 118	+ 99	+ 11
10	IX	− 95	− 46	....	− 11						

TABLE VIII—Continued.

FOURTH SERIES.

No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$	No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$
1	I	+ 7	± 0	....	+ 1	9	IX	− 84	− 57	....	− 11
2	II	− 26	+ 25	....	± 0	10	X	− 20	− 31	....	− 14
3	III	+ 8	− 8	....	± 0	11	XI	− 31	− 16	....	− 9
4	IV	+ 16	− 16	....	± 0	12	XI′	+ 2	− 11	....	− 1
5	V	+ 57	+ 28	....	+ 7	13	XII	− 25	− 15	....	− 7
6	VI	+ 116	+ 66	+ 79	+ 8	14	XIII	− 31	− 30	....	− 8
7	VII′	+ 33	+ 16	....	+ 2	15	XIV	− 28	− 0	....	− 3
8	VIII	+ 8	+ 15	....	+ 2						

FIFTH SERIES.

1	I	+ 7	− 7	....	± 0	8	IX	− 79	− 61	....	− 11
2	II	− 23	+ 20	....	± 0	9	X	− 21	− 31	....	− 14
3	III	+ 16	− 13	....	± 0	10	XI	− 31	− 18	....	− 9
4	V	+ 56	+ 23	....	+ 6	11	XI′	+ 2	− 18	....	− 2
5	VI	+ 105	+ 51	+ 84	+ 7	12	XII	− 20	− 18	....	− 7
6	VII′	+ 36	+ 13	....	+ 2	13	XIII	− 38	− 20	....	− 7
7	VIII	+ 0	+ 10	....	+ 1	14	XIV	− 16	− 15	....	− 3

SIXTH SERIES.

1	I	+ 0	+ 8	....	− 1	8	IX	− 72	− 72	....	− 11
2	II	− 25	+ 26	....	± 0	9	X	− 25	− 31	....	− 15
3	III	+ 26	− 26	....	± 0	10	XI	− 26	− 20	....	− 8
4	V	+ 56	+ 20	....	+ 6	11	XI′	+ 3	− 23	....	− 2
5	VI	+ 102	+ 51	+ 90	+ 7	12	XII	− 26	− 16	....	− 7
6	VII′	+ 34	+ 21	....	+ 2	13	XIII	− 26	− 25	....	− 7
7	VIII	+ 15	+ 18	....	+ 2	14	XIV	− 5	− 25	....	− 3

400-foot level.—The permanent contact on the 400-foot level was placed in a ferruginous clay seam, toward the southern end of the drift, and observations were made in a northerly direction from this point. The temporary contacts have been designated on the map (Fig. 27), as in the previous case. Point X. of the present survey coincides in position with XV. of the line on the 500-foot level. The following table (IX.), in which full statements of the position, etc., of the points are contained, will be intelligible without further description. As before, the bearing of the main linear loci only have been determined, the data referring to the lines joining the consecutive points, for which figures are given. Resistances, as above, are mean values for the circuits *P. C.*, *earth*, *T. C.*, *wire*, *P. C.*, and are essentially the resistances of the layers of rock surrounding *P. C.* and *T. C.*

TABLE IX.

No.	Points.	Level.	Distance.	Bearing.	Resistance.	Remarks.
		Feet.	*Feet.*		*Ohms.*	
1	P. C.	400	0	Origin	....	Red clay selvage.
2	I	400	100	....	2890	Black, fissured limestone, dry.
3	II	400	140	....	1040	White calcareous pulp, very moist.
4	III	400	139	....	1820	Gray limestone, compact, dry.
5	IV	400	85	N. 7° W.	710	Shale, very moist.
6	V	400	37	....	2050	Gray, fissured limestone, dry.
7	VI	400	88	....	1760	Limestone, compact.
8	VII	400	94	N. 49° E.	2740	Do.
9	VIII	400	89	....	1280	Quartzite, very wet.
10	IX	400	68	....	1820	Bunch of lead carbonate ore in limestone.
11	X	430	37	N. 71° E.	1030	Large breast of lead carbonate ore, chamber 15.

The results of the measurements of electromotive forces between *P. C.* and I.–X. are contained in Table X. They are given in a way entirely analogous to that adopted for the 500-foot level, and no further explanation is necessary. Intensities are expressed in electromagnetic units (*C. G. S.*), electromotive forces in volts. Water was used as an outer liquid.

TABLE X.

FIRST SERIES.

<table>
<tr><th>No.</th><th>P. C. connected with—</th><th>$i' \times 10^8$</th><th>$i'' \times 10^8$</th><th>$i''' \times 10^8$</th><th>$e \times 10^3$</th><th>No.</th><th>P. C. connected with—</th><th>$i' \times 10^8$</th><th>$i'' \times 10^8$</th><th>$i''' \times 10^8$</th><th>$e \times 10^3$</th></tr>
<tr><td>1</td><td>I</td><td>+ 22</td><td>+ 41</td><td>+ 35</td><td>+ 11</td><td>6</td><td>VI</td><td>+ 125</td><td>+ 93</td><td>+ 116</td><td>+ 19</td></tr>
<tr><td>2[1]</td><td>II</td><td colspan="3">— 7 | — 52 | — 67 | — 62</td><td>— 5</td><td>7</td><td>VII</td><td>+ 56</td><td>+ 50</td><td>.........</td><td>+ 15</td></tr>
<tr><td>3</td><td>III</td><td>+ 54</td><td>+ 52</td><td>+ 61</td><td>+ 10</td><td>8</td><td>VIII</td><td>+ 34</td><td>+ 43</td><td>± 0</td><td>+ 4</td></tr>
<tr><td>4</td><td>IV</td><td>— 49</td><td>— 145</td><td>— 45</td><td>— 7</td><td>9</td><td>IX</td><td>+ 4</td><td>— 6</td><td>.........</td><td>± 0</td></tr>
<tr><td>5</td><td>V</td><td>+ 0</td><td>+ 2</td><td>+ 9</td><td>+ 1</td><td>10</td><td>X</td><td>— 30</td><td>— 56</td><td>— 21</td><td>— 4</td></tr>
</table>

SECOND SERIES.

<table>
<tr><td>1</td><td>I</td><td>+ 22</td><td>+ 39</td><td>+ 34</td><td>+ 10</td><td>6</td><td>VI</td><td>+ 118</td><td>+ 88</td><td>+ 116</td><td>+ 19</td></tr>
<tr><td>2[1]</td><td>II</td><td colspan="3">— 26 | — 56 | — 73 | — 62</td><td>— 5</td><td>7</td><td>VII</td><td>+ 60</td><td>+ 45</td><td>.........</td><td>+ 15</td></tr>
<tr><td>3</td><td>III</td><td>+ 65</td><td>+ 43</td><td>+ 63</td><td>+ 10</td><td>8</td><td>VIII</td><td>+ 15</td><td>+ 37</td><td>+ 4</td><td>+ 3</td></tr>
<tr><td>4</td><td>IV</td><td>— 71</td><td>— 130</td><td>— 67</td><td>— 7</td><td>9</td><td>IX</td><td>— 4</td><td>+ 9</td><td>— 6</td><td>± 0</td></tr>
<tr><td>5</td><td>V</td><td>+ 8</td><td>± 0</td><td>+ 13</td><td>+ 1</td><td>10</td><td>X</td><td>— 63</td><td>— 62</td><td>— 37</td><td>— 6</td></tr>
</table>

[1] In these cases three consecutive exchanges of the terminals were made, their positions in Nos. 1 and 3 and in Nos. 2 and 4 being the same.

TABLE X—Continued.

THIRD SERIES.

No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$	No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$
1	I	+ 37	+ 30	+ 50	+ 11	6	VI	+ 138	+ 82	+ 140	+ 21
2[1]	II	— 9	— 47	— 26	— 37	— 4	7	VII	+ 67	+ 37	....	+ 15
3	III	+ 77	+ 30	+ 80	+ 10	8	VIII	+ 4	+ 28	+ 6	+ 2
4	IV	— 73	— 160	— 52	— 8	9	IX	+ 4	— 6	+ 13	± 0
5	V	+ 11	— 7	+ 22	+ 1	10	X	— 13	— 73	— 0	— 4

FOURTH SERIES.

1	I	+ 41	+ 22	+ 43	+ 9	6	VI	+ 140	+ 88	+ 142	+ 20
2	II	— 76	— 142	— 88	— 13	7	VII	+ 76	+ 58	+ 84	+ 19
3	III	+ 86	+ 56	+ 82	+ 13	8	VIII	+ 52	+ 13	+ 45	+ 4
4[1]	IV	—118	—130	—120	—183	— 10	9	IX	± 0	— 21	— 2	— 2
5	V	+ 35	— 15	+ 24	+ 1	10	X	— 30	— 56	— 24	— 5

FIFTH SERIES.

1	I	+ 39	+ 28	+ 41	+ 9	6	VI	+ 108	+ 108	+ 104	+ 19
2	II	— 91	— 130	— 112	— 13	7	VII	+ 60	+ 71	+ 62	+ 18
3	III	+ 87	+ 62	+ 82	+ 14	8	VIII	+ 19	+ 41	+ 4	+ 3
4[1]	IV	—153	— 45	— 49	—220	— 8	9	IX	— 15	— 9	— 22	— 2
5	V	+ 7	+ 6	+ 0	+ 1	10	X	— 52	— 34	— 50	— 5

SIXTH SERIES:

1	I	+ 45	+ 22	+ 49	+ 9	6	VI	+ 134	+ 78	+ 121	+ 18
2	II	— 67	— 130	— 80	— 12	7	VII	+ 80	+ 45	+ 76	+ 17
3	III	+ 82	+ 50	+ 82	+ 13	8	VIII	+ 58	+ 4	+ 45	+ 3
4[1]	IV	— 91	—108	—112	—168	— 9	9	IX	+ 7	— 28	+ 4	— 2
5	V	+ 24	— 15	+ 21	+ 1	10	X	— 13	— 67	— 11	— 4

[1] In these cases three consecutive exchanges of the terminals were made, their positions in Nos. 1 and 3 and in Nos. 2 and 4 being the same.

The values for electromotive force contained in Tables VIII. and X. are now to be referred to one and the same origin. For this purpose it will be convenient to select a point having an extreme position Point I., 500-foot level, is of this kind. As there is no means of assigning an absolute value to the potential of this point, it may be arbitrarily called zero, in which case the electromotive force between it and any succeeding point will be identical with the potential of the latter. In the following table (XI.) the potentials of all the points on the 400 and 500-foot levels have been calculated, that of No. I. (500-foot level) being zero. The values obtained from the different series are designated by indices (e', e'', e''', e^{iv}, e^{v}, e^{vi}). e_1 is the mean of the first three, e_2 of the last three; and e the mean of all the series.

TABLE XI.

No.	Points.	Level.	$e' \times 10^3$	$e'' \times 10^3$	$e''' \times 10^3$	$e_1 \times 10^3$	$e^{iv} \times 10^3$	$e^{v} \times 10^3$	$e^{vi} \times 10^3$	$e_2 \times 10^3$	$e \times 10^3$
		Feet.									
1	I	500	+ 1	− 1	± 0	± 0	+ 1	± 0	− 1	± 0	± 0
2	II	500	+ 1	± 0	± 0	± 0	± 0	± 0	± 0	± 0	± 0
3	III	500	± 0	− 2	± 0	+ 1	± 0	± 0	± 0	± 0	± 0
4	IV	500	± 0	− 1	± 0	± 0	± 0	....	....	± 0	± 0
5	V	500	+ 3	+ 3	+ 3	+ 3	+ 5	+ 6	+ 6	+ 6	+ 5
6	VI	500	+ 2	+ 3	+ 2	+ 2	+ 8	+ 7	+ 7	+ 7	+ 4
7	VII	500	+ 2	+ 2	+ 2	+ 2	....	....	....	....	+ 2
8	VII′	500	− 2	− 3	− 2	− 2	+ 2	+ 2	+ 2	+ 2	± 0
9	VIII	500	− 0	− 1	− 1	− 1	+ 2	+ 1	+ 2	+ 2	± 0
10	IX	500	−13	−13	−11	−12	−11	−11	−11	−11	−12
11	X	500	− 7	− 7	− 8	− 7	−14	−14	−15	−15	−11
12	XI	500	− 6	....	− 6	− 6	− 9	− 9	− 8	− 9	− 7
13	XI′	490	± 0	− 1	± 0	± 0	− 1	− 2	− 2	− 2	− 1
14	XII	480	− 8	− 6	− 7	− 7	− 7	− 7	− 7	− 7	− 7
15	XIII	460	− 6	− 6	− 6	− 6	− 8	− 7	− 7	− 7	− 6
16	XIV	450	− 2	− 1	− 2	− 2	− 3	− 3	− 3	− 3	− 3
17	XVI	450	+ 3	+ 2	+ 3	+ 2	....	....	....	....	+ 2
18	XVII	440	− 1	− 1	− 1	− 1	....	....	....	....	− 1
19	X[1] or XV	430	+11	+11	+11	+11	....	....	....	....	+11
20	IX or XVIII	400	+15	+15	+15	+15	+13	+13	+13	+13	+14
21	VIII or XIX	400	+19	+18	+17	+18	+19	+18	+19	+19	+18
22	VII or XX	400	+30	+30	+30	+30	+34	+33	+32	+33	+32
23	VI or XXI	400	+35	+34	+36	+35	+35	+34	+33	+34	+35
24	V or XXII	400	+16	+16	+16	+16	+17	+16	+16	+16	+16
25	IV or XXIII	400	+ 8	+ 8	+ 7	+ 8	+ 5	+ 7	+ 6	+ 6	+ 7
26	III or XXIV	400	+25	+25	+25	+25	+28	+29	+28	+28	+27
27	II or XXV	400	+10	+10	+11	+10	+ 2	+ 2	+ 3	+ 2	+ 7
28	I or XXVI	400	+26	+26	+26	+26	+24	+25	+25	+25	+25
29	P. C. or XXVII	400	....	....	....	....	....	....	....	....	+15

[1] To facilitate the construction of Fig. 28, current numbers have been given to the points on the 400-foot level. The new numbers are given with the original ones.

Table XII. has been prepared to show the character of e as a function of distance (see page 342). In it e has the same signification as in the preceding table. Under *distance*, however, is given the length in feet of the imaginary line joining Point I. with the point to which the datum refers. The data included under *bearing* also refer to this line. Current numbers have been given to the points on the 400-foot level. (See "Points," Table XI.)

TABLE XII.

No.	Points.	Level.	Distance from I.	Bearing.	$e \times 10^3$	No.	Points.	Level.	Distance from I.	Bearing.	$e \times 10^3$
		Feet.						*Feet.*			
1	I	500	....	Origin	± 0	16	XIV	450	635	S. 72° W.	— 3
2	II	500	84	S. 82° W.	± 0	17	XVI	450	600	S 69° W.	+ 2
3	III	500	123	S. 81° W.	± 0	18	XVII	440	640	S. 75° W.	— 1
4	IV	500	158	S. 63° W.	± 0	19	XV	430	700	S. 72° W.	+ 11
5	V	500	216	S. 53° W.	+ 5	20	XVIII	400	735	S. 72° W.	+ 14
6	VI	500	228	S. 54° W.	+ 4	21	XIX	400	805	S. 71° W.	+ 18
7	VII	500	268	S. 60° W.	+ 2	22	XX	400	890	S. 73° W.	+ 32
8	VII′	500	275	S. 64° W.	± 0	23	XXI	400	980	S. 71° W.	+ 35
9	VIII	500	300	S. 70° W.	± 0	24	XXII	400	1066	S. 71° W.	+ 16
10	IX	500	318	S. 77° W.	— 12	25	XXIII	400	1108	S. 70° W.	+ 7
11	X	500	420	S. 78° W.	— 11	26	XXIV	400	1228	S. 65° W.	+ 27
12	XI	500	515	S. 78° W.	— 7	27	XXV	400	1184	S. 59° W.	+ 7
13	XI′	490	595	S. 78° W.	— 1	28	XXVI	400	1276	S. 54° W.	+ 25
14	XII	480	600	S. 79° W.	— 7	29	XXVII	400	1332	S. 51° W.	+ 15
15	XIII	460	610	S. 79° W.	— 6						

Discussion of the results obtained on the 400 and 500-foot levels.—From a comparison of the resistances of circuits between different holes, as contained in Tables VII. and IX., we find that in cases of fissured, of tough and impervious, or of dry rock or earth, this quantity inclines toward a maximum; whereas, on the other hand, wherever the material is porous or moist minimal values are obtained. It is to be remembered that under ground, from the exceedingly damp atmosphere, as well as from infiltration of water, the rock forming the walls of the drifts is throughout very moist, and at the surfaces of the latter, at least, nearly saturated. Hence it follows that the conductivity of the rock is largely, if not wholly, due to the presence of moisture in its pores, and is therefore electrolytic. This important fact will be repeatedly referred to hereafter.

Intensities.—In Tables VIII. and X. the intensities of the currents observed in the different circuits have been very fully given, both because the present measurements are the first of the kind made, and because the character of these data furnishes an important criterion of the validity of the results subsequently derived from them. From an inspection of the tables, it is moreover obvious that an exchange of terminals in measurements of this kind, however tedious and laborious in case of long circuits, is indispensable. The intensities i' and i''', which are measured with the bags in the same position relatively to the holes, are usually very nearly of the same value, from which i'' generally differs, frequently having even the opposite sign.

Potential.—Between the values of e for the first three, and for the last three series, there is usually a good agreement. The means (e_1 and e_2) of these series, however, often show a lack of accordance which is greater than was expected. The discrepancies occur principally in the results obtained on the 500-foot level, and it was at first thought that they were largely to be referred to the fact that a solution of sodic sulphate was used as an outer liquid in the holes. In No. 11, Table XI., for instance, this liquid, instead of soaking into the rock, as usual, remained in the hole, gradually becoming concentrated by evaporation. In the repetition of the experiment, therefore, the exterior liquids in *P. C.* and X. were not of the same concentration, so that a discrepancy would not seem remarkable. Subsequent experiments, however, hardly corroborated this supposition. Another large difference occurs in the case of No. 27 of the same table; but for this hole it was impossible to obtain constant results, though the experiments were many times repeated. I am at a loss to account for this fact.

The actual relation between potential and distance will, of course, be exceedingly complex, and it would be little short of a waste of time to endeavor with the data at command to arrive at an empirical form for this function. On the other hand, a graphic representation of the change of potential due to a corresponding change of distance is certainly desirable. Accordingly, I have discarded more elaborate mathematical means and have represented the relation in question by the following simple plan: If all points on the 400 and 500-foot levels be joined by straight lines with Point I. on the 500, the horizontal projections of these will lie within a sector whose center is at I. and whose bounding radii subtend an angle of 31° approximately. It should be noted (Table XII.) that on passing through the ore bodies the variation of bearing is much smaller; that it is large both for points near I., where the actual length of arc subtended, however, is small, and for points on the 400-foot level, where, though the actual length of subtended arc is large, as all points are remote from ore a smaller change of potential may be expected. Bearing in mind, therefore, that the object is merely to represent in a systematic way the potential of consecutive points, a curve may be constructed by representing the linear distance of any point from I. as abscissa, the corresponding potential as ordinate. In this way Fig. 28 was obtained. From an inspection of the curve it appears that the ore body is in general at a lower potential than the points remote from it.

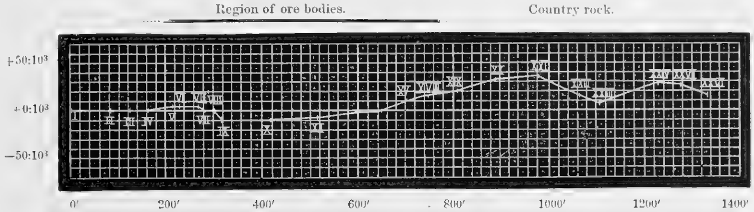

FIG. 28.—Earth potential and distance, Richmond mine, 400 and 500-foot levels.

Here it must be remarked that only the extreme points on the 400-foot level (XXVII., XXVI., etc.,) can, so far as known, be considered actually distant from ore. In the vicinity of Points I., II., etc., 500-foot level, there are not only the streaks of ore, *n* and *p* (Fig. 27), but also chambers 7 and 10, and still further east the large ore bodies of the Eureka Consolidated Mining Company. This has been indicated by the dotted line in Fig. 28.

The variation of potential is irregular, however—even more so than, with the rough method of delineation, would have been anticipated—and its amount is small. In fact, it will be seen that certain unavoidable errors might conspire to produce an almost equivalent change. From results of such a magnitude, in short, no prediction as to the occurrence of ore or electroactive material would be justified. Not to mention minor matters, the survey described suffers from a serious objection, due to the fact that the temporary contact in progressing from I. to XXVII. passed through a great number of varieties of rock, and therefore also, probably through a great variety of absorbed liquids, holding more or less saline matter in solution. In such a case the electromotive force due to the contact of these liquids would seem to come into play. As the matter will again be discussed (see page 356) I will add here only that electric effects thus produced cannot, *a priori*, be regarded as negligible. Furthermore, the preference

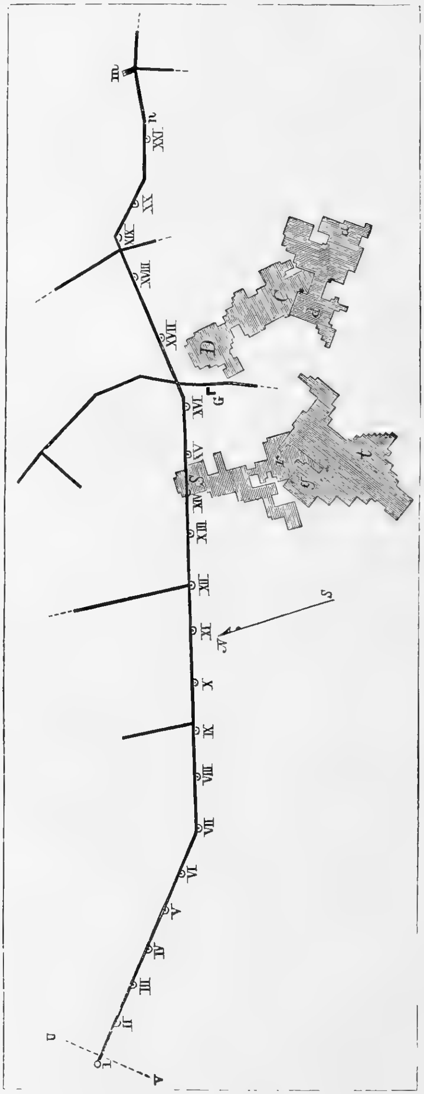

Fig. 29.—Plan of 600-foot level, Richmond mine. Scale, $\frac{1}{3000}$.

given to Point XV., in using it alone as a basis for the coördination of the results of the surveys on the 500 and 400-foot levels, is to be criticised. It was intended to use several consecutive points for this purpose; but in each case local interferences prevented. As a whole, however, the results are sufficiently interesting to justify further and more careful investigation.

Experiments on the 600-foot level. Results. —This series of measurements was made with the intention of observing the variation of potential encountered in passing across the ore body, without actually entering it. Care was also taken to place all the points, so far as practicable, in rock of the same variety, and to remove the ends of the line of survey as far from the ore body as possible.

The plan of the position of the drifts on the 600-foot level, relatively to the ore-chambers, is given in Fig. 29. As before, the points tapped are distinguished by small circles, to which Roman numerals are annexed. *P. C.* in this case coincides with Point VIII. and is in porous limestone. The great ore bodies have been lettered as in Fig. 27. Ore is also found at *G*, above and below the 600-foot level, and at *n* above it. *U V* is a line of contact between the shale of the west country and limestone. Table XIII. exhibits more exactly the disposition, etc., of the points. It will be intelligible without further explanation. (Cf. Table IX., page 338.)

TABLE XIII.

No.	Points.	Distance.	Bearing.	Resistance.	Remarks.
		Feet.		*Ohms.*	
1	I	0	....	1580	Shale, moist.
2	II	76	S. 49° E.	2350	Limestone.
3	III	77	S. 49° E.	1750	Do.
4	IV	65	S. 49° E.	3110	Do.
5	V	75	S. 49° E.	4015	Do.
6	VI	70	S. 49° E.	4420	Do.
7	VII	87	S. 52° E.	6300	Do.
8	VIII	94	S. 74° E.	......	Do.
9	IX	85	S. 74° E.	2480	Do.
10	X	71	S. 74° E.	5150	Do.
11	XI	91	S. 74° E.	3420	Do.
12	XII	80	S. 74° E.	4170	Limestone, faintly stained with iron.
13	XIII	90	S. 74° E.	3480	Limestone.
14	XIV	75	S. 74° E.	3200	Do.
15	XV	78	S. 74° E.	9490	Limestone, with calcareous spar.
16	XVI	79	S. 74° E.	15950	Limestone, hard, impervious.
17	XVII	127	N. 72° E.	3440	Limestone, stained with iron.
18	XVIII	118	N. 85° E.	3380	Limestone.
19	XIX	72	N. 85° E.	2525	Pocket of ferruginous earth in limestone.
20	XX	74	S. 49° E.	3275	Do.
21	XXI	121	S. 42° E.	4965	Limestone.

The results of the measurements of electromotive forces between VIII. (*P. C.*) and the *T. C.'s* are contained in Table XIV. The nomenclature being the same as that used above, the meaning of the data will be at once apparent. As before, four terminal bags, *A*, *B*, *C*, and *D*, were used. Intensities are given in electromagnetic units (*C. G. S.*), electromotive forces in volts; and are arbitrarily considered positive when the potential of *T. C.* is greater than that of *P. C.* (Point VIII.); or when the current travels $T.\ C. \longrightarrow \left\{ \begin{matrix} earth \\ wire \end{matrix} \right\} \longrightarrow P.\ C.$ The experiments were made in continuous series, starting with Point I. in the extreme west, in shale, and ending with XXI., near the shaft, in limestone. Water, which had previously been kept in contact with zinc, was used as an outer liquid.

TABLE XIV.

FIRST SERIES.

No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$	No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$
1	I	— 172	+ 16	— 189	— 16	11	XII	— 69	— 95	— 78	— 33
2	II	+ 43	— 64	+ 36	— 3	12	XIII	— 98	— 127	— 112	— 40
3	III	+ 81	— 105	+ 60	— 3	13	XIV	— 150	— 157	— 153	— 48
4	IV	+ 64	+ 65	+ 64	+ 17	14	XV	— 50	— 57	— 59	— 57
5	V	+ 52	+ 45	+ 50	+ 20	15	XVI	— 52	— 60	— 41	— 93
6	VI	+ 21	+ 9	+ 21	+ 6	16	XVII	— 88	— 105	— 93	— 30
7	VII	+ 9	+ 9	+ 12	+ 5	17	XVIII	— 170	— 198	— 169	— 57
8	IX	+ 9	— 10	+ 9	± 0	18	XIX	— 71	— 79	— 76	— 17
9	X	— 24	— 24	— 17	— 11	19	XX	— 55	— 76	— 59	— 18
10	XI	— 50	— 53	— 60	— 17	20	XXI	— 53	— 67	— 47	— 29

SECOND SERIES.

1	I	— 172	± 0	— 193	— 16	11	XII	— 76	— 93	— 79	— 33
2	II	+ 40	— 55	+ 38	— 2	12	XIII	— 103	— 122	— 114	— 40
3	III	+ 55	— 108	+ 53	— 5	13	XIV	— 160	— 153	— 152	— 48
4	IV	+ 64	+ 71	+ 62	+ 18	14	XV	— 55	— 59	— 60	— 59
5	V	+ 47	+ 43	+ 50	+ 19	15	XVI	— 50	— 55	— 43	— 90
6	VI	+ 17	+ 10	+ 19	+ 6	16	XVII	— 88	— 102	— 96	— 31
7	VII	+ 12	+ 5	+ 10	+ 5	17	XVIII	— 169	— 182	— 177	— 55
8	IX	+ 9	— 9	+ 5	± 0	18	XIX	— 81	— 72	— 81	— 18
9	X	— 24	— 28	— 21	— 12	19	XX	— 60	— 69	— 64	— 17
10	XI	— 52	— 57	— 50	— 16	20	XXI	— 67	— 64	— 53	— 30

THIRD SERIES.

1	I	— 172	— 3	— 165	— 17	11	XII	— 72	— 103	— 79	— 34
2	II	+ 33	— 38	+ 21	— 2	12	XIII	— 107	— 134	— 110	— 41
3	III	+ 40	— 83	+ 36	— 4	13	XIV	— 160	— 167	— 152	— 50
4	IV	+ 65	+ 71	+ 62	+ 18	14	XV	— 55	— 57	— 62	— 59
5	V	+ 47	+ 34	+ 48	+ 17	15	XVI	— 62	— 57	— 47	— 96
6	VI	+ 19	+ 9	+ 17	+ 6	16	XVII	— 91	— 100	— 95	— 30
7	VII	+ 9	+ 5	+ 9	+ 4	17	XVIII	— 167	— 182	— 176	— 54
8	IX	+ 10	— 19	+ 10	— 1	18	XIX	— 79	— 71	— 76	— 17
9	X	— 22	— 34	— 17	— 12	19	XX	— 64	— 69	— 65	— 18
10	XI	— 48	— 71	— 48	— 18	20	XXI	— 64	— 62	— 64	— 30

FOURTH SERIES.

1	I	— 79	— 98	— 78	— 11	11	XII	— 83	— 86	— 81	— 37
2	II	— 0	— 19	— 9	— 3	12	XIII	— 96	— 105	— 95	— 35
3	III	— 12	— 31	— 21	— 4	13	XIV	— 138	— 146	— 141	— 46
4	IV	+ 48	+ 52	+ 59	+ 19	14	XV	— 69	— 71	— 72	— 59
5	V	+ 36	+ 38	+ 43	+ 15	15	XVI	— 65	— 69	— 64	— 95
6	VI	+ 14	+ 14	+ 7	+ 5	16	XVII	— 72	— 95	— 69	— 30
7	VII	+ 7	+ 7	+ 7	+ 4	17	XVIII	— 148	— 143	— 143	— 52
8	IX	± 0	— 14	— 5	— 2	18	XIX	— 55	— 78	— 57	— 18
9	X	— 22	— 21	— 17	— 11	19	XX	— 60	— 84	— 60	— 21
10	XI	— 41	— 47	— 43	— 16	20	XXI	— 52	— 55	— 53	— 26

TABLE XIV—Continued.

FIFTH SERIES.

No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$	No.	P. C. connected with—	$i' \times 10^8$	$i'' \times 10^8$	$i''' \times 10^8$	$e \times 10^3$
1	I	− 84	− 83	− 96	− 11	11	XII	− 84	− 84	− 86	− 37
2	II	− 12	− 10	− 12	− 3	12	XIII	− 102	− 103	− 103	− 36
3	III	− 24	− 16	− 36	− 4	13	XIV	− 143	− 141	− 145	− 46
4	IV	+ 48	+ 59	+ 55	+ 19	14	XV	− 69	− 72	− 69	− 59
5	V	+ 33	+ 43	+ 38	+ 15	15	XVI	− 59	− 71	− 59	− 93
6	VI	+ 10	+ 14	+ 7	+ 5	16	XVII	− 74	− 95	− 65	− 30
7	VII	+ 5	+ 9	+ 5	+ 4	17	XVIII	− 145	− 145	− 136	− 52
8	IX	− 9	− 2	− 12	− 2	18	XIX	− 60	− 76	− 64	− 18
9	X	− 22	− 21	− 21	− 11	19	XX	− 67	− 76	− 62	− 20
10	XI	− 47	− 43	− 40	− 16	20	XXI	− 43	− 55	− 69	− 27

SIXTH SERIES.

1	I	− 86	− 90	− 98	− 12	11	XII	− 84	− 86	− 84	− 37
2	II	− 16	− 12	− 24	− 3	12	XIII	− 110	− 105	− 105	− 37
3	III	− 36	− 21	− 38	− 5	13	XIV	− 138	− 152	− 138	− 47
4	IV	+ 47	+ 62	+ 59	+ 20	14	XV	− 72	− 72	− 72	− 59
5	V	+ 31	+ 41	+ 36	+ 15	15	XVI	− 60	− 71	− 64	− 93
6	VI	+ 14	+ 7	+ 14	+ 5	16	XVII	− 76	− 93	− 74	− 31
7	VII	+ 7	+ 7	+ 9	+ 4	17	XVIII	− 136	− 141	− 141	− 51
8	IX	− 24	± 0	− 16	− 3	18	XIX	− 65	− 78	− 72	− 19
9	X	− 19	− 22	− 21	− 11	19	XX	− 67	− 76	− 60	− 19
10	XI	− 52	− 45	− 43	− 17	20	XXI	− 43	− 50	− 67	− 28

A comparison of the values of e obtained is given in Table XV. The plan is analogous to the above.

TABLE XV.

No.	Points.	$e' \times 10^3$	$e'' \times 10^3$	$e''' \times 10^3$	$e_1 \times 10^3$	$e^{iv} \times 10^3$	$e^{v} \times 10^3$	$e^{vi} \times 10^3$	$e_2 \times 10^3$	$e \times 10^3$
1	I	− 16	− 16	− 17	− 16	− 11	− 11	− 12	− 11	− 14
2	II	− 3	− 2	− 2	− 2	− 3	− 3	− 4	− 3	− 3
3	III	− 3	− 5	− 4	− 4	− 4	− 4	− 5	− 4	− 4
4	IV	+ 17	+ 18	+ 18	+ 18	+ 19	+ 19	+ 20	+ 19	+ 18
5	V	+ 20	+ 19	+ 17	+ 18	+ 15	+ 15	+ 15	+ 15	+ 17
6	VI	+ 6	+ 6	+ 6	+ 6	+ 5	+ 5	+ 5	+ 5	+ 6
7	VII	+ 5	+ 5	+ 4	+ 5	+ 4	+ 4	+ 4	+ 4	+ 5
8	VIII	± 0	± 0	± 0	± 0	± 0	± 0	± 0	± 0	± 0
9	IX	± 0	± 0	− 1	± 0	− 2	− 2	− 3	− 2	− 1
10	X	− 11	− 12	− 13	− 12	− 11	− 11	− 11	− 11	− 11
11	XI	− 17	− 17	− 18	− 17	− 17	− 16	− 17	− 17	− 17
12	XII	− 33	− 33	− 35	− 34	− 37	37	− 37	− 37	− 35
13	XIII	− 40	− 40	− 41	− 40	− 35	− 36	− 37	− 36	− 38
14	XIV	− 48	− 48	− 50	− 49	− 46	− 46	− 47	− 46	− 48
15	XV	− 57	− 59	− 59	− 58	− 59	− 59	− 59	− 59	− 59
16	XVI	− 93	− 90	− 96	− 93	− 95	− 93	− 93	− 94	− 93
17	XVII	− 30	− 31	− 30	− 31	− 30	− 30	− 31	− 31	− 31
18	XVIII	− 57	− 55	− 55	− 55	− 53	− 52	− 51	− 52	− 54
19	XIX	− 17	− 18	− 17	− 17	− 18	− 19	− 19	− 19	− 18
20	XX	− 18	− 17	− 18	− 18	− 21	− 20	− 19	− 20	− 19
21	XXI	− 29	− 30	− 30	− 30	− 27	− 27	− 28	− 27	− 29

Table XVI., finally, contains the data necessary for the approximate representation of earth-potential as a function of distance. By arbitrarily assuming the potential of Point VIII. as zero the final means in Table XV. are identical with the potential of the points to which the data refer. The third and fourth columns of Table XVI. contain the length and bearing of the imaginary lines joining I. with the succeeding points.

TABLE XVI.

No.	Points.	Distance from I.	Bearing.	$e \times 10^3$	No.	Points.	Distance from I.	Bearing.	$e \times 10^3$
1	I	0	Origin.	− 14	12	XII	850	S. 61° E.	− 35
2	II	76	S. 49° E.	− 3	13	XIII	935	S. 63° E.	− 38
3	III	153	S. 49° E.	− 4	14	XIV	1010	S. 64° E.	− 48
4	VI	220	S. 49° E.	+ 18	15	XV	1080	S. 64° E.	− 59
5	V	295	S. 49° E.	+ 17	16	XVI	1160	S. 65° E.	− 93
6	VI	365	S. 49° E.	+ 6	17	XVII	1280	S. 68° E.	− 31
7	VII	450	S. 50° E.	+ 5	18	XVIII	1380	S. 70° E.	− 54
8	VIII	540	S. 54° E.	± 0	19	XIX	1450	S. 71° E.	− 18
9	IX	615	S. 57° E.	− 1	20	XX	1510	S. 70° E.	− 19
10	X	685	S. 58° E.	− 11	21	XXI	1630	S. 70° E.	− 29
11	XI	775	S. 60° E.	− 17					

Discussion.—From the results in Table XIII. for the resistance of different circuits similar conclusions to those on page 341 are deducible. Wherever the structure of the rock and coexisting circumstances are favorable to the absorption of moisture, there also minimal values for this quantity are found. Unusually high values were obtained for the holes XV. and XVI. But the rock at these points was so tough and tenacious that the miners complained of the slow progress made in drilling.

Remarks analogous to the above are applicable to the values for intensity on this level.

The results for earth-potential in Table XV. harmonize much better than those for the preceding levels. The individual values in the two series, as well as the means of the series themselves, are in fair accordance. This might be ascribed to the fact that the holes were mostly in rock of the same variety, and that strong salt solutions were discarded in completing the contact between the terminal bags and the earth.

By a method of procedure similar to that already employed the relation between potential and distance may be represented graphically. It will also be seen, from an inspection of Table XVI., that the considerations involved in constructing Fig. 28 are more pertinent in this case, as the main drift itself is more nearly linear. Laying off potential as ordinate, distance as abscissa (Table XVI.), Fig. 30 is obtained.

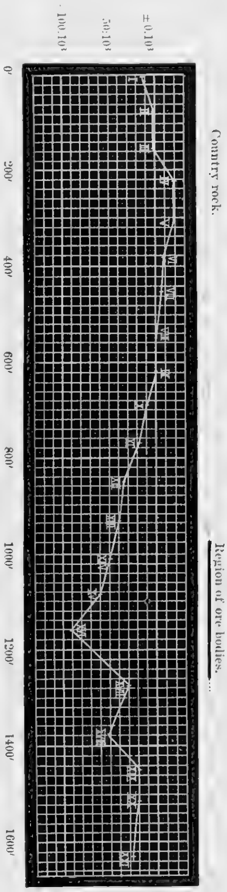

FIG. 30.—Earth-potential and distance, Richmond mine, 600-foot level.

Both Fig. 28 and Fig. 30 demonstrate the remarkable result that the region of ore bodies coincides with a region of low potential. This is all the more striking, as in the first case, taking in general a northerly course, the ore bodies are approached from barren rock (400-foot level). In the second the course of survey, while passing toward the ore region, was mainly in an easterly direction. The two lines of survey may, roughly speaking, be said to be at right angles to each other. In one case, moreover, the sequence of points tapped intersects the ore bodies, whereas in the other it remains exterior to them throughout its whole extent.

Comparing the results of the two surveys, the indications on the 600-foot level are found to be much the more pronounced; in fact, they transcend values which can be accounted for as an aggregate of incidental errors. It may be remarked here, that it is a very improbable chance which would place the region of greatest electrical disturbance in coincidence with the region of ore bodies, if the latter were without influence in producing the former. There is no reason apparent why the part of the main drift on the 600-foot level, between Points I. and X., should not be just as active as that between Points X. and XXI., unless it be that these points lie nearest to ore, and consequently that we are here rapidly approaching the seat of an electromotive force.

Chambers No. 14 and No. 15 connected electrically.—In the survey on the 400 and 500-foot levels, two ore bodies, Nos. 12 and 15, were indirectly connected, but the indications obtained were much smaller than was anticipated. It appeared desirable therefore to test this matter still more carefully by connecting the huge ore-masses in chambers No. 14 and No. 15. Accordingly a *P. C.* in a large breast of ore (lead carbonate) in chamber No. 15 was placed successively in contact with three different points, at a distance of about 100 feet one from another, in chamber No. 14. Each of these was also in ore, the first in lead carbonate, the second in lead carbonate and earthy sulphide, the third finally in a mixture of carbonate, sulphide, and ferruginous earth. Table XVII. contains the results of the electrical measurements. A single set of observations, with one exchange for each, was made.

TABLE XVII.

FIRST SERIES.

No.	P. C. joined with—	$i' \times 10^8$	$i'' \times 10^8$	$e \times 10^3$
1	I	− 16	− 3	− 6
2	II	− 8	− 10	− 7
3	III	− 10	− 13	− 7

SECOND SERIES.

No.	P. C. joined with—	$i' \times 10^8$	$i'' \times 10^8$	$e \times 10^3$
1	I	− 18	− 2	− 6
2	II	− 7	− 10	− 6
3	III	− 11	− 13	− 7

THIRD SERIES.

No.	P. C. joined with—	$i' \times 10^8$	$i'' \times 10^8$	$e \times 10^3$
1	I	− 11	− 8	− 6
2	II	− 11	− 10	− 7
3	III	− 11	− 13	− 7

In considering these results, it is strikingly apparent that the evidences of electric action are almost altogether absent. It is true that in all probability chambers Nos. 14 and 15 are but parts of one and the same large ore-mass, but in the place where the experiments were made they are to some extent, at least, locally disconnected. The results lead to the inference either that the ore of both chambers is remarkably similar in character, so as to present no appreciable electric difference, or that it is here without electrical properties altogether (earthy), the field of electric action being confined to certain definite parts of the ore-deposit. (See also page 364.)

Experiments on the surface.—Encouraged by the results on the 600-foot level, it seemed not impossible that currents might also be observed on the surface itself, insomuch as the ore extends in places to within 100 feet from the surface, while vestiges of croppings, etc., still remain

A line of points lying in general in a north-and-south direction, and at distances of about 100 feet apart, was chosen, the object being to extend the electric survey from shale in the north, free from ore, over Ruby Hill and the large ore bodies in its interior, to quartzite in the south, also more or less free from ore. It was hoped that in this way a passage through a field of electrical activity might actually be made. Unfortunately, the work was interrupted by a heavy snow-storm and accompanying frosts.

P. C. was placed about half way up the hill in compact limestone. Point I. is the most northerly of the series, and remote from ore; Point IX. approximately over the Richmond ore bodies. The results are contained in the following table. e is the mean of a single triple set. The potential of *P. C.* (Point VI.) is arbitrarily put equal to zero.

TABLE XVIII.

No.	Points.	Resistance.	$e \times 10^3$	Remarks.
1	I	17,000	− 20	*Débris;* lowest point.
2	II	14,000	− 30	Do.
3	III	13,000	− 30	Do.
4	IV	13,000	− 10	Do.
5	V	13,000	− 10	Shale.
6	VI	....	± 0	Limestone; (P. C.).
7	VII	150,000	+ 10	Do.
8	VIII	40,000	+ 20	Limestone; highest point.
9	IX	20,000	+ 40	Do.
10	X	25,000	+ 50	Do.

In the table the unusually high values for the resistances of the circuits, *P. C.* earth *T. C.*, are a striking feature. This may be due either to the compact and impervious structure of the rock (the drill making very slow progress), or, as the experiments were made in the early spring, to the possibility that the moisture in the rock was still frozen. In either case, however, the supposition that the conductivity of the rocks is principally due to the presence of moisture in their pores receives fresh support.

The values for earth-potential again exhibit a marked variation in passing toward the ore-deposit. But, unlike former cases, the passage from points remote to those nearer the ore-region is one from lower to higher potential. As nothing is known about the distribution of potential with reference to ore bodies, this is not to be regarded as at variance with former results. Not overmuch reliance, however, must be placed on the values of *e* in this table. They were obtained under unfavorable circumstances, and not checked as in the former cases.

According to Matteuci,[1] a difference of potential exists between points at different levels, in virtue of this fact alone. "Ce courant est ascendant dans la partie métallique du circuit; son intensité augmente à mesure que les lignes sont plus longues, et que la différence de niveau entre ces extrémités est plus grande." But in the present case the direction of the current is not only the opposite of this, but the electromotive force continues to increase even in greater ratio after the highest point of the series has been reached. The effects, therefore, are not such as Matteuci observed. The reader is further referred to page 360.

REPETITION OF SOME OF THE EXPERIMENTS AFTER AN INTERVAL OF ABOUT ONE HUNDRED AND THIRTY DAYS.

The preceding experiments are to be regarded as incomplete in two particulars. In the first place, the data are the results of but a single method of measurement, the application of which is not immediately evident; in the second, no criterion of their constancy in point of time has as yet been obtained. The additional results now to be given were obtained on the 600-foot level of the Richmond mine, all of the former holes (points tapped), with the single exception of No. I., being used over again. In place of the latter, this having become inaccessible, a fresh hole, about 25 feet to the east of the old one, but also in shale, was drilled.

The experiments were made after an interval of more than four months from the time at which the original data were obtained.

Methods.—From an inspection of the magnitude of the electromotive forces contained in the foregoing tables, it will be seen that they fall well

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[1] Ann. de Chim. et de Phys., (4), T. X., p. 148, 1867.

within the scope of a good electrometer. Such an instrument, properly protected against the moisture of the underground air, would have been most serviceable for the purpose. Unfortunately, one could not be obtained in time for the work. The following methods were therefore resorted to:

In the first place the greater part of the data were checked by the method already described. This, it will be remembered, was chosen because of its simplicity and the comparative ease with which any fault in the connections could be ascertained.

The potential of the same holes was now measured by a method in which the electromotive force is expressed in terms of the increment of the reciprocal of intensity of current, and the corresponding increment of the resistance of the circuit, to which the former is due. In order to vary the resistance at pleasure a rheostat was introduced. If the resistances w_1 and w_2 correspond to the intensities i_1 and i_2, respectively,

$$e = \frac{w_1 - w_2}{\frac{1}{i_1} - \frac{1}{i_2}},$$

where e is the electromotive force to be measured.

Finally, the whole of the experiments formerly made on the 600-foot level were again repeated by a zero method. Here great care had to be taken to effect the complete insulation of all parts. This was accomplished in the manner previously indicated, by suspending the terminal wires, as well as all the connections, from threads. The accompanying diagram, Fig. 31, will show how this was done. *A* and *B* are clamp screws, suspended from the threads *a* and *d*, respectively, *R* (rheostat) is the large, *r* the small resistance, *K* a double key, *C* a commutator, *G* the galvanoscope. For a zero current in the latter (the effects

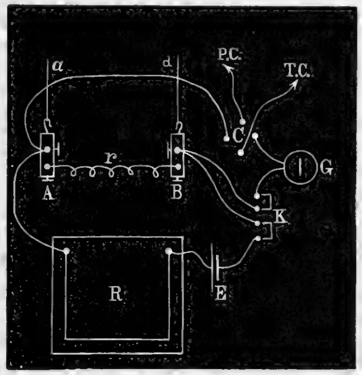

FIG. 31.—Disposition of apparatus.

due to the normal element E and the lode electromotive force compensating each other in G), approximately,

$$e = E\,\frac{r}{R+r}.$$

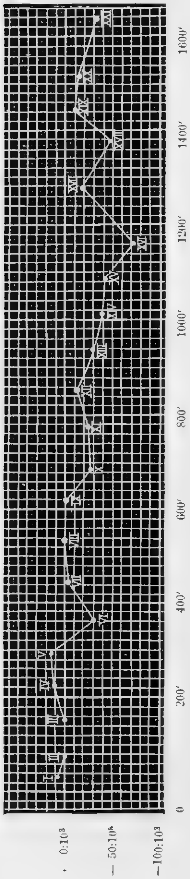

FIG. 32.—Earth-potential and distance, Richmond mine, 600-foot level (new results).

The resistance r was wrapped on a small piece of wood and the whole subsequently boiled in paraffine. The body of the key K, and that of the commutator C, were similarly prepared, being boiled in linseed oil, and the mercury cups covered internally with a thick coating of wax. Moreover, the wires of both in passing through the wood were additionally insulated from the latter by a covering of gutta-percha; the ends only being uncovered and communicating with the mercury in the cups. In consequence of these precautions it was found that this comparatively complicated method could be employed in these wet drifts with complete success, and the adjustments having once been made, it proved to be nearly as expeditious as either of the other methods.

As the result obtained is derived from an expression which is independent of the resistance of the circuit, the method could be used with advantage in studying the manner of variation of potential in passing, as it were, continuously from any *T. C.* to the next. But the actual observations will be more appropriately cited in connection with another topic (see page 361).

It will be remembered that in the former experiments four contact bags were used throughout, which were so combined as to give three independent values for the electromotive force to be measured. The results thus obtained, however, being usually so nearly identical, it was thought that this precaution might safely be dispensed with. Two contact bags only, therefore, were employed. In all other respects, however, the former plan (see page 328) was rigidly adhered to, with such slight variations, of course, as the different methods rendered necessary.

Results.—The following table, containing the potential of the consecutive points on the 600-foot level—that of No. VIII. being arbitrarily put equal to zero, as before—will be intelligible without much further explanation. The results of the different methods are arranged in parallel columns, and in the order in which they were described. For the sake of comparison those obtained in the former survey are also added, and a final column shows the difference between the two.

TABLE XIX.

No.	Points.	$e \times 10^3$, determined—			$e \times 10^3$, mean.	$e \times 10^3$, old value.	$\delta(e) \times 10^3$.	Remarks.
		By old method.	With rheostat.	By compensat.				
1	I′	....	....	+ 7	+ 7	− 14	....	New and old holes do not coincide.
2	II	....	....	+ 1	+ 1	− 3	− 4	
3	III	....	....	+ 1	+ 1	− 4	− 5	
4	IV	....	....	+ 12	+ 12	+ 18	+ 6	
5	V	....	....	+ 15	+ 15	+ 17	+ 2	
6	VI	....	....	− 30	− 30	+ 6	+ 36	
7	VII	− 3	....	− 4	− 4	+ 5	+ 9	
8	IX	− 1	− 1	− 1	− 1	− 1	± 0	
9	X	− 29	− 25	− 31	− 28	− 11	+ 17	
10	XI	− 25	− 25	− 25	− 25	− 17	+ 8	
11	XII	− 13	− 12	− 14	− 13	− 35	− 22	
12	XIII	− 30	− 23	− 24	− 29	− 38	− 9	
13	XIV	− 39	− 39	− 40	− 39	− 48	− 9	
14	XV	− 41	− 40	− 47	− 43	− 59	− 16	
15	XVI	− 72	− 75	− 76	− 74	− 93	− 19	
16	XVII	− 15	− 15	− 23	− 18	− 31	− 13	
17	XVIII	− 48	− 47	− 50	− 48	− 54	− 6	
18	XIX	− 8	− 13	− 7	− 9	− 18	− 9	
19	XX	− 14	− 13	− 14	− 14	− 19	− 5	
20	XXI	− 31	− 32	− 39	− 34	− 29	+ 5	

The results obtained by different methods present throughout a fair agreement, when it is remembered that errors amounting to a few thousandths of a volt are introduced by circumstances beyond the observer's control. Between the mean of the new and the mean of the former results there are a number of annoying discrepancies. In part, though by no means wholly, these are due to a difference in the values of the standard electromotive force employed in the two cases. With the knowledge at present available it would be of little use, however, to attempt to assign reasons for the remaining variations. A matter of greater importance is that the general character of the curves, as derived from the two series of results, is essentially the same.[1]

UNAVOIDABLE ERRORS AND MISCELLANEOUS CRITICISMS.

Moisture in the rocks.—By far the most serious difficulty encountered in endeavoring to interpret the results obtained, is that due to the difference of potential of two liquids in contact. The conductivity of rocks is, as has been seen, largely, if not wholly, to be ascribed to the presence of moisture in their pores. This moisture unquestionably holds saline matter in solution. Moreover, it is altogether probable that the solution in one rock of a particular structure is in general different from that in another of different structure and many hundred feet distant from the former, even if the composition of both is essentially the same. In tapping two points at some distance apart by the aid of two metals (plates or gads) supposed identical in every respect, two members of the continuous sequence of solutions contained in the rocks are, in fact, put in metallic contact. The difference of potential thus obtained would be that due to the resultant action of the series of liquids included between the points. This electromotive force is, however, principally dependent on the extreme members of the series, *i. e.*, those at the points tapped; and in the present investigation it was hoped that the discrepancy thus arising might be very largely eliminated by putting the same liquid in both holes, and by exchanging not only the metallic terminals—amalgamated zinc—but also the terminal solutions (zinc sulphate). Hence the "bag" form of the terminal.

It was thought not superfluous to test the matter with the aid of the contact bags themselves; all the more as it would thus appear to what extent the results obtained with the latter are trustworthy. The two liquids, whose electromotive force was to be measured, were separated from one another by a porous septum of animal membrane. As in the mines, the terminal bags were exchanged. In passing them out of the first liquid into the second, care was taken to wipe off the liquid adhering to the outside.

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[1] Compare Figs. 30 and 32.

If now, e be the electromotive force of the two solutions in contact, ε that due to the difference between the zincs alone, in the first position of the bags A and B (A in water and B in the liquid to be tested), the apparent force would be

$$\varepsilon \pm e;$$

in the second position of the bags (B in water and A in the liquid to be tested),

$$\varepsilon \mp e,$$

the connections themselves remaining unaltered. A mean of both measurements gives ε; half the difference, e. The following are some of the results:

	$\varepsilon \times 10^3$	$e \times 10^3$
Both bags in water	1.0	0.2
Bags alternately in solution of $Na^2 SO^4$ and in water	1.0	2.8
Both bags in water	2.8	0.4
Bags alternately in salt solution and in water	3.4	2.2
Both bags again in water	3.4	0.6
Both bags in water	3.0	+ 0.4
Bags alternately in $Zn SO^4$ solution and in water	3.6	− 0.4

It will be seen that in the different sets ε is fairly constant. The value of e is small, as anticipated, notwithstanding that nearly concentrated solutions were used. In the case of zinc sulphate e is practically zero, as it should be, the bags themselves containing this solution.

The following table contains analogous experiments made in the mines. Holes IX. and X., 600-foot level, were put in contact. Measurements were made by a zero method:

	$e \times 10^3$
Water in both IX. and X.	− 28
Water in X.; concentrated brine in IX.	− 27
Concentrated brine in both IX. and X.	− 27

Two other holes similarly treated gave:

	$e \times 10^3$
Brine in one only	− 14
Brine in both	− 17

Apparently, therefore, large discrepancies are not produced in this way.

Of course all these experiments are only intended to furnish estimates as to the probable magnitude of disturbances of an analogous kind, which may possibly have influenced the data given above.

Mr. E. Kittler[1] has recently commenced a new study of the question of potential difference due to the contact of liquids. From a large number of careful experiments he finds electromotive forces between them far exceeding, as a rule, those met with in the measurements of earth currents here described. These forces, however, obey the law of Volta's potential series.

From all these considerations, it seems to follow that in the present investigation the discrepancies due to the presence of different liquids in the rocks have been eliminated to a great extent. Certainly their effect can hardly be estimated as much greater than a few thousandths of a volt. It is obvious, moreover, that the use of simple metallic contacts (plates and gads) is under all conditions unsafe. To this is to be added the fact that metallic plates are never identical in their electrical properties, and that their difference (as large effects of polarization are also included therein) cannot be eliminated by such a process of commutation as was employed.

The phenomenon of conduction of rocks being essentially hydro-electric, the determination of the thermo-electric power earth|copper, for which it was at first thought the high temperature on the lower levels of the Comstock Lode, in comparison with those at the surface, would offer excellent facilities, has no further interest. No attempt of this kind was therefore made.

If the hole drilled for the reception of the terminals be regarded as a cylinder with a hemispherical base, the directrix of the former as tangent to the sphere corresponding to the latter, its axis as normal to the plane face of the drift, approximate values may be derived for the specific resistance of the rock met with. Let h be the height of the cylinder, a the common radius of both the latter and the hemisphere. Let r be the radius of any similar figure, the axis of whose cylinder and center of hemisphere coincide with those of the hole. Finally, let σ be the specific resistance of the rock, or the resistance in ohms between opposite faces of a cubic centimeter.

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[1] E. Kittler: "Ueber Spannungsdifferenzen, etc." Wied. Ann., XII., p. 572 *et seq.*, 1881.

The elementary resistance of a shell at the distance r from the axis and of the thickness dr, is then

$$dw = \frac{\sigma}{2\pi}\,\frac{dr}{r(r+h)},$$

and, therefore, the resistance of the layer of rock between coäxial and concentric figures, the inner radius being a, the outer r, is

$$\Big[w\Big]_a^r = \frac{\sigma}{2\pi h}\, l\,\frac{(a+h)r}{(r+h)a},$$

the symbol $\Big[w\Big]_a^r$ being used to express the resistance of the layer of rock between the similar surfaces just defined. If r is allowed to increase to infinity, approximate values for σ can be determined from the data given above for the resistances of the circuits, and the known dimensions of the holes. In this way it appears that the mean value of this quantity was about

$$\sigma = 40{,}000,$$

whereas values as high as 500,000 and as low as 20,000 were met with. From the invariable presence of moisture, however, these figures possess only minor interest.

If the resistance of layers of rock between consecutive similar surfaces be compared, the same notation being again employed, in round numbers,

$$\frac{\Big[w\Big]_{10}^{\infty}}{\Big[w\Big]_a^{10}} = 0.6; \quad \frac{\Big[w\Big]_{100}^{\infty}}{\Big[w\Big]_a^{100}} = 0.07; \quad \frac{\Big[w\Big]_{1000}^{\infty}}{\Big[w\Big]_a^{1000}} = 0.007, \text{ etc.},$$

all dimensions being expressed in centimeters, and a being 1.2 cm.; whence it follows that the resistance of coäxial and concentric layers decreases, though hardly as rapidly as might be desirable. In point of fact, however, the convergence is more rapid than this approximate calculation indicates. A drift may with greater accuracy be regarded as a cylindrical tunnel, into the sides of which the contact holes have been drilled, with their axes at right angles to that of the drift. Now, it is obvious that as r (in the former signification) increases, the values of dw will in this case decrease more rapidly than in the previous one; this because the superficial area of the infinitesimally thin shell increases much more rapidly. The actual analysis, however, is unnecessary here The points of greatest interest have already been sufficiently illustrated by what precedes.

Earth-currents.—A second important consideration relative to the causes which might have produced discrepancies in the present investigation is the effect to be ascribed to earth-currents. Although numbers of experiments have been made in different parts of the world as to the magnitude and direction of such currents, I am unable to estimate their effect in this case, especially as the constants for the currents probably vary with the position of the field of observation on the surface of the earth. Most observers have availed themselves of telegraphic connections between points very many miles apart. Matteuci,[1] I believe, was the only one who laid a carefully insulated line especially for this purpose, and it is to his investigation that we can with greatest advantage refer. Yet, though his points were at a distance of six kilometers apart, the currents obtained, so far as can be seen, were certainly not much larger than those here recorded If, however, the variation of potential in the above experiments were due to some normal, non-local cause, it would be fair to assume a linear change of potential with distance throughout the comparatively small area in which the experiments were made. Such is by no means the case. In fact, some of the largest variations observed occur within distances of a few hundred feet, while elsewhere a range of 1,000 feet is without marked alteration of potential. It is probable, therefore, that earth-currents have not perceptibly affected the results.[2]

Drill-holes.—The angular and somewhat irregular curves (Figs. 28, 30, 32) might give rise to a suspicion that the difference of potential observed is in some way to be ascribed to the accidental condition of the holes themselves. *A priori*, therefore, the presence of little pieces of steel, worn or broken off from the drill, crystals of iron pyrites, particles of ore, etc., in the walls of the hole should not be disregarded. That such material is, however, entirely without disturbing effect will be seen from the following experiments:

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[1] Ch. Matteuci: "Sur les courants électriques de la terre." Ann. d. Chim. et de Phys., [4], T. IV., p. 177, 1865; *ibid.* [4], T. X., p. 148, 1867.

[2] Temporary disturbances, such, for instance, as are due to atmospheric induction, are obviously without influence in the present case. Inductive action, moreover, is hardly to be expected from the clear, dry air of Nevada.

In a particular case the intensity i_1 obtained by connecting two holes in the ordinary manner was

$$i_1 = 101 : 10^8.$$

A thin strip of platinum was subsequently introduced into one of the holes and firmly pressed against its sides. The intensity i_2 then measured proved to be

$$i_2 = 99 : 10^8;$$

or, practically, the same as before. An effect due to the platinum was therefore absent.

Two holes, about 18 inches apart, were drilled in solid rock and connected as usual. The measurements made for difference of potential, by the original method, gave, in four successive experiments, different bags being used for each,

$$1)\ e = +1 : 10^3$$
$$2)\ e = -1 : 10^3$$
$$3)\ e = \pm 0 : 10^3$$
$$4)\ e = \pm 0 : 10^3,$$

or zero, as from the proximity of the holes it ought to be.

Finally, the potential of a number of points lying between Nos. V. and VII., on the 600-foot level of the Richmond mine, was determined. A zero method being used, it was only necessary to put the terminal bags in contact with the rock at the points chosen, by allowing them to recline against the wall. Care was taken to prevent any part of the copper wire from touching it. Two points, *A* and *B*, were thus established between VII. and VI.; three, *C*, *D*, and *E*, between VI. and V. The following table gives the results, the potential of No. VIII. being put equal to zero, as before:

TABLE XX.

No.	Points.	$e \times 10^3$	Distance from VII.	Remarks.
1	VII	− 4	0	Drill-hole.
2	A	− 15	30	
3	B	− 44	60	
4	VI	− 30	87	Drill-hole.
5	C	− 23	105	
6	D	− 9	120	
7	E	+ 2	140	
8	V	+ 15	157	Drill-hole.

In Fig. 33 these results are graphically represented. It appears, notwithstanding the different kinds of contact at V., VI., VII., and at *A*, *B*, *C*, *D*, *E*, that the progress of the curve in passing from VI. to V. is continuous. The experiments, therefore, failed to detect any specific action due to the holes. Nos. V., VI., and VII. were especially chosen, because, as will be seen from a comparison of Figs. 30 and 32, this part of the curve presents a curious and pronounced anomaly, the newer results differing very remarkably from the earlier. It was natural to suppose that, in the time which had elapsed between the two series of measurements, hole No. VI. had in some way been interfered with. The results just cited, however, preclude such a supposition. Even larger masses of metal seem to be without marked effect. Between the date of the earlier and that of the newer observations, for instance, a track had been laid from the vicinity of the hole No. I. to No. XV.

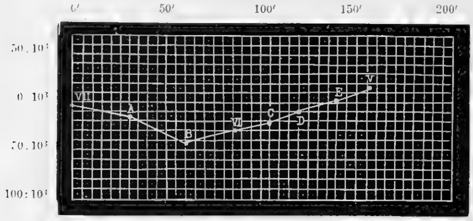

FIG. 33.—Potential of intermediate points.

Terminal bags.—There occur a few cases in my notes in which, though in every other respect the behavior was normal, different results were obtained for the same hole at nearly the same time, by employing different bags, viz.:

IV. $e = 0:10^3$
$e = 2:10^3$
$e = 5:10^3$

VII. $e = 2:10^3$
$e = 6:10^3$.

These cases are rare, however, and their effect is of minor importance. More worthy of consideration are the successive differences of potential due to the bags alone when employed for a long period of time. The quantity referred to has already been considered on page 357, under the symbol ε. It may readily be derived from the tables for intensity. The following table (XXI.) probably contains good examples of its consecutive states, the data given being deduced from those for the holes I.–XIV. on the 600-foot level. If the bags are called *A*, *B*, *C*, *D*, the electromotive force ε between *A* and *B* may be conveniently represented by $A \mid B$, between *A* and *C* by $A \mid C$

etc. The values of ε, as derived both from the direct and return series, are given in the table, the latter being primed. Heavy black lines across the table indicate either that the bags were refilled or that the experiments had to be temporarily discontinued.

TABLE XXI., containing $\varepsilon \times 10^8$.

No.	Points.	A | B	A | C	A | D	A′ | B′	A′ | C′	A′ | D′
1	I	− 17	− 16	− 15	− 1	± 0	± 0
2	II	− 12	− 11	− 8	− 2	± 0	+ 1
3	III	− 16	− 15	− 11	− 1	+ 1	+ 1
4	IV	± 0	+ 1	+ 1	± 0	+ 1	+ 2
5	V	− 1	− 1	− 3	± 0	+ 1	+ 1
6	VI	− 2	− 2	− 2	+ 1	+ 2	− 3
7	VII	± 0	− 2	− 1	± 0	+ 2	± 0
8	IX	− 2	− 2	− 3	− 1	+ 1	+ 3
9	X	− 1	− 1	− 4	± 0	± 0	− 1
10	XI	± 0	− 1	− 3	− 1	± 0	± 0
11	XII	− 4	− 3	− 5	− 1	± 0	± 0
12	XIII	− 4	− 2	− 4	+ 2	± 0	+ 1
13	XIV	− 1	− 1	− 2	− 1	+ 1	− 2

The successive values of ε are not constant, though in the majority of cases they are so small as to be immaterial. At times, however, values sufficiently large to be important are reached. An exchange of terminals is therefore indispensable, especially as experiments will usually be sufficiently extensive to involve interruptions. The gradual variation observed in the value of ε can most probably be referred to a corresponding change in the concentration, etc., of the solution (zinc sulphate) contained in the bags. It is hardly probable that it is due to polarization, or a change in the surface of the amalgamated zinc strips. It is interesting that, in spite of the fact that for the holes I., II., and III. the electromotive force between the bags in the direct and return series differs largely, the lode-currents deduced from the two sets of data are practically equal. (See Table XV.)

Wire.—In the above experiments especial care was taken to prevent errors due to leaks in the wire. The galvanometer was sufficiently delicate to register a fault of this kind of 5,000,000 ohms' resistance with certainty. As has been mentioned, every leak introduces an electromotive force zinc|copper;[1] hence the great necessity, notwithstanding the fact that the latter must act through a very great resistance, of avoiding leakage.

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[1] For we have the closed couple: Copper (of wire); liquid (moist earth, etc.); zinc (of bag).

General remarks.—The opinion has been expressed (page 351) that the field of electric excitation is confined to particular parts of the ore body. That this should be the case is not surprising, as the conclusion has already been reached that contact between different kinds of material is necessary for the production of currents. In the connection made between chambers No. 14 and No. 15, as well as in the survey on the 400 and 500-foot levels, the ore actually met with was principally lead carbonate, at times stained with sulphide and ferric oxide. Now, disregarding the sulphide, which is here very unfavorably associated, more pronounced electrical properties can hardly be ascribed to the remaining constituents of the deposit than to the surrounding rock itself. For, judging from physical properties, cerusite may be regarded as an insulator with as much right as calcite, earthy lead carbonate as limestone. In fact, it seems to follow that the feeble, though none the less positive, reaction observed on the 600-foot level is already partially obscured when the line of points on the 500-foot level is reached, and would perhaps, *cœt. par.*, be equally obscured on the 700-foot level. I am also inclined to infer that the currents observed on the surface are not due, or, rather, not immediately due, to the deeper ore bodies (Nos. 11, 12, 13, 14, 15, etc.), but to the deposits, also of considerable size, occurring in what are known as the Lizette Tunnel workings. The entrance to the latter is on a level with the mouth of the shaft, and the ore masses are distributed in a vertical range from Point I. to a level even above Point X. on the surface. These ore bodies, throughout their extent, are comparatively near the line of holes used in the surface survey. It is, moreover, quite probable that an intimate connection exists between these and the large group of ore bodies below.

In consideration of the statements made in the foregoing paragraph, and allowing as accurately as possible for discrepancies, the results thus far reached may be regarded as agreeing well with the fundamental hypothesis.

CONCLUDING REMARKS.

On reviewing the results described it is strikingly evident that the electromotive forces met with are invariably small, very frequently, indeed, quite at the limit of the accurately measurable. It is true that the electrically active material was probably galena, which, as Fox long ago observed, is unfavorable for observations like the present. It is a question, however, whether results much larger than these will generally be obtained. I cannot believe that Reich's earnest appeal for general research in the direction of electric prospecting has been altogether disregarded. There is much more to lead one to infer that many undertook the study of the question, but, disappointed with feeble reactions and discordant results, abandoned the matter altogether. Reich, at the end of his last paper, gives a list of the apparatus desirable, which, however, except where the action is so intense as it was found to be in Cornwall, and to a less extent at Freiberg, would certainly be insufficient.

The very large currents obtained in the localities just mentioned rendered it not improbable, at the outstart of the present investigation, that important conclusions might be drawn from the results of a minute magnetic survey[1] of the interior of the mines, or across the vein on the surface; and preparations for such a purpose were, in fact, made. But the currents obtained galvanometrically dictated the abandonment of this project.

The study of the electric activity of ore bodies should be carried out on a broader basis than was possible in the present case, to reach the best results. A single line of survey, or the investigation of the variation of potential in a single drift, is far from sufficient. The endeavor should be made to map the equipotentials as surfaces traversing the whole mine, carefully considering their position and contour relatively to any ore already in sight, and their change of form on leaving it. The inferences to be drawn herefrom would certainly compare in value with those of a purely geological

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[1] Fox himself entertained an idea of this kind.

character, even though dependence must be placed on the latter for a complete interpretation of the results.

Furthermore, it will be desirable to carry out Fox's original idea, namely, of investigating the electrical properties of ores and those minerals of the heavy metals which are usually found associated with them; not that the results of such an investigation could ever furnish a clew as to the particular ore to which an observed electric effect is due (it is here that our knowledge of the locality must aid us), but that the *class* of ores, in prospecting for which an electric method would be peculiarly applicable, could thus be defined. The knowledge we possess of the conductivity and the position of ores in the electrical scale is largely the result of experiments made a long time ago. Recent observers have made but few quantitative additions, and even these—probably from improperly chosen methods—are frequently discordant.

The method which has been described seems to me especially worthy of consideration, from the fact that by means of it an electric survey, made on the surface, may detect not only the presence but also the approximate position of ore bodies under ground. With such an end in view the experiments should be extended over a large area, and the potential at all portions of the surface determined. Suppose, now, that at each point of the projection of the latter on a fixed horizontal plane, a vertical line is erected, of a length proportional to the earth-potential at this point. The ends of all such lines together make up a second imaginary surface, coëxtensive with the first, which will represent the electric state graphically at each point of the territory over which the survey has been carried.

The effect of normal earth-currents would then express itself in the progress and contour of the imaginary surface as a whole, and would not destroy its regularity. If its extent is not too large, this (normal) surface will be a more or less inclined plane. As it has been observed that earth-currents are not constant, even for short periods of time, the latter is, moreover, to be regarded as slowly oscillating, more or less parallel to itself, about a certain temporarily fixed position of equilibrium. But it is probable that the limiting positions of the plane are so near to one another that for this purpose they may be regarded as coincident.

Local action, however, in contrast to the foregoing, would probably manifest itself locally in the imaginary surface, as a hillock or depression. It is to such anomalies that attention should subsequently be directed, the electric activity of ore bodies, differences of potential of liquids in contact, and Matteuci's effects[1] constituting the salient points to be considered. In the interest of expeditious work all measurements should be made electrometrically, the lines of survey radiating from a central point (*P. C.*) the potential of which is arbitrarily taken as zero.[2]

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[1] Those mentioned, p. 352.

[2] The prosecution of the experiments described in this chapter was aided by the cordial coöperation of Messrs. Patton, Lamb, and Ballard, of Virginia City, and Messrs. Rickard, Westcott, Harris, and Bryan, of Eureka, Nevada. The work is also indebted to Professor Michie, of West Point, for the loan of a Rowland magnetometer made by Mr. Wm. Grunow, of New York.

CHAPTER XI.

SUMMARY.

BY GEORGE F. BECKER.

Purpose of this chapter.—A very large portion of the foregoing pages is necessarily occupied by detailed descriptions, written to enable readers to judge whether the facts warrant the opinions expressed, and by discussions of a somewhat technical character. There may be those, however, who will be interested to know in brief what conclusions have been reached, but who have no inclination to undertake the somewhat serious task of weighing the evidence adduced, and of following the arguments in detail; and for such the present chapter is written, but with the proviso that full and fully qualified statements are to be found in the body of the report, and there only.

History and statistics.—No more condensed statement of the technical and economical relations of the COMSTOCK mines can be presented than that which is given in Chapter I., itself a meager abstract of reports which will appear hereafter; nor is it necessary further to reduce the digests of the previous memoirs on the LODE which constitute Chapter II. In some respects the present volume is a tribute to the acumen of preceding observers, upon whose investigations that here described is to a great extent built up. That the recent development of the science of microscopical petrography and the immensely increased facilities for observation, due to the extension of the mine workings, should have led to some views different from those heretofore entertained concerning the geology of the DISTRICT is anything but surprising.

LITHOLOGY.

Importance of the rock determinations.—In areas so largely covered by massive rocks as the WASHOE DISTRICT, lithological determinations form the necessary preliminary to geological investigation, for few points in the history or the structure of such a region are independent of the character of the rocks involved. Moreover, the economical importance of the DISTRICT, the obscure character of some points in its geology, and the great weight of the authorities whose investigations had already been published, made it essential that the work done under the new United States Geological Survey should be supported by the strongest and most detailed evidence. The collections embrace over 2,600 specimens and 500 microscope slides. The locality of each specimen was fixed with great care on the maps at the time of collection, and no time or pains was spared in preparing the geological maps and sections. In laying down the various formations the microscope was in constant use, slides being ground as the occasion arose, and the results obtained from them finding immediate application in the extension of the work.

The area in which the COMSTOCK lies is characterized by a wide-spread and profound decomposition of the rock masses, and a study of the lithology of the DISTRICT resolves itself primarily into an investigation into decomposition. In spite of the most painstaking choice of specimens, there is not one in fifty of those collected underground which contains a particle of either of the characteristic bisilicates or of the lithologically equivalent unisilicate, mica, secondary minerals replacing them throughout. Even the feldspars are rarely intact, and are sometimes wholly decomposed. When the steps of these processes of degeneration are once understood, however, it is comparatively easy to infer the original composition and structure of the rock. Some of the results obtained are the following:

Decomposition.—Hornblende, augite, and mica generally pass into a chloritic mineral, which, so far as can be judged by any optical tests now known, is almost without exception the same, from whichever of the ferro-magnesian silicates it may have originated. This chlorite is generally green, but in especially compact masses appears greenish-brown under the microscope.

It is strongly dichroitic, but except in dense masses appears nearly black between crossed Nicols. It is fibrous, often spherolitic, and invariably extinguishes light parallel to the direction of the fibers. It thus bears a considerable resemblance to fibrous green hornblende, but the cases are very rare, if they actually occur, in which a careful examination will not serve to discriminate between the minerals. This chlorite is decidedly soluble. It occurs in veinlets and diffused through the groundmass and through other minerals when these have become pervious through decomposition. It is especially striking as an infiltration in altered feldspars, where, of course, it is readily visible. All the stages can be traced, from the first inconsiderable attack upon the bisilicates or the mica through instances in which chlorite occurs wholly or almost wholly as admirable pseudomorphs after the ferromagnesian silicates, and up to cases in which the secondary mineral is wholly diffused through the mass of other products of decomposition.

Epidote is usually in WASHOE a product of the decomposition of chlorite. Comparatively very few occurrences of epidote are explicable on the supposition that the mineral is the direct result of the decomposition of the primary silicates; none are inexplicable on the supposition that chlorite represents an intermediate stage in the alteration, and hundreds of cases show beyond question that epidote develops in chloritic masses, sending characteristic denticles and fagot-like offshoots into the comparatively homogeneous chlorite. Several drawings illustrating these processes are shown in Plate II. They are photographic in their fidelity. Epidote, too, is possibly soluble to a very slight extent, but certainly far less so than chlorite. The veinlets of epidote are often, though perhaps not always, a result of the alteration of chlorite. No evidence has been obtained that feldspars are ever converted into epidote, and the dissemination of fresh hornblende particles in feldspars in any considerable number has not been observed. In many cases, on the other hand, it can be shown that feldspars have been impregnated with chlorite, from which epidote has afterwards developed. Chlorite does not always change to epidote, and appears often to be replaced by quartz and calcite. This is frequently visible in slides which also show its alteration to epidote. No certain evidence of the alteration of epidote has been met with.

In the decomposition of the feldspars, the first stage appears to be the formation of calcite. This sometimes leaches out, leaving small irregular cavities, and these cavities are not infrequently filled with liquid, sometimes carrying a bubble, which is commonly stationary, but occasionally active. Thus secondary liquid inclusions are formed, which may mislead in the diagnosis of a rock. Primary liquid inclusions are either more or less perfect negative crystals or vesicular bodies. The vesicles often assume strange forms through pressure, such as are often observed in air-bubbles in the balsam of a slide, but their outlines are composed of smooth curves. The secondary fluid inclusions are bounded by jagged lines. Inclusions of this kind are never met with unaccompanied by other evidences of decomposition, and thus are abundant in the altered outer crust of andesite masses, the inner portions of which show none of them. There is every reason to suppose that such secondary inclusions would form in older rocks, and it is believed that many of them have been detected in the pre-Tertiary eruptives of the DISTRICT; but in the older rocks their secondary character can only be suspected, not proved.

Kaolin possesses so few characteristic optical properties that it is not recognized with ease or certainty under the microscope. No kaolin has been identified in the WASHOE rocks, and while it is by no means asserted that they contain none, it seems hardly possible that, had it formed a prominent constituent, it would have escaped observation. The presence of enormous masses of "clay" on the COMSTOCK does not prove the existence of much kaolin, for the so-called clays of veins are largely attrition mixtures.

An increase in volume appears to accompany the decomposition of the WASHOE rocks. This is perceptible where dense masses, such as the more compact andesites, are subjected to the process. Angular blocks are then converted into a series of concentric shells of comparatively soft matter, which approach the spheroidal shape more and more as the diameter diminishes.[1] Often a nodule of undecomposed rock is found at the center, and such masses afford the very best opportunity for studying the macroscopical appearances resulting from degeneration. When the attacked mass is large,

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[1] Prof. R. Pumpelly has described the course of decomposition almost in the same words, in his paper "On the Relation of Secular Rock-disintegration to Loess, etc." (Amer. Journ. XVII., 1879, 136.) I did not happen to see Professor Pumpelly's paper until after this passage was written.

erosion often exposes the fresh core, which then, offering greater resistance, projects as a "cropping," or, if it has an elongated form, it protrudes like a dike above the surrounding country. As the tendency of the mere action of atmospheric agencies is to the production of ferric hydrate rather than of chlorite from the bisilicates, the first impression which such a mass produces is that of an older and a younger rock in conjunction. Nevertheless, sufficiently thorough examination will reveal a transition. When the rock is not solid, but brecciated or loose-grained, sufficient space often seems available to permit the requisite increase of volume without disintegration. Large and often prominent masses of very strongly cohesive decomposition-products derived from breccia are common in the DISTRICT.

The mineralogical character and the microscopical phenomena of decomposition seem to be identical in the different rocks. Those refined manifestations of physical character by which it is so often possible to discriminate between older and younger rocks, and between the various rock species when fresh, are nearly or quite obliterated by the decomposition process, which impresses its own character on the product.

Rocks of the District.—The rocks occurring in the WASHOE DISTRICT are granite; metamorphic schists, slates, and limestone; eruptive diorite of three varieties; metamorphic diorite; quartz-porphyry; an older and a younger diabase; an older and a younger hornblende-andesite; augite-andesite, and basalt.[1] Chapter III. contains a discussion of each of these rocks and a detailed description of about seventy-five slides, and is well illustrated. Here they can be dismissed with a very few remarks.

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[1] The signification attached to these names has varied somewhat as the science of lithology has progressed. Some of the main points of their definitions as here understood are as follows:

Granite, pre-Tertiary non-vitreous crystalline rock, of which the principal constituents are orthoclase, quartz, and mica or hornblende.

Diorite, pre-Tertiary non-vitreous crystalline rock, of which the main constituents are plagioclase and hornblende. It may or may not contain quartz.

Quartz-porphyry, pre-Tertiary glass-bearing porphyritic rock, of which the main constituents are orthoclase, quartz, and hornblende or mica.

Diabase, pre-Tertiary, more or less porphyritic rock, of which the main constituents are plagioclase and augite.

Andesite, Tertiary or post-Tertiary, glass-bearing, more or less porphyritic rock, of which the main constituents are plagioclase and hornblende, mica, or augite. The andesites in which augite is the characteristic bisilicate appear to be separate eruptions, while mica and hornblende replace one another to a variable extent in the same eruption. In the andesites feldspar predominates.

Basalt, Tertiary or post-Tertiary plagioclase augite rock, with predominant augite, usually characterized by the presence of olivine.

Concerning the granite and basalt there has scarcely been a question. They are eminently characteristic occurrences. The metamorphic diorite sometimes resembles eruptive diorite, and has been taken both for diorite and granite; usually it bears some resemblance to augite-andesite or basalt, and has been determined microscopically as an unusual variety of the latter rock. It is composed essentially of oligoclase and hornblende. The hornblende was originally colorless, but through some change (perhaps absorption of water) it is in large part converted into an intensely green variety. The hornblende polarizes in unusually intense colors.

The quartz-porphyry underlies both hornblende-andesite and diabase. The microscope, Thoulet's method of separation, and analysis, show that the predominant feldspar is orthoclase. It is characterized by the association of liquid and glass inclusions usual in quartz-porphyry, to which also the groundmass corresponds. In one locality, near the *Red Jacket*, the quartz is nearly suppressed, and the rock is excessively fine-grained. It is a felsitic modification of the ordinary variety. This rock, which Baron v. Richthofen determined correctly, has since been called quartz-propylite, dacite, and in its felsitic modification rhyolite. Most of the quartz-porphyry is greatly decomposed.

The eruptive diorite is sometimes granular, sometimes porphyritic. In the porphyritic diorite mica frequently predominates over hornblende. Quartz is irregularly disseminated through the rock. In the granular diorite the hornblende is sometimes green and fibrous, sometimes brown and solid. In some cases it can be shown that the latter variety of hornblende is altered to the former, and possibly this is ordinarily the case. Augite is not uncommon, and a part of the fibrous green hornblende is very likely uralite, but in the granular rock the outlines of the crystalline grains are rarely sufficiently regular to determine this point. In the porphyritic diorites the fresh hornblende is always brown. Even in this latter variety of the diorites well-developed feldspars are rare. The porphyritic diorites have for the most part been regarded as propylite, and some occurrences of the granular rock have been classed in the same way. Some of the fresher porphyritic diorites have been mistaken for andesites, the resemblance to which is occasionally strong.

The older diabase is porphyritic, and almost the whole of it is in a very advanced stage of decomposition. When fresh, it considerably resembles an augite-andesite; its groundmass, however, is thoroughly crystalline and it contains no glass inclusions, but frequent fluid ones; the augites, too, show both pinacoidal and prismatic cleavages, and a tendency to uralitic decomposition. It is also manifestly older than the other diabase. An important characteristic is the lath-like development of the porphyritic feldspars, for in cases of extreme decomposition of the bisilicates this characteristic at least serves to suggest whether the rock is dioritic or diabasitic. The older diabase has been considered as propylite or andesite, according to the stage of decomposition. The younger diabase ("black dike") is very highly crystalline and not porphyritic. It is bluish when fresh, but in course of a few hours turns to a smoky brown. It is identical with many of the diabases of the New England and the Middle States.

The older hornblende-andesite and the augite-andesite where fresh are typical rocks macroscopically and microscopically. When decomposed they have been taken for propylite. The younger hornblende-andesite which overlies the augite-andesite is a cross-grained, soft, often reddish or purplish rock, with large glassy feldspars. It has always been supposed to be trachyte; but when endeavoring to determine the different species of feldspar under the microscope, I was unable to include any satisfactorily determinable sanidins in the list. Dr. G. W. Hawes was kind enough to undertake the separation of the feldspars by Thoulet's method, and analyses of the feldspars were made by Mr. F. P. Dewey. The specimen selected was the most trachytic in appearance, that of Mount Rose, but no feldspar whatever was found corresponding either physically or chemically to orthoclase. There is much reason to believe that trachyte occurs less often than had been supposed in the Great Basin area.

Apart from the effects produced by decomposition the Washoe rocks are typical of their kind, and correspond to representative specimens of the same species from other parts of the world, even in the minutiæ of mineralogical composition and physical structure. This persistence of rock types in minor features, which would seem to be fortuitous, or at least unessential, is one of the most remarkable facts established by microscopical lithology, and indicates a repetition of absolutely identical physical and chemical conditions at distant points, which is far from having received an adequate explanation.

Propylite.—The present investigation of the geology of the WASHOE DISTRICT has failed to establish the existence of propylite. Full proof of this responsible statement cannot of course be given in this summary of results. It consists in a process of exhaustive elimination. A study of each of the rocks of the DISTRICT, in all stages of decomposition, has led to the identification of all of them with other and previously recognized species. The reduction of rocks of originally different aspect to an apparently uniform character by chloritic decomposition is strikingly evinced by a mere list of the species in the DISTRICT, which have been grouped under the terms "propylite" and "quartz-propylite." These are granular diorite, porphyritic diorite, diabase, quartz-porphyry, hornblende-andesite, and augite-andesite. The peculiar habitus which is always referred to in descriptions of propylite appears to consist in the impellucidity of the feldspars, the green and fibrous character of the hornblende, the greenish color which often tinges feldspars and groundmass, and a certain blending of the mineral ingredients. The impellucidity of the feldspars (which surprisingly alters the appearance of rocks originally containing transparent unisilicates) is due to incipient decomposition, especially, as it seems, to the extraction of calcite. The "green hornblendes" are simply pseudomorphs of chlorite after hornblende or augite, as the case may be. Excepting the granular diorite, not one of the rocks from which propylite forms has ever been found in the WASHOE DISTRICT containing primitive green hornblende, though uralite is common. The other characteristics are due to the diffusion of chlorite and the formation of epidote from it. The description of propylite as a species arose from the erroneous determination of chlorite as green hornblende—a very natural mistake before the microscope was brought to bear on the subject, since even with that instrument the same error may be committed if color and dichroism are exclusively relied upon as diagnostic tests. The microscopical characteristics of propylite are illusory. Finely disseminated hornblende in the groundmass of a WASHOE rock is very rare, and far rarer is the presence of particles of hornblende in feldspars. The propylites contain glass inclusions and primitive liquid inclusions, or not, according to the rock from which they were derived. Base is rare in propylites; where it originally formed a constituent of the rock, it has for the most part undergone devitrification.

A reëxamination has been made of all the slides of propylites from other localities as well as from the WASHOE DISTRICT, descriptions of which have been published in different government reports. These, too, can be referred to other rock species with great probability, in spite of advanced decomposition, and I do not hesitate to affirm that there is no proof yet known of the existence of a pre-andesitic Tertiary eruption in the United States.

The term "propylite" should not be retained in the nomenclature of American geology even to express certain results of decomposition, for the equally loose term "greenstone" seems to cover the same ground and has priority.

A few minor questions of interest were raised by the microscopic examinations, in addition to those bearing directly upon the identification of the rocks. Such are the occurrence of zonal plagioclases and their bearing on Tschermak's feldspar theory; hornblendes with concentric belts of magnetite, and the indications they furnish as to the conditions under which "black borders" form, and some other small points.

STRUCTURAL RESULTS OF FAULTING.

Evidences of faulting.—The evidence of faulting on the COMSTOCK is manifold, and has been recognized by all observers. The irregular openings in the vein, the presence of horses, the crushed condition of the quartz in many parts, the presence of slickensides and of rolled pebbles in the clays, are all conclusive on this point. Both to the east and west of the vein, too, the country rock shows a rude division into sheets, and along the partings between the plates evidences of movement are perceptible, decreasing in amount as the distance from the vein increases, according to some law not directly inferable. All the evidence points to a relative upward movement of the foot wall.

The question of the character of the contact surface, whether it is a faulted surface or a continuation of a former exposure of the east front of Mount Davidson, is not to be settled by mere inspection. A cross-section to scale shows immediately that while the dip of the lode is 40° or more, the maximum slope of Mount Davidson is about 30°. This fact, taken in connection with the character of the west wall where exposed, indicates that the surface is the result of faulting. A natural surface sloping for a long distance at an angle of above 40°, too, is very unusual. On the other hand, the coincidence between the contours of the west wall and those of the exposed surface has been notorious from the earliest days of mining on the LODE, and it seems a less violent supposition that the steep flank of the mountain passes over into the still steeper wall of the vein than that the range has experienced an erosion modifying its angle from 10° to 20° and has still retained the details of its topography otherwise unaltered. It is plain that the elucidation of the faulting action on the COMSTOCK is a very important structural problem, and that it is most desirable to account quantitatively for the results, as well as to prove the existence of a notable dislocation.

Discussion of faulting under certain conditions.—The most striking and wide-spread evidence of the faulting is the apparent relative movement on the contact surfaces between more or less regular sheets of the east and west country rocks for a long distance in both directions from the LODE. Each sheet appears to have risen relatively to its eastern neighbor, and to have sunk as compared with the sheet adjoining it on the west. The consideration of a sheet or plate of rock under the influence of friction of a relatively opposite character on its two faces, therefore, forms the natural starting point for an examination of the observed conditions. It is shown in Chapter IV. that if a country divided like the COMSTOCK area into parallel sheets experiences a dislocation on one of the partings under a compressive strain equal at each parting, a vertical cross-section will show a surface line represented by two logarithmic equations. The discussion is also extended to the case in which the compressive strain is not uniform, but varies proportionally to the distance from the fault-plane. This case also results in a logarithmic equation of a more complex character.

A discussion of the logarithmic equation as an expression of faulting action leads to some very interesting results, some of which are as follows:

Where a fault of the class under discussion has occurred, and where the resulting surface has not been obscured by deep erosion, the original surface can be reconstructed or calculated, and the amount of dislocation determined. This is also true where more than one rock is involved.

Where, as is nearly always the case, the movement on the fault-plane is equivalent to a rise of the foot wall, the hanging wall seen in cross-section will assume the form of a sharp wedge, and this wedge will be very likely to yield to the compressive strain, and break across.

If the movement of the foot wall on the fault-fissure were downward, a surface line would form which is scarcely ever met with in nature, and the inference is that faults of this kind are of extreme rarity. This not only confirms the observations made in mines, but places the fact on a wider basis of observation.

If a fault, accompanied by compressive strain, takes place on a fissure in otherwise solid rock, the walls are likely either to be distorted, if they are composed of flexible material, or to be fissured into parallel plates if the material is rigid. In the latter case the sheets of rock will also arrange themselves on logarithmic curves.

If the intersection of a fault-fissure with the earth's surface is not a straight line, but is sinuous or broken, the secondary fissures will be parallel to the original one, and in the resulting surface each inflection of the trace of the fissure on the original surface concave toward the lower country will be represented on the faulted surface by a ravine, and each inflection convex towards the lower country will result on the faulted surface in a ridge. There is also a direct relation between the contours of the foot wall of such a fissure and the surface contours. If the original surface was a horizontal plane, the surface contours will be identical with the foot wall contours.

Application to the Comstock.—The theory, though worked out independently of the COMSTOCK, applies to it with much precision. Equations can be given representing very closely the surface line of a cross-section, the amount of the fault can be determined, etc. It can be shown that the erosion since the beginning of the fault is very slight, that the cañons of the range were produced by faulting, and have been only slightly modified by erosion, whence the correspondence of the contours of the foot wall with those of the surface. The east fissure is a result of the faulting, and the ore has been deposited since WASHOE became a region of insignificant rainfall. The sheeted structure of the country is, in all probability, due to the fault.

It is, of course, most unlikely that the COMSTOCK is the only vein in which the deposition of ore is recent and has been accompanied by faulting, and a repetition of a part of the conclusions as to the occurrence of veins in such cases may be welcome to some readers.

Application to other veins.—In a locality modified by faulting action, attended by horizontal pressure, the fact will appear in the parallelism of the exposed edges and faces of rock sheets. If erosion has not seriously modified the surface resulting from the faulting action, the logarithmic curve will be recognizable to the observer looking in the direction of the strike.

The main cropping of the vein is to be sought at the point of inflection of the curve, which will be found nearly or exactly midway between the top and bottom of the hillside. One or more secondary vein-croppings should be looked for below the main cropping, and these, so far as yield is concerned (but not in regard to location of claim), may prove even more important than the main fissure.

The dip of the vein will be to the same quarter as the slope of the surface, but, of course, greater in amount. The flatter the surface curve the smaller the angle of dip will be. The mean strike will be nearly or quite at right angles to the direction of the spurs and ravines of the faulted area.

If, besides the movement of one or the other wall in the azimuth of the dip, there has been a dislocation in the direction of the strike, chimneys will open, all of them on the same sides of the different ravines. Surface evidences will often enable the prospector to determine on which side the chimneys are to be found. On the barren sides evidences of crushing and of closure of the fissures are probable.

The fissure is more likely to have a constant dip (barring the secondary offshoots) than a constant strike, but, of course, irregularities of dip, like those in strike, will result in chambers which may be productive.

Offshoots into the hanging wall may occur at any depth, but none, except those near enough to the main cropping to reach the surface where it has a very considerable slope, are likely to be continuous.

Finally, it is shown that the law of land slips is also capable of expression by logarithmic equations, and that a large part of the details of the topography of grassy hills is formed in obedience to this law.

OCCURRENCE AND SUCCESSION OF ROCKS.

Succession.—The succession of rocks made out in the WASHOE DISTRICT is as follows: Granite, metamorphics, granular diorites, porphyritic diorites, metamorphic diorites, quartz-porphyry, earlier diabase, later diabase ("black dike"), earlier hornblende-andesite, augite-andesite, later hornblende-andesite, and basalt.

Granite and metamorphics.—Granite occurs on the surface only in a very limited area near the *Red Jacket* mine, but it is certain that it has a considerable underground development, for it has been struck at the *Baltimore*, the *Rock Island*, and by a tunnel to the southwest of the latter beyond the limits of the map.

The granite is overlaid by metamorphic rocks, which, however, are less metamorphosed close to it than at a distance from it, and the probabilities are that the sedimentary strata were laid down upon the massive rock. The sedimentary rocks are limestones, crystalline schists, and slate. They are badly broken and highly altered, and the search for fossils was not rewarded by success; but the general geology of this part of the Great Basin leaves little doubt that they are Mesozoic. A considerable area of metamorphics has been exposed in the southwest of the region by the erosion of the overlying eruptive masses. North and east of Silver City, however, the surface shows scarcely any metamorphics, while they play a large part in the underground occurrences as far as the *Yellow Jacket*. In the Gold Hill mines black slates form the foot wall of the LODE. They are intensely colored with graphite, and often very highly charged with pyrite. They are frequently mistaken for "black dike," but a moment's inspection in a good light shows their sedimentary origin. The presence of such carbonaceous rocks at greater depths would explain the formation of hydrogen sulphide. There is also an obscure occurrence of metamorphic limestones in the *Sierra Nevada* mine between granular and micaceous diorite. It appears to be conformable to the face of the granular diorite. The metamorphics in and about Gold Hill seem both to overlie and to underlie diorite, and there is little doubt that sedimentary strata were present at the period of the diorite eruption.

Between the metamorphics and the quartz-porphyry in the southwest portion of the area is a considerable extent of metamorphic diorite. In some occurrences this rock is a distinct breccia, and bears a strong resemblance to augite-andesites or basalts, while elsewhere it is extremely like Mount Davidson diorite. Besides the surface occurrences, it is found particularly well developed in the *Silver Hill* mine.

Diorites.—The principal exposure of diorites is on the west of the LODE through Virginia City, but there are several outlying occurrences about the *Forman* shaft, and again far to the east at the *Lady Bryan* mine, which show that the underground development of the rock is a very extensive one. It forms the foot wall of the LODE from the *Yellow Jacket* north. The diorite is excessively uneven in its composition, and in almost any area of a hundred feet square several modifications are to be found. This fact, taken in connection with the microstructure of the rock, is pretty conclusive evidence that it has never reached a higher degree of fluidity than the plastic state. The varieties can be roughly classified as granular diorite, porphyritic hornblendic diorite, and porphyritic micaceous diorite. But intermediate varieties are of constant occurrence. There seems, nevertheless, to be a certain amount of order in the disposition of the different varieties. Mount Davidson, from Bullion Ravine to Spanish Ravine, is almost altogether granular, but to the north and south of these limits porphyritic forms prevail. In the neighborhood of the *Utah* mine mica becomes the predominant ferromagnesian silicate, and this variety is also the one which occurs in the neighborhood of the *Forman* shaft. How this orderly disposition of the various diorites came about is a somewhat obscure question, as a possible answer to which an hypothesis is advanced.

Diabases.—The diabase appears but to a very trifling extent upon the surface, though it is by no means unlikely that an exposure of this rock occupied the position now covered by Virginia City. Underground it is extensively developed from the *Overman* to the *Sierra Nevada*, and from the LODE to the *Combination* shaft, as is seen in the cross-section on the *Sutro Tunnel* line, Atlas-sheet VI. Its great importance is due to the fact that all the important bodies of the COMSTOCK have been intimately associated with it, as are many of the other famous silver mines of the world. This diabase is of a rather unusual character, being more than commonly porphyritic, and containing comparatively little augite—a trifle less than twenty per cent. In appearance it is often not dissimilar to the andesites, but the resemblance does not extend to details. Almost the whole of this diabase is greatly decomposed, and has hitherto escaped recognition on that account.[1]

Between the east-country diabase and the west wall of the COMSTOCK occurs a thin dike, which has long been known as "black dike." It is only in the lower levels that fresh occurrences of this material have been met with. The "black dike" appears to be identical with the Mesozoic diabases of the Eastern States, from which it is scarcely distinguishable macroscopically, microscopically, or chemically. This younger diabase forms a remarkably thin and uniform dike, nowhere more than a few feet in thickness, extending from the *Savage* southward to the *Overman*, and then branching off to the southwest as far as the *Caledonia* shaft. This is the only dike known in the DISTRICT, excepting one of diorite in diorite, in spite of the prevalence of eruptive rocks. Its presence shows that the fissure on which the COMSTOCK LODE afterwards formed was first opened in pre-Tertiary times, and its uniform thickness indicates that its intrusion antedates any considerable dislocation on the contact. This inference receives strong confirmation from the evidence already adduced that the faulting is a comparatively recent phenomenon.

The occurrence of the two diabases also goes a long way toward demonstrating the nature of the fork in the vein, which has always been a mysterious point in the geology of the LODE. The prolongation of the "black dike" beyond Gold Hill is toward American Flat, whereas the older diabase extends in the direction of Silver City.

Andesites.—Much the larger part of the surface of the DISTRICT is occupied

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[1] Though diabase is the most important east-country rock, it by no means coincides in position either below ground or above with the rocks which have been regarded as propylite.

by andesites, of which there are three varieties distinguishable both lithologically and geologically. These are a younger and a later hornblende-andesite, the latter of which has hitherto been considered a trachyte, and an augite-andesite intermediate in age. The older hornblende-andesite has in part long been recognized as such, and is deceptive only when highly decomposed. It occupies a belt immediately east of the older diabase (see Atlas-sheet VII.), a large area on the heights immediately west of the diorites, and a considerable area at and north of Silver City. The latter occurrence is noteworthy for the unusual size of the hornblendes, which are sometimes several inches in length. The augite-andesite occupies a second belt of country east of the LODE and beyond the earlier hornblende-andesite, and is also extensively developed to the north and south of the diorite. The *Forman* shaft penetrates 1,200 feet of this rock before passing into the hornblende-andesite.

The reasons are given elsewhere for considering the rock heretofore regarded as trachyte to be an andesite. Its roughness and softness, its red and purple colors and large glassy feldspars made the mistake an easy one. The Flowery Range, the Sugar Loaf, Mount Emma, and Mount Rose, are all of this rock, which also occurs in two little patches close to the *Sierra Nevada* mine. These latter have been cut off from the quarry above the *Utah* by the erosion of Seven-Mile Cañon. The patches of rock near the *Combination* shaft and the new *Yellow Jacket* which have sometimes been regarded as trachyte are merely decomposed older hornblende-andesite.

Basalt.—The occurrence of basalt is exceedingly limited, and is confined within the area of the map to two small localities, one at Silver City and the other a mile west of it. It is a fine, fresh, and typical rock.

Area of decomposition.—The area of most profound decomposition is shown as nearly as may be on the sketch map, Fig. 1. The amount of decomposition increases with depth. The period at which it was produced is almost certainly the same as that of the faulting action and the deposition of ore. It cannot have been earlier than the eruption of the later hornblende-andesite, and was more probably posterior to it. There is no indication of a connection between the basalt eruption and the solfataric action, and it is not improbable that the latter, though of volcanic origin, was independent of any eruption of lava.

CHEMISTRY.

The chemical history of the Comstock is no doubt a very complex one, nor are there by any means sufficient data to trace it in detail. All that can be attempted here is to show that the results observed might naturally follow from highly probable causes.

The decomposition of the rocks shows three important features—the formation of pyrite from the bisilicates and mica, the decomposition of the ferro-magnesian silicates into chlorite, which is in part further altered to epidote, and a partial change of the feldspar.

Decomposition of the Fe.-Mg. silicates.—The pyrite appears to have formed at the expense of the bisilicates or mica. The really fresh rocks contain no pyrite, but minute crystals often occur in or are attached to partially decomposed bisilicates. Sometimes distinct pseudomorphs of pyrite after augite or hornblende are visible, but this is not common, because the average size of the pyrite crystals is about one-half that of their hosts. A macroscopical comparison, too, of series of rocks increasingly decomposed shows that the pyrite is apparently associated with the ferro-magnesian silicates, and in extreme cases replaces them with an entire correspondence of distribution, so that the cumulative evidence is all in one direction. It is well known that ferrous silicates in contact with waters charged with hydrogen sulphide produce pyrite.

The transformation of the bisilicates and mica to chlorite is a familiar fact, and the general character of the change is not obscure, though its details are far from clear. It must be accompanied by a separation of all the lime, and of much of the silica and magnesia. It probably took place for the most part in the absence of free oxygen.

Epidote is very common on the surface, while under ground it seems rare and confined to the neighborhood of fissures. The conversion of chlorite to epidote must be accompanied by a substitution of lime for magnesia, and by the conversion of ferrous to ferric oxide It might very readily occur in the presence of solutions containing carbonic acid and free oxygen, or when surface waters mingled with waters rising from lower levels, for epidote is far less soluble than chlorite, and under these circumstances would form in obedience to the general law of precipitation. Its occurrence is usually compatible with this supposition, but it is not so decisive as to warrant a positive assertion that the conditions of its formation are those indicated.

Decomposition of feldspars.—The triclinic feldspars of the WASHOE DISTRICT retain their optical properties in a recognizable form much longer than the ferro-magnesian silicates. Among the mine rocks it is very rarely that bisilicates or mica occur undecomposed, but it is the exception when a slide of a tolerably hard rock does not show recognizable feldspars. When the feldspars are altered they are replaced by an aggregate of polarizing grains, which appear to be quartz and calcite with some opaque particles, but with no transparent amorphous material. Kaolin could hardly be present in large quantities without being recognized microscopically. The analyses of the clays, too, show that when allowance is made for the presence of hydrous chlorite there is not enough water to correspond to any large percentage of kaolin. In fact the analyses of the clays so exactly correspond to the composition of the firm rocks that the great masses of clay evidently represent only equal volumes of disintegrated rock. On the whole, therefore, it appears improbable that there has been any great amount of kaolinization in the WASHOE DISTRICT.

Lateral-secretion theory.—As is well known, Prof. F. Sandberger has very ably maintained what is known as the lateral-secretion theory of ore deposits. With a view to testing the probabilities of this theory, with reference to the COMSTOCK, the rocks of the DISTRICT have been assayed with all possible precaution. The principal rocks containing precious metals were also separated by Thoulet's method, and the precious metals traced to their mineralogical source. The results of this investigation show many interesting facts, among which are the following: The diabase shows a noteworthy contents in the precious metals, most of which is found in the augite; the decomposed diabase contains about half as much of these metals as the fresh rock; the relative quantities of gold and silver in the fresh and decomposed diabase correspond fairly well with the known composition of the COMSTOCK bullion; and the quantity of precious metals which has been leached out of the diabase is comparable with that which the Lode must have contained at its discovery. There are also relations between the inclosing rocks and the ore deposits not found in contact with diabase.

The gangue of the Comstock is almost exclusively quartz, though calcite also occurs in limited areas. The ore minerals elude investigation for the most part because they are so finely disseminated as merely to stain the quartz, but it is fairly certain that they are principally argentite, and native silver and gold, accompanied in some cases by sulph-antimonides, etc. The chloride has rarely been identified. Where ore is found in diorite, or in contact with it, it is usually of low grade, and its value is chiefly in gold. The notably productive ore bodies have been found in contact with diabase, and they have yielded by weight about twenty times as much silver as gold.

Reagents.—It would perhaps be legitimate to infer from the chemical phenomena enumerated and the association of minerals that waters charged with carbonic acid and hydrogen sulphide had played a considerable part on the Comstock. This is not, however, a mere inference, for an advance boring on the 3,000-foot level of the *Yellow Jacket* struck a powerful stream of water at 3,080 feet (in the west country), which was heavily charged with hydrogen sulphide and had a temperature of 170° F, and there is equal evidence of the presence of carbonic acid in the water of the lower levels. A spring on the 2,700-foot level of the *Yellow Jacket*, which showed a temperature of above 150° F., was found to be depositing a sinter largely composed of carbonates.

Baron v. Richthofen was of opinion that fluorine and chlorine had played a large part in the ore deposition on the Comstock, and that this is possible cannot be denied; but, on the other hand, it is plain that most of the phenomena are sufficiently accounted for on the supposition that the agents have been merely solutions of carbonic and hydrosulphuric acids. These reagents will attack the bisilicates and feldspars. The result would be carbonates and sulphides of metals, earths and alkalies, and free quartz; but quartz and the sulphides of the metals are soluble in solutions of carbonates and sulphides of the earths and alkalies, and the essential constituents of the ore might, therefore, readily be conveyed to openings in the vein, where they would have been deposited on relief of pressure and diminution of temperature. It is by no means unlikely that, as at Steamboat Springs, evaporation aided in inducing precipitation

Substitution.—It has been claimed that the ore and quartz have been deposited by substitution for masses of country rock. This hypothesis is exceedingly doubtful on chemical grounds, but there is also at least one insuperable physical objection to it. In all processes involving the solution of angular bodies it is a matter of common observation that points and corners, which expose a greater surface than planes, are first attacked; consequently masses exposed to solution, substitution, weathering, and the like, always tend to spheroidal forms. Now, nothing is more common than to find masses of country rock included in the ore-bearing quartz. These masses, in all cases which have come under my observation, are angular fragments, in form precisely such as result from a fresh fracture; not a single instance has been observed in which a spheroidal rock was surrounded by more and more polyhedral concentric shells of quartz and ore.

HEAT PHENOMENA OF THE LODE.

High temperatures met.—One of the famous peculiarities of the COMSTOCK LODE is the abnormally high temperature which prevails in and near it. This manifested itself in the upper levels, and has increased with the depth. The present workings are intensely hot. The water which flooded the lower levels of the Gold Hill mines during the winter of 1880–1881 had a temperature of 170° F. This water will cook food, and will destroy the human epidermis, so that a partial immersion in it is certain death. The air in the lower levels more or less nearly approaches the temperature of the water according to the amount of ventilation. The rapidity of the ventilation attained in the mines is something unknown elsewhere, yet deaths in ventilated workings from heat alone are common, and there are drifts which, without ventilation, the most seasoned miner cannot enter for a moment. Except where circulation of air is most rapid, and in localities not far removed from downcast shafts, the air is very nearly saturated with moisture. It is a serious question how far down it will be possible to push the mines in spite of the terrific heat.

The origin of the high temperature of the COMSTOCK has been sought in the kaolinization of the feldspar contained in the country rock and in residual volcanic activity.[1]

Kaolinization hypothesis.—The theory that kaolinization is the cause of the heat appears to rest upon two positive grounds—that the solidification of water liberates heat, and that flooded drifts have been observed to grow hotter. It is also claimed in favor of the kaolinization hypothesis by its author that there is no evidence of any other chemical action proceeding with sufficient activity to afford an explanation, and that the retention of igneous heat in the rocks is a sheer impossibility, while the hypothesis that the heat is conveyed from some deep-seated source to the mines by means of currents of heated water is characterized as somewhat violent and as unnecessary.

So far as I am aware, there are no theoretical grounds upon which the heat involved in kaolinization can be estimated. The decomposition of feldspar into kaolin and other products (supposing kaolin to result from the decomposition of plagioclase) involves several processes, of which some are more likely to absorb than to liberate heat. But supposing an anhydrous aluminium silicate formed without loss of heat, the thermal results of its combination with water are by no means certain. Were the water contained in kaolin not water of hydration, but chemically combined, it would be possible from known experiments to compute approximately the heat which would be produced. It is shown in Chapter VII. that the corresponding temperature would be so high as to be utterly at variance with known facts. The water is therefore the water of hydration. Of the heat involved in the hydration of salts we know that it is usually small, that it is sometimes negative, and that the different molecules of water combine with differing amounts of energy, but of the heat of hydration of kaolin we know nothing.

With a view to testing the theory of kaolinization as far as possible, Dr. Barus, at my request, undertook some very delicate experiments

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[1] Friction and the oxidation of pyrite have also been suggested, but have not been seriously advocated.

presently to be described. The result of these experiments, in a word, was that finely divided, almost fresh east-country diabase, exposed to the temperature of boiling water and the action of saturated aqueous vapor for a week at a time, and for several weeks in succession, showed no rise of temperature perceptible with an apparatus delicate to the $\frac{1}{1000}$ of a degree C.

It is by no means certain that kaolinization was effected by these experiments. The particles of rock were indeed coated with a white powdery substance, but this was probably the residuum of the evaporated water. It is still possible that, when kaolinization occurs, heat is liberated. It is also possible that at temperatures above the boiling point and pressures greatly exceeding 760^{mm}, feldspars are kaolinized, but it appears no longer reasonable to ascribe the heating of drifts, which are at nearly normal pressure, to the reaction on the rocks of water below the boiling point. The scene of active and heat-producing kaolinization, if it exists at all, must, therefore, be at remote depths. As was explained in a previous paragraph, the present examination has not resulted in tracing any considerable amount of kaolinization on the COMSTOCK; while, had the heat of the LODE been maintained ever since its formation at the expense of the feldspars, but little undecomposed feldspar could now remain. In short, while it cannot be demonstrated that the heat of the COMSTOCK is not due to the prevalence, at unknown depths and pressures, of a chemical change of unknown thermal relations, I have failed to find any proof that it is due to kaolinization.

Solfataric action.—Of the origin of the heat of solfataras not very much is known; yet, as they commonly occur either as an accompaniment of volcanic activity, or in regions characterized by the strongest evidences of past volcanic activity, it is usual and seems rational to connect them as cause and effect, or as different effects of a common cause. There seems to be no special opportunity on the COMSTOCK for an elucidation of the whole theory of vulcanism, but considerable grounds for connecting the heat there manifested with that chain of phenomena.

That solfataric action, as commonly understood, once existed on the COMSTOCK is certain. That the time at which the LODE was charged with ore is not immeasurably removed from the present, seems to be demonstrated by the trifling character of the erosion which has since taken place. The water entering at the bottom of the new *Yellow Jacket* shaft in the winter of 1880–'81, at a temperature of 170° F., was highly charged with hydrogen sulphide. The Steamboat Springs, only a few miles west of the COMSTOCK, lie in a north and south line like the COMSTOCK, close to the contact of ancient massive rocks and andesites. Some of them are boiling hot, are charged with solfataric gases, and are now depositing cinnabar and silica as at the time of Mr. Phillips's visit many years ago. There is much evidence in the structure of the country and in the relations of the fresh rocks to the decomposed masses that alteration was effected by rising waters, and the chemical changes traced are such as could have been effected only by vast quantities of soluble sulphides and carbonic acid, which could hardly have been produced on the necessary scale except by the aid of heat. A deep-seated source of heat, therefore, probably gave rise to the decomposition, and the conditions point to vulcanism as its source.

Source of the waters.—The flood of waters still requires explanation, and an hypothesis is suggested to account for it. No meteorological station exists at Virginia City, but the rainfall is so small that the country is a sage-brush desert, and the precipitation is insufficient to account for the water met with on the LODE. The main influx of water, and especially of hot water, is from the west wall, and when encountered it is found under a head often of several hundred feet. Between the COMSTOCK and the main range of the Sierra Nevada, the whole country is covered by massive rocks, principally andesites, with occasional croppings of granite. The general structure of the country, and the exposures of sedimentary rocks in the mines, lead to the supposition that the underlying strata dip eastward, and the inference is that the COMSTOCK fissure taps water-ways leading from the crests of the great range. If the heat is conveyed to the LODE by waters from great depths, the variations in temperature are readily explained. The distribution of the heated waters would be determined by the presence of cracks, fissures, and clay-seams, and the uniformity of distribution of heat would further be disturbed, even at considerable distances from the surface, by the infiltration of surface water. One published observation, which is important in this connection, is that a large proportion of the rocks in the Vir ginia mines are dry. This is very true in the sense in which "dry" is used in mining, *i. e.*, there are many places where water does not drip from the walls, but the present examination has failed to reveal rocks which are not moist; indeed, the occurrence of really desiccated rock thousands of feet below the surface, near vast quantities of water, would disprove the generalization of the perviousness of rocks, which is one of the best established in geology. Unless, therefore, very strong proof to the contrary can be adduced, the conduction of heat on the COMSTOCK must be considered as taking place in moist rock.

Discussion of the thermometric observations.—The relation of the temperature to the depth from the surface is evidently one of great interest, but not entirely simple. If the rock were wholly uniform in character and unfissured, the relation of temperature to depth would be wholly regular and would be represented by a curvilinear locus. As the source of the heat was approached the rate at which the temperature rose would rapidly increase, and under the ideal conditions supposed, it would be possible to deduce the constants of the equation and to calculate the position of the source of heat. But unless the source of heat were so close to the surface that the errors introduced by the presence of fissures, the lack of homogeneity of the rock, and the percolation of surface water were insignificant in comparison with the rate of increase of the temperature, such a calculation would not be possible. A careful record of temperatures has been kept at three of the newer shafts to a depth of above 2,000 feet. On plotting these temperatures as ordinates and the depths as abscissæ no indication of regular curvature appears, being wholly obscured by the fluctuations due to the disturbing causes mentioned. In other words, there is as yet nothing in the observations to show any but local divergences from a strict proportionality between depth and temperature. The source of heat must, consequently, lie at a very great distance from the surface as compared with the depth yet reached, and the curve is to be regarded as still sensibly coincident with its tangent.

In order to eliminate the fluctuations of temperature as far as possible Mr. Reade and Dr. Barus have computed the observations made at the *Forman*, *Combination*, and new *Yellow Jacket* shafts by the method of least squares, and also, for comparison with them, the observations of Mr. J. A. Phillips at the Rose Bridge Colliery.

Chapter VII. contains the details for these localities and for the famous deep boring at Sperenberg, near Berlin. Here it is sufficient to state that on the COMSTOCK the temperature of the rock rises about 3° F. for every additional depth of 100 feet, or about twice as fast as in ordinary localities; and that boiling water will probably reach the workings at some point not long after the 4,000-foot level is passed.

Observations have also been made in the *Sutro Tunnel*, and these when plotted give a very remarkable result, for the curve shows that the temperature rises in a geometric ratio as the LODE is approached. This is capable of no other explanation than that the east country is heated from a plane in the immediate neighborhood of the LODE. Combined with the results obtained from the shafts this curve, without any reference to geological reasoning, indicates that the source of heat is at a vast depth compared with that of the mines, and that the heat is communicated upward along or near the fissure, and thence to the country rock by conduction.

THE LODE.

General character of the vein.—The condition of the LODE during the period in which the field work for this report was done was not what could have been wished, for almost the only ore in sight was the remnants of the great bonanza of the *Consolidated Virginia* and the *California*, and the accessible exposures of the vein were meager and unsatisfactory. The study of the COMSTOCK was thus necessarily directed to the conditions of its occurrence rather than to details of vein structure.

A glance at the surface map shows that the LODE is a long and wide belt of vein-matter ramifying at each end into divergent branches,[1] and the cross-section exhibits a remarkably regular foot wall dipping to the east at an

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[1] The scale of the surface map is not large enough to permit all of the minor fluctuations of the walls to be shown, nor are the mine maps sufficiently complete to furnish data for a full exhibition of these irregularities on a larger scale. For more detail the reader is referred to Mr. King's section on the 331-foot level of the Virginia mines.

angle of from 33° to 45°. Near the top, in most of the sections, one or more secondary fissures diverge from the main LODE and penetrate the east wall, thus cutting off a body of country rock, or "horse," which is approximately triangular in cross-section. This horse is of variable vertical and horizontal dimensions, and often divided by sheets of clay or quartz. Below the horse the vein is for the most part narrow.

The walls.—The hanging wall of the LODE between the points at which it branches is older diabase, which also extends some distance on the southeast branch towards the *Justice*, and towards the *Scorpion* on the northeast branch. Its limits in the latter direction are unknown. Almost all of this diabase is in an advanced stage of decomposition. The foot wall of the main fissure is granular diorite, except in Gold Hill, where this rock is replaced by metamorphic slates, and is much less decomposed than the hanging wall. The northern and southern branches of the vein pass through or along the contacts of various older rocks. The black dike or younger diabase appears in the *Savage* and *Hale & Norcross*, but not to the north of these mines, and has been followed on or near the foot wall to the fork at the *Overman*, and thence in a southwesterly direction toward American Flat. It is the behavior of the two diabases which has given rise to this fork, the older diabase forming the hanging wall of the easterly branch for some distance from its origin, while the narrow dike of the younger variety marks the course of the westerly vein. To the north also there are indications that the direction of the branches was predetermined; the northeasterly one by the contact between diabase and diorite, and that which has been explored in the *Sierra Nevada* and *Utah* mines by the presence of metamorphic rocks and some intrusive stringers of diabase.

Contents of the vein.—The contents of the vein is simple on the whole. Besides fragments of country rock, practically the only gangue which it contains is quartz; though calcite occurs in insignificant quantities in the main LODE, and is the prevalent mineral in the *Justice*. The principal ore is argentite, accompanied by gold, probably in a free state, though sulphur salts occasionally form rich stringers and pockets. The distribution of ore is very variable. That associated with the diorite carries a little gold and almost no silver, while that associated with diabase is regarded as a silver ore, though nearly half its value is usually in gold. The proportion of the two metals varies greatly in different portions of the LODE and even in the same ore body. It is probable that the COMSTOCK contains but little quartz which is wholly barren; while, as is usual in silver veins, it is only in certain spots that the tenor reaches a point at which extraction is profitable. These concentrations, or "bonanzas," usually occur in masses of quartz of lower grade, and large bodies of quartz usually contain "bonanzas" when they are associated with the diabase, though to this rule there are exceptions. The *Justice* bonanza is the only one of any moment which is not associated with that rock. The quartz is in great part in a highly crushed condition, resembling nothing so much as ordinary commercial salt. When the fine dust from such masses is examined under the microscope in polarized light, it is immediately seen to consist of fragments of quartz crystals; the larger particles can be shown to have the same origin by direct examination. Very solid quartz bodies are also met with in certain positions.

Crushing action.—The presence of faults on the COMSTOCK is abundantly proved, as has already been shown. The secondary fissures form one evidence of such a movement, and as a large portion of the ore occupies the openings between the great horse and the east country, it is plain that the deposition of ore was preceded by faulting. The only movement which can have crushed the quartz must also have been in the nature of a fault, and some of the bonanzas show a parallelism in the lines of dynamical action to the dip of the LODE. It is not probable that the solid masses of quartz were formed at a later date than those now found in a crushed condition, for it appears to be only when the quartz has been deposited in sheets parallel to the west wall that it has escaped comminution. Certain stringers of rich ore in the bonanzas have seemed to possess great solidity, and may possibly have been formed after the final cessation of movement; otherwise the entire period of quartz deposition seems to have been embraced by that of the faulting movement. It is much more probable that the total fault was accomplished by a great number of small slips in the same sense than that one large throw preceded and another followed the filling of the vein.

Clays.—The clays of the COMSTOCK are not largely composed of kaolin, but represent sheets of rock triturated and decomposed without any great translocation of material. This fact is determined chemically, but confirmed by the relation of the clays to the faulted structure; for while they are excessively abundant in and near the secondary fissure where the influence of the surface interfered with the development of the regular system of fissures found in the lower levels, they are comparatively rare and thin below the bottom of the great horse.

Infrequency of lenticular openings.—The sections show that the lower portions of the LODE, considering its enormous scale, are narrow and remarkable for the absence of the lenticular openings which frequently characterize faulted veins. If the hypothesis developed under the head of the structural results of faulting is correct, this peculiarity is almost a necessary consequence of the conditions under which the COMSTOCK formed, for the slip of the actual walls of the vein is on that theory only the relative movement of two successive sheets, and if these are assumed to be twenty-five feet thick, it would not amount to above a hundred feet. The intensity of the faulting action was less toward the ends of the LODE than near the middle, the force being distributed over a wide area by the branching, and probably also to some extent by numerous east-and-west fractures, singly of small extent. The south end of the main LODE seems to have been less forcibly faulted than the north end This is partly ascribable to the character of the foot wall, stratified rocks being less rigid than massive ones, and partly to the fact that the dip is about 10° less

Character of the spaces occupied by bonanzas.—The evidence appears conclusive that the ore bodies occupy spaces which once inclosed only fragments of country rock, with numerous interstices. These openings seem to have been due to faulting action variously modified by local circumstances In the *Consolidated Virginia* and neighboring mines a projecting mass upon the foot wall gave rise to a local rent in the diabase. In the Virginia group an irregularity in the dip of the foot wall prevented the broken edge of east country, the great horse, from following the main body to its final position; and a crescent-shaped opening resulted which furnished an opportunity for the deposition of an extensive system of bonanzas. In Gold Hill, on the other hand, the opening appears to be a result of non-conformity of the wall surfaces brought into opposition.

Lateral secretion.—The course of the ascending waters appears to have been much influenced by the narrowness of the vein in the lower levels. It is highly probable that on some straight or sinuous line, at depths greatly exceeding those yet reached, the vein is closed nearly water-tight from one end to the other. If so, water ascending in vast quantities, as it must once have done, would be forced into the network of capillary fissures which pervades the east country. Having become saturated with soluble substances by contact with the immense surface here exposed to its action, it would seek the main fissure once more as the path of least resistance, and there deposit quartz and ore through changes in physical conditions, or in virtue of chemical reactions. It is not unlikely that concentration by evaporation was an important influence in accelerating precipitation. The character of the deposited quartz evidently varied greatly from time to time, but though the causes were probably very simple in their general nature, the conditions under which they acted, considered in detail, must have been exceedingly complicated. On the whole, the later deposits were probably the richer, and it is not impossible that a part of the rich pockets and stringers was formed at the expense of older deposits of lower grade.

The east wall of the LODE is in most places very indistinct, though occasionally, as at the *Savage* connection with the *Sutro Tunnel*, nothing could be clearer. This is due in part to the percolation of strong currents from the east country during the deposition of ore, and partly to dynamical action on irregular deposits crossing the lines of motion.

Probabilities for lower depths.—The COMSTOCK is essentially a deposit at the contact of diabase with underlying rocks, and so long as the hanging wall shows a heavy body of diabase the prospects for ore are good, mere depth not being likely to exert any prejudicial effect upon the ore-bearing character of the vein. In the search for ores explorations should be confined to a moderate distance from the diabase contact, for no important bonanza except the *Justice* body has been found which does not extend to within a very short distance from this contact; nor are any bodies likely to occur far from it which will pay the expense of discovery. The first condition for the formation of a quartz body is an opening to receive it. The group of mines worked through the *Union* shaft and the *Jacket, Crown Point*, and *Belcher* mines show peculiarities of structure which point to the likelihood of such openings at lower levels. Openings such as that which contained the *Consolidated Virginia* and *California* bonanza, however, give almost no warning of their approach from above, and may at any time be struck in the intermediate mines; but a series of bodies nearly on one level, such as were found in the secondary fissure (the "Virginia vein") is not likely to recur.

THE THERMAL EFFECT OF KAOLINIZATION.

Kaolinization hypothesis.—The view that the heat of the COMSTOCK is due to the kaolinization of feldspar is new and ingenious, but purely speculative, for there is no unquestionable, direct evidence in support of it; while the process is so complicated and so little understood that there is abundant room for difference of opinion in any discussion of the theory involved. Dr. Barus contrived and executed experiments to test the assertion that a rise of temperature followed the action of heated waters from the east-country rock of the COMSTOCK. These experiments he has described and discussed in Chapter IX.

The thermal effect of kaolinization may be defined as the quantity of heat generated by the action of the aqueous vapor on the unit mass of the given feldspathic rock in the unit of time. It is to be regarded as a function of the percentage quantity of feldspar originally contained in the given rock, and of the temperature of this material, as well as of the time during which the action has been going on. *A priori* the thermal effect may be either positive, negative, or zero. The experiments were undertaken to ascertain in how far the fundamental principle of the kaolinization hypothesis, namely, that the thermal effect is positive, agreed with facts. Such a research was also desirable because of the intrinsic interest which attaches to the question.

Considered from a physical point of view, the question is rather a difficult one, and of a kind in which satisfactory results can be reached only by a laborious process of gradual approximation. As even in final experiments the thermal effect may escape detection, the purpose of the first experiments may be said to consist in reducing the positive and negative limits within which this effect must lie to the smallest possible interval.

Character of the experiments.—In processes such as kaolinization, action may usually be accelerated by an increase of temperature, provided that the latter is not sufficient to render the products unstable in a normal case. In the experiments it would have been desirable to act upon the rock with steam at a temperature from the boiling point of water upward, but with the primitive facilities available in Nevada, the use of superheated steam was not practicable.

The apparatus in which the rock was subjected to the action of steam closely resembles that usually employed for the determination of the boiling point of thermometers. The rock to be acted upon was crushed fine and packed into a cylindrical receptacle open at the top, and provided with a wire-gauze bottom. This was supported in the steam space of a boiler provided with an external packing. The object of the arrangement was to allow the heat, possibly generated in the mass of rock by the process of kaolinization, to accumulate.

Measurements of temperature.—The difference of temperature between the interior of the rock and the steam surrounding it was determined by the aid of a thermopile consisting of three bismuth-platinum couples, one junction being placed at the center of the pulverized rock, and the other in the steam-jacket surrounding the rock receptacle. The electromotive force was measured by a method of compensation. The constants of the apparatus were frequently rechecked, and divers precautions were observed in the experimentation, and in the mathematical treatment of the measurements, as is explained in Chapter IX. The means employed enabled the observer to detect a variation in the difference of temperature between the two ends of the thermopile as small as 0.001° C.

Details of apparatus and method.—The boiler was heated by two kerosene stoves, each containing two broad wicks. The oil could be replenished without interfering to an appreciable extent with the flames. The water lost by evaporation was replaced drop by drop by means of a simple device, and a glass water-gauge indicated the progress of evaporation. The whole aim was to make the process a continuous one, and, had it not been for accidents, a nearly constant source of heat and a nearly constant water-level would have made it possible to keep up an ebullition of nearly constant intensity for an indefinite period of time.

The rock used was earlier diabase from the hanging wall of the LODE collected in the main *Sutro Tunnel.* It had undergone only a trifling amount of decomposition.

The experiments were continued during a period of nearly five weeks, unfortunately with an accident between the first and second, and another between the second and third. On the average, three observations of the difference of temperature of the ends of the thermopile, or, say, $T-t$, were made during each twenty-four hours.

Mathematical treatment and results.—In order to obtain a comprehensive view of the large number of data obtained it will be sufficient to assume the empirical relation,

$$T-t=\alpha+\beta\chi,$$

where α and β are constants to be calculated by the method of least squares, χ the time in hours corresponding to any particular $T-t$, and dated from the commencement of the series of experiments to which the results belong. Under variation of α, an apparent thermal effect not due to kaolinization may be conveniently understood.

For α a mean value of —0.05° C. was found. The interior of the rock was, therefore, invariably *colder* than the surrounding steam It follows, also, that it is impossible, even after the lapse of a great interval of time, to heat so large a mass of material to an equal temperature throughout. The variation of α will add itself algebraically to β; and unless the thermal effect of kaolinization is comparatively large, will entirely vitiate the significance of the latter constant. β gives nominally the rate of increase of the temperature of the interior of the rock per hour in consequence of a thermal effect. Instead of reporting β, however, it is more expedient to give the corresponding rate B referred to a year as the unit, viz.:

$$B=8{,}765\,\beta$$

For reasons which appear in Chapter IX. the experimental data may be conveniently divided into two portions. In the first of these it was found that

$$B = +1^\circ.5 \pm 0^\circ.1;$$

in the second

$$B = -0^\circ.9 \pm 0^\circ.1.$$

Hence it appears that the variation of α alone was observed. The values of B are to be regarded as an index of the errors incident to the method in its present form, and it is moreover probable that the effect of kaolinization is negligible in comparison.

THE ELECTRICAL ACTIVITY OF ORE BODIES.

Preliminary statement.—It is well known that Fox, Reich, and others made experiments of great interest upon the electrical phenomena of ore bodies. Bernhard von Cotta earnestly recommended that these experiments should be further pursued, as they seemed to him likely to lead to results of practical importance in the discovery of ore bodies. If this recommendation has ever been followed out, no account of the investigation has been published. It was my earnest desire to see the subject pursued, and Dr. Barus was invited to join the Survey on account of his special fitness for this inquiry. All the plans and details of the electrical surveys made are due to Dr. Barus, the general scope of the work and the localities only being prescribed; and a résumé of his results is given below. Neither of the localities chosen was the best possible for the purpose. It was evidently necessary in such an inquiry to begin by the examination of ore bodies already exposed. At the date of the examination there was very little ore in sight on the Comstock. At Eureka large bodies of ore were exposed, but being in an oxidized condition would be likely to give weaker currents than sulphides of similar quantity and distribution. These two localities, however, were the only ones practically available, and at the same time accessible through extensive workings. The results are nevertheless of great interest, and a considerable advance has been made towards a solution. It is one of the plans for the future to repeat these experiments under more favorable conditions. The following summary is in Dr. Barus's own words:

Nature of the problem.—The problem offered is not apparently a difficult one, and consists simply in determining the variation of earth-potential at as many points as may be desirable within and in the vicinity of the ore body; or, in other words, in tracing the contour and position of the equipotential surfaces.

It is practicable, however, to systematize the method of research, *a priori*. In the first place, Reich's hypothesis that lode-currents, if present, are due to hydro-electric action is quite a safe and natural one. It is known that a number of ores—especially sulphides—possess metallic properties. The presence of two or more of these in the same ore body is not an uncommon occurrence, and electric action at their surfaces of contact may fairly be anticipated. The currents thus generated have a very close analogy to those technically known as "local currents" in batteries, which are due to impurities in the zinc. In the second place, it is obvious that if currents are met with in a region of ore deposits, such currents must be constant, both in intensity and direction, because electrical action has been going on for an indefinite period of time. The equipotentials corresponding to this flow will, therefore, have fixed and definable positions relatively to the ore body.

Suppose, now, that from a point remote from the ore body a line has been drawn towards it and prolonged beyond to about the same distance. It is not necessary for the present purposes that this line should actually pierce the deposit; but only that certain of its parts should be sufficiently near ore, and more so than its extreme points, and that it should lie wholly within or entirely upon the surface of the earth. Suppose, moreover, that the ores are so associated as to generate electrical currents.

If, then, beginning at one end of the line the values of earth-potential are determined at consecutive, approximately equidistant points, it is obvious, inasmuch as the line passes by the seat of an electromotive force, or, in other words, through the field of sensible electrical action, that progress from one extremity of the line to the other must be accompanied by a passage of the corresponding values of earth-potential, through a maximum or minimum, or both, or a number of such characteristic variations. In short, the earth-potential at any point may be regarded as a function of the distance of this point from the assumed origin of the line. The assertion that this function will pass through a characteristic change of the kind specified is only another way of stating that the line may be chosen so long that, in comparison with its extent, the field of sensible electrical action will be local, or its linear dimensions in the direction in question small. Maxima in a general sense are, therefore, to be regarded as criteria, and as indicating the part of the line nearest to the electrically active ore body.

Practically, since we possess no means of measuring potential absolutely, it is sufficient to assume a value (zero) for one of the points of the series. The electromotive force between this and any of the other points is then the potential of the latter.

Methods employed.—In making the actual measurements, the simple problem above enunciated became quite complicated, because the small lode electromotive forces were affected by a number of errors, which, in the aggregate, might possibly produce an effect in the same order. On the COMSTOCK, where the mine workings were, without exception, in very barren or nearly exhausted parts of the vein, no definite evidence of currents due to the LODE itself was obtained. Even at Eureka, in spite of the enormous ore bodies in sight, the range of variation of potential corresponding to a distance of 2,000 feet in the underground experiments very rarely reached 0.1 volt; while usually this variation lay within a few hundredths of a volt. These limits, in a case where such disturbances exist as action between terminals, polarization, earth currents (normal), bad insulation of circuit at any point, difference of potential between liquids in contact, incidental effects due to masses of metal distributed throughout the mine, etc., are to be considered as comprehending a rather dangerously small interval. This small variation of potential is to be attributed to the earthy character of the Eureka ores. For the manner in which the effects of the disturbances were to a large extent eliminated, the reader must be referred to Chapter X.

Of the different surveys made, the one on the 600-foot level of the Richmond mine, west drift, presents the greatest interest, because it was here that all the precautions necessary could be satisfactorily applied. The line of survey, moreover, lay completely outside of the ore body, and all the points tapped were in rock essentially of the same kind. The measurements were made in various galvanometric ways, and the results were subsequently checked by a "zero" method. It was found that the distribution of potential along the length of the drift, even after an interval of four months, had not materially changed, and that, on passing from barren rock towards and across the ore body, small though decided variations of potential were encountered in its vicinity.

Results.—The electrical effects observed were too distinctly pronounced to be referable to an aggregate of incidental errors, and they were of the character which must have been produced had the ore bodies been the seat of an electromotive force. The experiments made cannot be said to have settled the question as to whether lode currents will or will not be of practical assistance to the prospector. Indeed, as yet it cannot even be asserted with full assurance that the currents obtained are due to the ore bodies. What has been observed is simply a local electrical effect sufficiently coincident with the ore body to afford in itself fair grounds for the assumption that these contained the cause. Giving the investigations of Fox and Reich proper weight, however, the supposition that the currents in the Richmond mine were not due to the ore bodies is extremely improbable. But, unfortunately, they are so weak as to require an almost impracticable delicacy in the researches designed to detect and estimate them. It is highly probable that under certain circumstances more powerful currents are generated than those found at Eureka. It is not unlikely, for example, that galena, cinnabar, and the copper sulpho-salts produce electrical effects of far greater magnitude, and that the method might be readily available for the discovery of such ores. The results thus give much encouragement to further investigations in this direction.

Method proposed.—In the experiments thus far made, the variation of potential along a single line of electric survey only has been determined. It is obvious, however, that in order to derive the full benefits from such a method a number of these surveys must be coördinated. An endeavor should be made, by passing toward and from the ore body in all directions, actually to determine the contours and positions of the equipotential surfaces. It is not improbable that the interpretation of the results would furnish clews for the economical exploitation of mines, comparable in value to those of a purely geological character. Both should go hand in hand. Under ground, this general method of research is not always feasible, as it presupposes that the mine has been already widely exploited. On the surface of the earth, however, it may to some extent be applied; and in this case the endeavor would be to obtain the traces of the equipotential surfaces on that of the earth. Suppose, for instance, that the potential at every point in several square miles of the earth's surface were known. Then let this surface be projected on a fixed horizontal ("XY") plane, and the value of earth-potential corresponding to each of the points be constructed as "Z." In this way a new (potential) surface would be obtained coëxtensive horizontally with the former. Terrestrial electrical action would manifest itself upon the new surface as a whole and would not affect its regularity. Local action, on the other hand, would produce an effect circumscribed in comparison with the horizontal extent of the area under consideration. We should expect to find a hillock or depression, or both, or a number of these inequalities in the imaginary potential surface.

NOTE TO CHAPTER III.

FELDSPAR DETERMINATIONS BY SZABÓ'S METHOD.

In the present state of lithological science it is most desirable both to determine the feldspathic constituents of rocks with accuracy and to bring the evidence of independent methods to bear for this purpose. Where rocks are extremely coarse-grained, and at the same time carry feldspars the solidity of which is unimpaired by cracks, the results of the examination of cleavage flakes under the microscope leaves little to be desired; but such rocks are exceptional. The determination of feldspars in rock-slides is subject to two disadvantages. Crystals of above a millimeter in diameter are very likely to be broken in grinding, and thus to escape examination; and though the microscopist may often infer the presence of two or more feldspars, he can be absolutely certain only of the most basic species present.

Szabó's method,[1] on the other hand, discriminates with great delicacy, not only the well-established feldspar species, but also the mixed feldspars, perthite and loxoclase, and the intermediate feldspars, andesine and bytownite, as to the independence of which mineralogists are not agreed. It is also particularly applicable to the larger feldspars, so seldom obtained in perfect form in slides. The weakness of the method lies in the fact that it is not applicable to very fine-grained rocks, or to the minute feldspars of coarser rocks, unless a separation has first been effected by Thoulet's method; but this limitation does not prevent its being excellently adapted to confirm and supplement the results of microscopic examination.

At the time of writing Chapter III. I did not feel competent to apply Szabó's method, never having had an opportunity of seeing it carried into practice; but while the proofs of this volume were under correction, Professor Szabó visited the country and was good enough to illustrate his method experimentally to some of the members of the Survey, including myself. After convincing myself of the accuracy of the results obtainable and acquiring familiarity with the manipulation by repeatedly testing a series of classical feldspars, such as anorthite from Monte Somma, labradorite from Labrador, orthoclase from Baveno, etc., I proceeded to an examination of the feldspars of the WASHOE rocks, the results of which are given below. From five to ten crystals in each specimen mentioned were tested, and no results obtained are omitted.

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[1] Joseph Szabó, Ueber eine neue Methode die Feldspathe auch in Gesteinen zu bestimmen. Buda-Pesth, Franklin-Verein, 1876. See, also, Fouqué et Lévy, Minéralogie Micrographique, p. 108.

Granite, close to *Red Jacket* mine.

The orthoclastic feldspar gave reactions corresponding to perthite or loxoclase, showing a mixture of amazonite with a triclinic feldspar. This mixture is also readily recognizable under the microscope. The triclinic crystals are in part oligoclase and in part answer to andesine.[1] Under the microscope I have noticed no crystals more basic than oligoclase.

Granular diorite, Bullion Ravine at Water Company's flume.

All the feldspars tested gave reactions for andesine, with a tendency rather towards labradorite than towards oligoclase. Under the microscope the maximum angles found answered to labradorite, but the occurrence of zonal structure was noted.[2]

Granular diorite, *Utah*, 1950.

In this specimen labradorite, andesine, and crystals of intermediate composition were found.

Porphyritic diorite, Ophir Ravine, south side.

Labradorite and andesine only were detected.

Metamorphic diorite, *Amazon* dump.

All the feldspars tested were oligoclase, according with the microscopic results.

Quartz-porphyry, 1,000 feet south of *Lawson's Tunnel.*

Amazonite and oligoclase were found, as well as a feldspar slightly more basic than oligoclase, but not so much so as andesine. This mineral is therefore much more closely allied to oligoclase than to labradorite. No angles of extinction exceeding those of oligoclase were observed in the slide. Oligoclase was also found in the rock described on page 109 (slide 304).

Earlier diabase, *Sutro Tunnel*, north branch, 50 feet south of *Ophir*.

All but one of the crystals tested proved to be labradorite. The exception was an andesine.

Earlier hornblende-andesite, North Twin Peak.

A single feldspar had a composition intermediate between labradorite and andesine. The remainder were characteristic labradorites. The zonal feldspar described on page 61, and shown in Plate III., Fig. 13, is from the same cropping, though not from the same specimen.

Earlier hornblende-andesite, 1,200 feet northwest of Geiger Grade Toll House.

The microscopic examination led to the supposition that anorthite, labradorite, and oligoclase were all present, the last, however, only as microlites. The crystals tested by Szabó's method proved to be andesine and a feldspar intermediate between this and labradorite. No anorthite was met with. This fact, however, of course does

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[1] It is usual to regard andesine as peculiar to volcanic rocks, and the plagioclase of granite is often supposed to be exclusively oligoclase. Professor Rosenbusch, however (Physiog. der Massigen Gest., II., 121), mentions finding plagioclases in granites which showed angles of extinction corresponding to all of the feldspar species excepting anorthite.

[2] For some remarks on the indications of zonal structure, see page 61.

not prove that none is present in the rock, but only that it is comparatively infrequent. That it was not the predominant feldspar was also inferred from the microscopic examination.

Augite-andesite, peak south of Crown Point Ravine, marked 7075.

Anorthite, bytownite, and labradorite were detected in this specimen. The anorthite was found under the microscope, and its presence prevented the detection of labradorite, except among the microlites. But on page 64 it is stated of the augite-andesite that, though "anorthite has been identified in a few slides, * * * in most cases the maximum angles of extinction correspond to labradorite."

Augite-andesite, above Ophir grade, due west of *Belcher* hoisting-works.

This, too, showed anorthite, labradorite, and an intermediate variety. Anorthite was found also in the augite-andesite from Basalt Hill.

Later hornblende-andesite, quarry 2,000 feet northeast of *Sutro Tunnel* Shaft III.

All of the feldspars tested (more than a dozen) gave very sharp reactions for andesine.[1] Nearly all of them show zonal structure.

Later hornblende-andesite, quarry 2,000 feet east of Occidental Mill.

An andesine, an oligoclase, and several crystals of intermediate composition were found. This accords excellently with the analyses of these feldspars made by Mr. Dewey.[2]

Later hornblende-andesite, quarry above *Utah* mine.

Labradorite, andesine, and an intermediate variety were detected.

It was not found practicable to examine the feldspars of the later diabase (black dike) or the basalt, on account of the fine grain of these rocks.

On the whole, the examination strongly confirms the results of the microscopical analysis, and the only rocks in which the flame-reactions revealed feldspars which might have been detected by the microscopic method are the granite and the quartz-porphyry, each of which shows, in addition to oligoclase, an unsuspected, more basic feldspar, which is, however, more closely allied to oligoclase than to labradorite.

While the optical behavior of a few of the large feldspars in the WASHOE andesites indicates that they are mixtures of different species, this is exceptional. They are ordinarily polysynthetic individuals, showing only two angles of extinction. In a large proportion of cases the crystallographic relations of the twinned lamellæ are further emphasized by the presence of zonal structure. Granting the accuracy of Szabó's method, it is therefore extremely difficult to suppose that the prevalence of crystals giving the flame-reactions for andesine in the andesites, and particularly in the rock from the quarry northeast of *Sutro* Shaft III., is due to aggregations of two distinct species. The uniformity of the reactions obtained is also an argument against

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[1] Professor Szabó examined two crystals from this specimen, and pronounced them very characteristic andesine.

[2] See pages 67 and 154.

such a supposition. In examining some fine instances of so-called perthite from the original Canadian locality and from others on the Atlantic coast I have found the reactions extremely variable, depending, as one cannot but suppose, on the relative proportions of the two component feldspars which happened to be present in the little fragment tested. In the andesite referred to, on the other hand, the reactions of the feldspars were as regular as those obtained from different fragments of a single standard feldspar. The facts, therefore, do not appear to me to warrant the supposition either that these crystals are mixtures of different feldspar species independently crystallized or that they correspond in composition to some one of the unquestioned varieties. They must rather be set down as isomorphous mixtures, in the sense in which that term is to be understood in Tschermak's theory of feldspar-composition.

INDEX TO MINING CLAIMS.

[Atlas-sheet III.—Map of the WASHOE DISTRICT showing Mining Claims.]

Mine.	Latitude, N. 39°.		Longitude, W. 119°.	
	Minutes.	Seconds.	Minutes.	Seconds.
Agassiz	18	53	38	15
Alabama	17	50	37	25
Alexander	16	27	38	45
Alhambra	15	05	38	16
Allen, or Peruvian	19	27	38	30
Alpha	17	40	39	15
Alpine	17	50	38	20
Alta	16	30	39	00
Alta (Patent)	16	35	38	55
Amazon	14	45	38	40
America	19	07	37	20
American	14	45	41	00
American	15	15	38	25
American Eagle	14	45	38	50
American Flat	16	30	40	20
Andes	18	40	39	00
Andrews	18	25	38	13
Arctic	19	50	37	20
Argonaut	15	50	37	43
Arizona	16	50	40	30
Atlantic	15	40	38	55
Bailey	18	00	37	25
Baltic	16	35	40	38
Baltimore American	16	40	40	10
Baltimore Consolidated	16	35	40	05
Belchapin	16	45	39	15
Belcher	17	15	39	30
Belcher Extension	16	45	39	18
Benjamin	15	45	39	15
Benton	16	35	39	00
Best & Belcher	18	27	38	50
Blue Jacket	19	25	38	22
Boehler	14	05	38	30
Bonanza	18	55	38	58
Boyle	16	42	38	50
Brilliant	16	50	38	57
Browne	19	20	38	17
Buckeye	16	00	37	35
Bullion	17	50	39	08
Caldwell	17	15	38	39
Caledonia	16	50	39	50
California	18	40	38	50
California	16	20	39	30
California Bank	19	40	38	00
Capital	16	30	38	43
Capital No. 2	16	50	38	45
Carolina	19	35	37	52
Carolina	16	18	38	08
Carson	15	00	37	50
Cavour	19	27	37	10
Cherokee	15	30	38	17
Chollar	18	05	39	00
Chonta	16	45	39	12
Chonta	16	28	39	07
City of Melbourne	17	20	38	20
Clemons	18	52	39	12
Cliff House	16	00	38	30
Clyde	16	50	39	00
Cole	18	50	39	18
Colorado	19	20	38	00
Colossus	19	40	37	00
Columbia	19	30	37	25
Columbia	14	10	38	22
Columbia	14	05	38	25
Comet	15	30	38	51
Comet Extension	15	15	38	55
Compromise	16	40	38	20
Concordia	18	35	37	25
Confidence	17	35	39	20
Consolidated Virginia	18	30	38	50
Cook & Gray	16	10	38	21
Cosmopolitan	18	10	37	15
Cosmopolitan	16	30	38	00
Coso	16	20	38	40
Coupon	15	15	38	55
Coupon No. 2	15	05	38	55
Coye	14	30	38	25
Crevice	17	20	39	06
Cromer	15	56	38	10
Crown Point	17	20	39	20
Crown Point Extension	17	05	39	18
Crown Point Ravine	17	30	39	32

Index to mining claims—Continued.

Mine.	Latitude, N. 39°.		Longitude, W. 119°.	
	Minutes.	Seconds.	Minutes.	Seconds.
Crystal Ridge	19	20	37	05
Culver	17	20	38	30
Culver Addition	17	15	38	37
Curtis	17	10	39	10
Daney	14	40	38	10
Daniel Webster	19	45	36	55
Dardanelles	16	55	39	27
Dardanelles	16	15	38	02
Dayton	15	20	38	11
Dayton No. 2	14	20	38	15
Dean	16	50	37	40
De Forest	15	15	39	05
Delaware	15	55	41	15
Del Rey	15	30	38	40
Dexter	18	50	37	30
Dexter	18	10	37	35
Diamond	19	27	37	45
Dios Señor	14	45	38	15
Drexel	15	20	38	20
E. Chapin	16	50	39	15
E. Comstock	16	55	39	15
Edinburgh	14	55	38	40
E. Europa	17	35	38	37
Elevator	15	30	39	15
Elliot	19	35	37	30
Emigrant	15	50	38	28
Enderwood	16	10	38	45
English Company	16	15	39	05
Enterprise	16	40	39	30
E. Overman	17	10	38	25
E. Savage	18	15	38	10
Esperance	19	50	36	45
Esperanza	15	36	38	10
Essex	18	55	37	15
E. Star	15	05	38	35
Estello	15	30	38	30
Europa	17	30	38	45
Exchequer	17	45	39	15
E. Yellow Jacket	17	25	38	30
Fairfax	18	45	38	15
Flora Temple	16	20	38	10
Florida	15	20	40	30
Francisco Marsano	19	40	37	10
Frankel	16	33	40	20
Franklin-German	15	15	37	30
French	14	55	38	20
Front Lode Consolidated	16	55	39	10
Fry	19	35	37	55
Fry	16	55	39	06
Genesee	14	55	38	10
Georgia	15	55	40	40
German	16	20	38	18
German	16	15	38	20
Gila Mina	16	05	38	32
Glasgow	14	50	38	30
Glen	19	40	37	20
Globe	16	40	40	38
Golden Arrow	19	10	37	10
Gold Hill Company	16	40	37	25
Gold Hill Tunnel	17	30	39	10
Gold Lead	19	10	38	46
Gold Leaf	15	35	38	35
Goodman	15	40	39	10
Gould & Curry	18	20	38	50
Grant	15	50	38	10
Great Eastern	18	05	37	30
Great Western	14	35	38	15
Green	15	50	38	40
Grosh	17	35	39	00
Grosh Consolidated	17	33	38	50
Hale & Norcross	18	10	39	00
Hale & Norcross, S. E. Extension	17	45	38	40
Hardy	18	45	38	35
Harlem	15	30	39	10
Hartford	16	05	38	55
Hawkeye	16	20	37	30
Hawley Consolidated	14	05	38	15
Hayward	17	27	38	05
Hector	19	15	38	15
Henry Clay	19	37	37	00
Hercules	18	35	37	35
Hillside	15	15	38	35
Holman	16	20	38	30
Imperial	17	38	39	20
Independent	19	55	38	15
Industry	15	35	37	50
Insurance	18	45	39	02
Iowa	19	00	38	50
Irving	19	45	38	37
Jackson	15	10	38	20
Jacob Little	19	10	38	48
James	19	50	38	20
Joe Scates	18	30	38	26
Joe Scates	18	15	38	33
John Auer	18	18	37	30
Julia	17	50	38	50
Julia, E. Extension	17	50	38	25
Julia No. 2	17	50	38	35
Jura	16	55	40	20
Justice	16	20	39	02
Kate	18	35	37	35
Kennebec	18	50	37	45

Index to mining claims—Continued.

Mine.	Latitude, N. 39°.		Longitude, W. 119°.	
	Minutes.	Seconds.	Minutes.	Seconds.
Keystone	20	15	38	10
Keystone	16	35	39	10
Knickerbocker	16	48	40	05
Kossuth	15	00	38	05
Kossuth Extension	15	15	38	00
Lady Washington	16	30	39	05
La Fayette	18	25	37	30
Lanzac	15	30	38	45
La Plata	17	15	39	40
Lassen	19	40	37	35
Lawson	16	30	40	40
Leo	16	05	38	35
Leviathan	17	10	39	20
Lexington	16	00	39	07
Lincoln	19	20	38	55
Little Giant	16	03	38	30
Little York	19	25	38	45
Lookout	14	45	37	40
Lord of Lorne	15	50	39	40
Lowery	16	55	38	00
Low Range	18	20	38	24
Lucerne	16	07	38	50
Mackey	19	10	37	05
Manhattan Consolidated	19	55	36	30
Margarita	19	20	37	25
Margarita No. 2	19	15	37	20
Marsano	19	35	37	15
Marvel	19	10	38	10
Mary	18	15	38	15
Mary Ann	18	50	38	05
Maryland	16	40	40	00
McErlain	16	10	38	10
McGinnis & Bazan	16	20	37	40
McKibben	18	42	39	12
Memnon	14	10	38	15
Memphis	16	35	39	03
Metela	20	02	38	10
Metropolitan	15	00	38	10
Mexican	18	50	38	45
Miami	18	40	38	10
Midas	16	00	38	20
Mill Site	16	45	38	25
Mill Site	16	45	40	25
Mill Site	16	35	37	37
Mill Site	16	20	40	20
Mint	18	10	38	30
Mississippi	16	05	38	25
Missouri	17	35	38	25
Mitchell	16	17	38	47
Modoc Chief	17	20	38	45
Monte Christo No. 2	18	20	37	10
Monte Cristo	18	35	37	15
Montezuma	18	30	37	40
Monumental	17	10	38	50
Mooney & Whiteman	14	25	38	15
Moore & Morgan	17	35	38	30
Morning Star No. 2	18	57	37	30
Mountain View	19	15	37	45
Nagle	16	00	40	10
N. Chipman	17	17	38	47
N. Comstock	19	25	38	10
N. Consolidated Virginia	18	55	38	05
N. Dayton	15	20	38	30
Nevada	16	30	40	30
Nevada No. 3	16	25	40	24
New Empire State	20	30	38	15
New Oregon	16	50	40	05
New York	16	45	39	07
New York Mill Site	16	43	39	02
Niagara	16	05	38	40
Nigger Ravine	16	00	38	00
N. Knickerbocker	17	00	39	50
N. Lexington	16	20	39	10
N. Mexican	19	08	38	05
N. Milton	19	20	37	40
N. Occidental	17	20	37	43
N. Ophir	19	05	38	15
North	20	15	38	50
Northern Light	18	20	37	20
Northern Light	18	53	38	00
N. Prospect	17	20	37	55
N. Star	19	15	37	15
N Star	15	40	40	40
Occidental	17	05	37	43
Ohio	19	50	37	40
Ontario	17	20	39	50
Ophir	18	45	37	50
Original Gold Hill	17	35	39	28
Orleans	19	50	38	30
Oro	19	55	38	45
Oro	17	12	39	40
Overman	17	05	39	35
Overman No. 2	16	40	39	25
Overton	19	00	39	20
Palmetto	18	42	39	12
Patten	16	35	40	00
Pearson	16	25	38	50
Peruvian, or Allen	19	27	38	30
Peytona	19	25	38	35
Phœnix-Western	15	15	37	50
Picton	16	10	39	20
Pioneer	19	20	37	50

Index to mining claims—Continued.

Mine.	Latitude, N. 39°.		Longitude, W. 119°.	
	Minutes.	Seconds.	Minutes.	Seconds.
Piute	16	40	38	48
Plato	16	00	38	05
Plutus	18	35	38	20
Porphyry	20	10	38	45
Potosi	17	55	39	05
Pride of Washoe	18	20	39	05
Prospect	17	10	38	00
Red & White Cross	18	20	38	20
Reno	18	35	38	10
Rock Island	16	15	40	37
Rocky Bar	18	40	38	00
Roman Capital	18	25	38	28
R. R. Consolidated	17	50	38	20
Sacramento	19	10	38	43
Sadie	18	30	37	10
Sallie Hart	19	30	38	10
San Francisco	15	55	40	25
Santiago	15	05	39	20
Savage	18	15	38	55
S. Belcher	17	00	39	18
S. California	16	50	38	15
S. Chipman	17	10	38	45
S. Consolidated Virginia	15	40	39	05
Scorpion	19	05	37	50
Sec. Line	16	48	39	25
Seg. Belcher	17	10	39	30
Senator	18	00	38	35
Sewell & Sheel	14	40	37	47
S. Grosh	17	20	39	00
Shamo	18	45	38	13
Shanley	18	38	37	45
Sheridan	19	15	38	25
Sherwood	16	50	38	53
Sierra	16	05	38	53
Sierra Nevada	19	10	38	20
Silverado	16	05	37	45
Silver Central	15	00	37	56
Silver Hill	16	10	38	50
Silver Leaf	17	30	38	15
Silver Leaf	15	45	38	30
Silver Star	16	55	37	20
Solid Silver	19	05	38	55
South Buckeye	15	10	37	35
South Comstock	15	55	38	30
South End	15	30	39	00
South Jacket	17	00	38	35
South Lucerne	15	55	38	45
South Overman	16	30	39	25
South St. Louis	15	40	38	45
Southern Star	15	15	38	40
Stevens	16	25	38	55
St. John's	17	30	37	35
St. Lawrence	14	35	38	50
St. Louis	19	35	37	45
St. Louis	16	00	38	42
Storey	17	05	37	15
Storey	17	00	39	00
Succor	16	10	38	31
Sullivan	16	50	38	45
Sunrise	19	05	37	35
Sunrise	17	00	37	30
Superior	17	35	39	55
Sutro	19	30	38	40
Swan	16	40	40	20
Table Mountain	15	35	38	23
Tam O'Shanter	15	50	39	24
T. & C. Brooks	14	10	38	05
Tarto	16	13	38	52
Tehama	17	30	38	11
Thornberg	19	50	38	30
Thornton	19	00	37	50
Troy Consolidated	19	35	37	40
Tucker	17	00	38	20
Twin	16	00	38	10
Twin Peaks	17	05	39	05
Tyro	20	15	38	40
Union Consolidated	18	55	38	45
Utah	19	35	38	30
Utah	16	55	40	30
Utah, 1st N. E. Extension	19	40	38	10
Utah, 2d N. E. Extension	19	50	38	00
Venis	18	55	38	05
Vermont	18	48	38	20
Victoria Garber	19	05	37	35
Virginia Standard	18	40	37	05
Vivian	16	15	38	10
Volcano	15	20	39	00
Vulcan	15	30	38	35
Ward	19	45	38	20
Ward	17	38	38	45
Wasatch	18	25	38	05
Washoe Consolidated	16	35	39	55
Waters	19	32	37	35
W. Belcher	17	20	39	40
W. Crown Point	17	15	39	35
Webber	14	40	38	00
Wells-Fargo	19	30	37	45
Western	15	30	38	10
W. Justice	16	20	39	10
Woodville	16	20	38	55
W. Star	15	05	38	45
Yankee	16	50	38	20
Yellow Jacket	17	30	39	20

GENERAL INDEX.

[To facilitate the use of the geological map, Atlas-sheet IV., the positions of the more noteworthy localities mentioned in the text are indicated in the index by letters and numbers attached in parentheses. The map is provided with a corresponding series of letters and numbers answering to each minute of surface.]