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No. 79

A LATE VOLCANIC ERUPTION IN NORTHERN CALIFORNIA AND ITS PECULIAR LAVA

J. S. Diller

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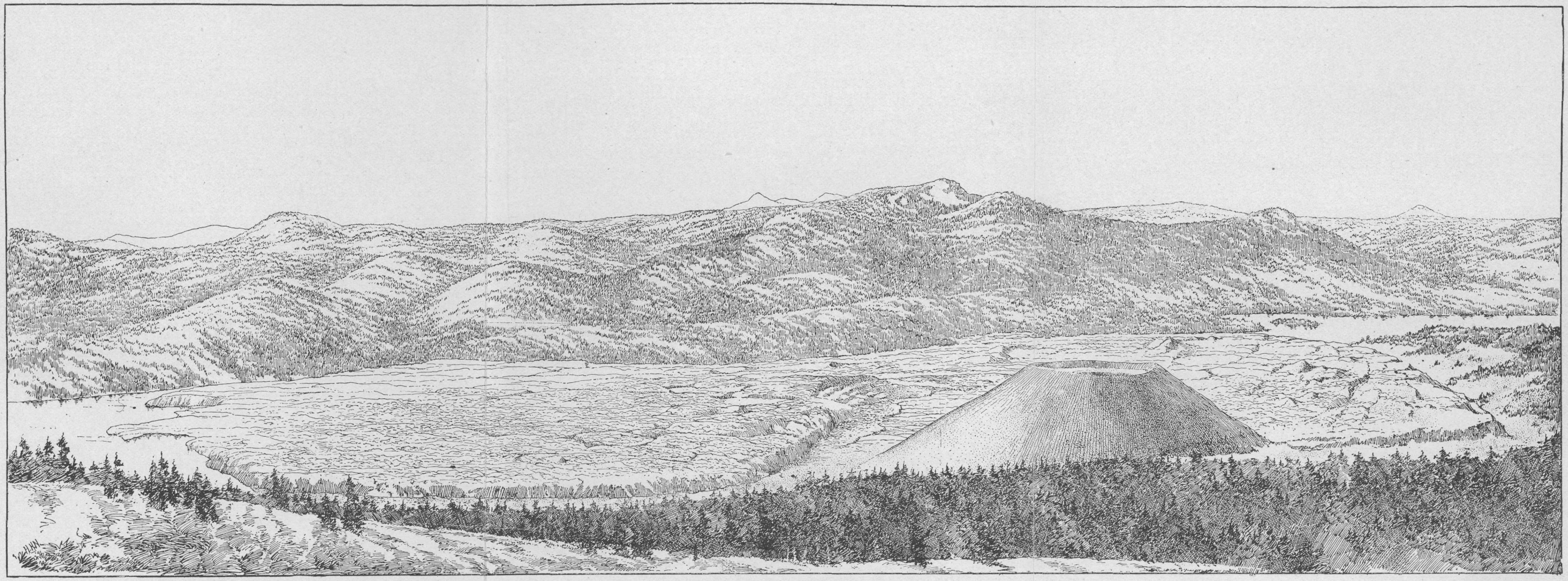

THE CINDER CONE AND LAVA FIELD FROM PROSPECT PEAK.

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

A LATE VOLCANIC ERUPTION

IN

NORTHERN CALIFORNIA

AND

ITS PECULIAR LAVA

BY

JOSEPH SILAS DILLER

WASHINGTON
GOVERNMENT PRINTING OFFICE
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The Lassen Peak, Volcanic Ridge, which connects the northern end of the Sierra Nevada in California with the Coast Range and separates the upper portion of the Sacramento Valley from the great interior basin, is composed chiefly of lavas from many volcanic eruptions. The vents which supplied these lavas may be roughly classified according to size into three groups. They are surmounted by volcanic cones of corresponding dimensions. The smallest cones are the newest, most numerous, and most widely distributed, and to this group belongs the Cinder Cone, 10 miles northeast of Lassen Peak.

It marks the scene of one of the very latest volcanic eruptions in this country. The utter desolation of the place and the apparent newness of the Cinder Cone and the lava and ash field are most surprising.

The Cinder Cone is remarkably regular, smooth, and dark colored. It is composed wholly of ejecta. Rising with steep slopes to a height of 640 feet above its base, it incloses a perfect crater 240 feet deep.

Large volcanic bombs are thickly scattered about the base of the Cinder Cone, from which the ash field extends away in all directions for a distance of about 8 miles. About a quarter of a mile from the cone the layer of volcanic sand is 7 feet thick, and its lower portion is composed of pumiceous fragments. As the distance from the cone increases the sand becomes thinner and finer until it disappears.

The lava field is an extremely rough, tabular pile of large, angular fragments of lava. It terminates upon all sides in a steep, terrace-like edge, averaging about 100 feet in height. A part of the lava is covered with volcanic sand and separated from the newest flow, which forms the greater portion of the field, by about 10 feet of infusorial earth deposited in Lake Bidwell, where it extended farther south than now.

The history of this little volcano embraces two epochs of eruption, strongly contrasted in their phenomena and separated by a considerable interval of repose. The first epoch was characterized by a violent explosive eruption which formed the Cinder Cone and the ash field. Within the latter part of this period of violence some lava was effused, and this was partially covered by succeeding showers of ashes. Then followed the lacustrine period, after which came the quiet effusive eruption of the large mass of rough lava that gave the lava field its present shape and volume.

Judging from the trees which have grown upon the volcanic sand near the Cinder Cone since it was formed, the first and violent eruption probably occurred nearly a hundred years before the American Revolution. The second or effusive eruption took place at a much later date, but certainly more than 50 years ago.

The lava is basalt, one of the commonest kinds of volcanic rock, but it is especially noteworthy on account of the phenocrystic quartz which it contains. The mode of occurrence and distribution of the quartz through the lava demonstrates that it is indigenous to the basalt, and that it was formed at an early stage of its crystallization. This is a characterizing feature of quartz basalt, which is not nearly as rare as was once supposed. Almost thirty occurrences of it are already known.

A LATE VOLCANIC ERUPTION IN NORTHERN CALIFORNIA AND ITS PECULIAR LAVA.

By J. S. Diller.

INTRODUCTION.

The entire absence of easily recognized volcanic craters in the eastern part of the United States has tended to create the impression that in volcanoes this country is below the average; but to dispel this notion it is necessary only to make a trip through our Northwest. In Washington, Oregon, California, Nevada, and Idaho is the largest volcanic field of the world. It is very true that there are no active craters like Vesuvius, but some of the Western volcanoes have been so recently eruptive that we can scarcely say they are things of the past, and there is abundant evidence to show that their internal fires are still smoldering.

The Lassen Peak district in later geological epochs has been the scene of profound volcanic extravasations, which resulted in its characteristic mountain topography. Lying between the Sacramento Valley on the one hand and the platform of the Great Interior Basin on the other, it joins the northern end of the Sierra Nevada to the irregular mountains of the Klamath province, so intimately related to the Coast Range.

The northern portion of the district is traversed by the Pit River, the modern representative of the ancient water way which, during the closing epoch of the Cretaceous age, lay beneath the sea. Its topographic elements are in general strongly contrasted with those of neighboring districts. The Sierra Nevada and Coast Ranges are elevations formed by uplifting the original surface over large areas, but the Lassen Peak volcanic ridge, which is the most general feature of the district, resulted chiefly from the superficial accumulations of material thrown out from within the earth and piled up in mountain masses about the point of exit. The large vents are represented by great cones lying in a broad belt, so that their coalescing bases form an irregular ridge culminating in Lassen Peak.

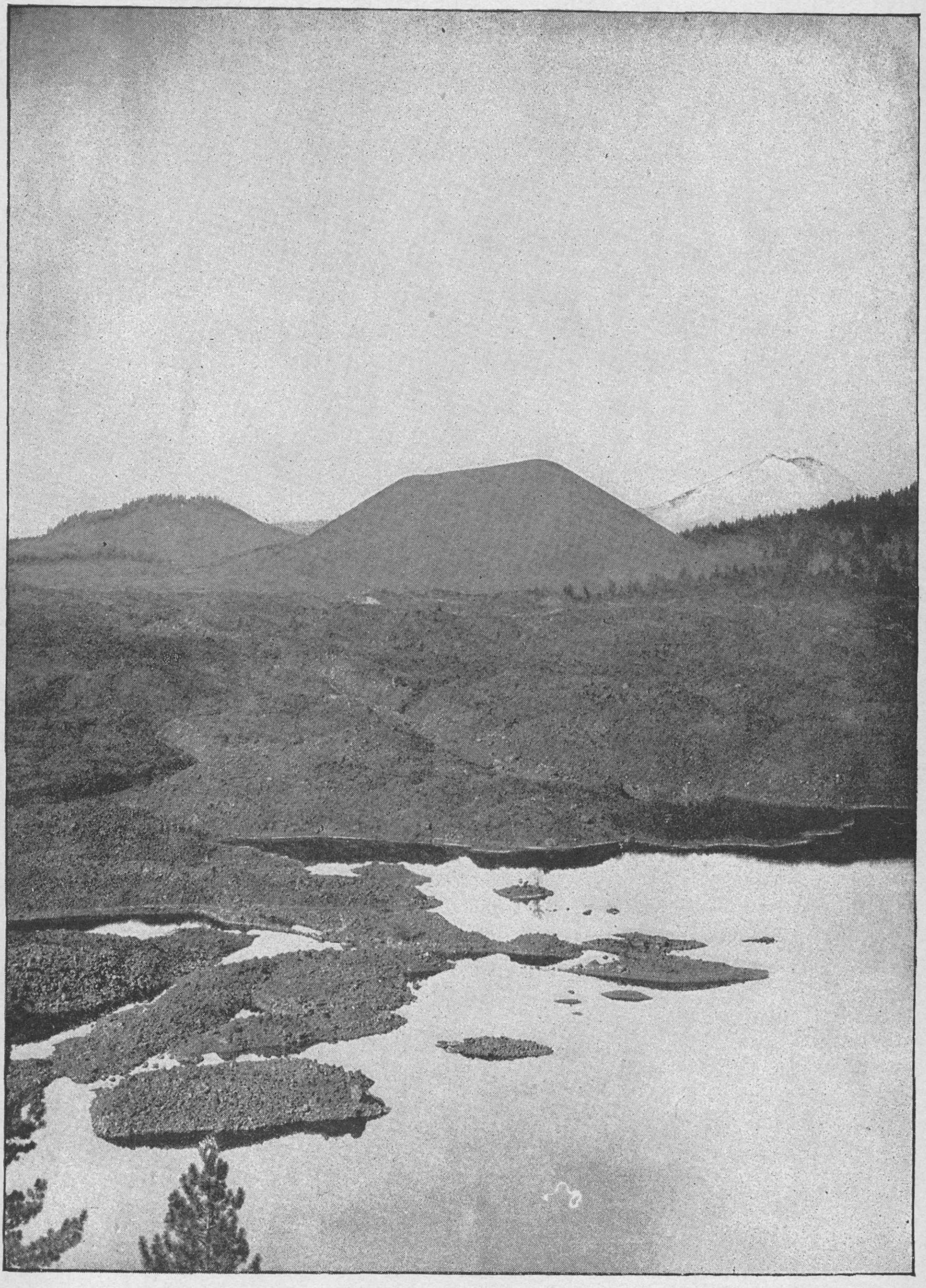
The volcanic cones, of which there are many scores in the district, may be divided according to size into three groups. Those of the first magnitude are four in number, and most ancient; then follow those of the second magnitude, in greater number, of later age, and wider distribution; finally, those of the third magnitude are smallest and most numerous, and have the widest distribution. The last stage of eruptive volcanic action has been manifested in these cones, and to this group belongs the Cinder Cone, 10 miles northeast of Lassen Peak, in the vicinity of Snag Lake.

The material brought to the surface from beneath by volcanic action to build up new topographic features is delivered in two different ways, and both may be in progress at the same time. In the one case the matter, which is wholly fragmental, is violently hurled into the air to be distributed in large part by the winds. In the other case the matter rises to the surface and flows out a continuous body, whose distribution is controlled by the laws of liquids. The ejection gives rise to a cinder cone about the vent, and spreads volcanic sediments far and wide over the adjacent country, covering up the slight irregularities of the original surface so as to produce the flowing contours which characterize ash fields. The effused material forms a lava field, whose features are determined largely by the physical condition of the lava at the time of its eruption.

GENERAL VIEW OF THE SCENE.

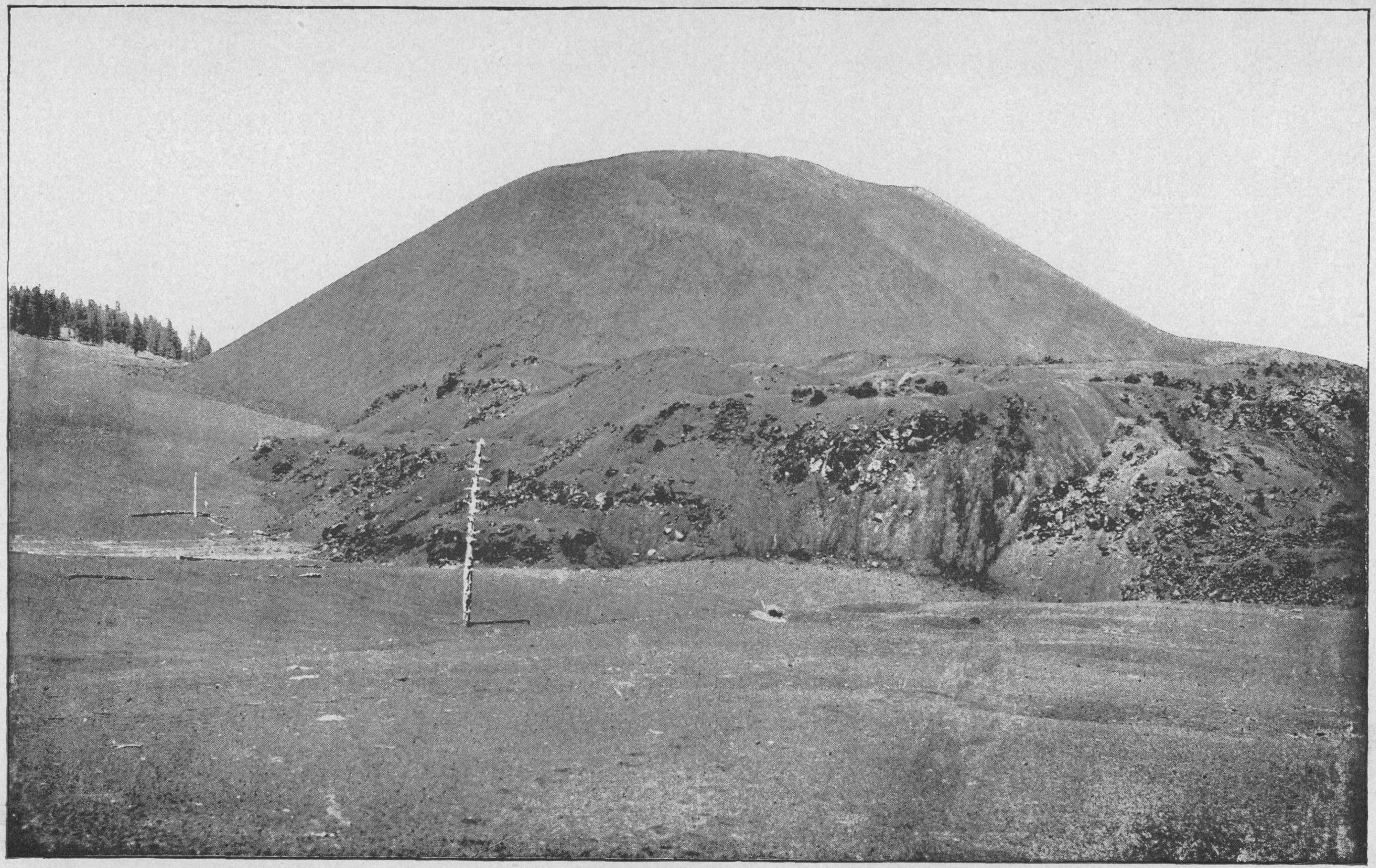
From the summit of Lassen Peak looking northeast a dark and desolate lava field and crater are pointed out as "The Cinder Cone," and it proves of sufficient interest to receive during the summer the occasional visits of those who are in search of the new and the marvelous. A better example of its kind can not be found anywhere. The nearest stage line ends at Shingletown, Shasta County, nearly 40 miles from the scene of the late eruption. It may be most comfortably reached on horseback by way of Deer Flat and the Hat Creek road, but a camping outfit must be carried along, as there is no settlement near the place. A much more interesting trip to the same place may be made from Plumas County, going by way of Morgan's Springs, Bumpass's Hades, and Lassen Peak and returning through Hot Spring Valley. From the latter locality Tartarus Lake and the geyser near Willow Lake may be easily reached.

Approaching the region the traveler first encounters a sprinkling of fine volcanic sand and small bits of dark brown pumice spread upon the ground. These increase as he goes nearer until the volcanic sand gives character to the whole landscape, imparting a dull, dark hue to the soft earth and rendering travel on foot fatiguing. The best general view of the scene is obtained from the summit of Prospect Peak,



THE LAVA FIELD AND CINDER CONE.

Lassen peak in the distance.



THE CINDER CONE, LOOKING NORTH.

3 miles northwest of the Cinder Cone, above which it rises over 2,000 feet. (Pl. I.)

The lava field lies between Snag Lake on the south and Lake Bidwell on the north. Its greatest length is about 3 miles. When the first near view of the lava field and Cinder Cone is obtained the impression of newness is very vivid. One looks in vain for steam rising from the crater and feels disappointed at seeing no visible signs of heat within the thick lava field. Charred tree trunks apparently long ago dead attest the scorching temperature of the place in recent times, but one searches in vain on the living trees for bits of volcanic sand from the eruption that might have lodged in knot holes or other places suited to catch it as it fell.

THE CINDER CONE.

The Cinder Cone is always the principal point of interest on account of its novelty as well as its importance and the excellent view it affords of the whole scene. From its summit the eye ranges over the lava field stretching from Snag Lake to Lake Bidwell, all encircled in the deep green pine forest which covers the gentle slopes of the ash-mantled hills.

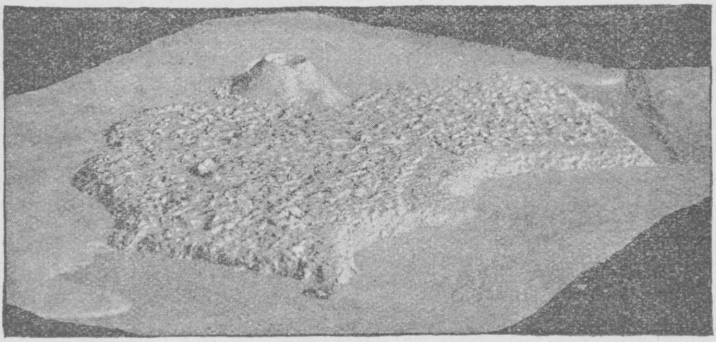


FIG. 1.—Model of lava field and cinder cone, looking northwest across Snag Lake.

A fine view of the lava field and Cinder Cone with Lassen Peak in the distance may be obtained on the slope northeast of Lake Bidwell (Pl. II), but a more comprehensive idea of the scene is conveyed by the model from which Figs. 1 and 2 have been prepared.

The Cinder Cone represented in Pl. III is regular in form with a surprisingly smooth dark surface showing no traces of water ways or other marks of the ravages of time. It rises to an elevation of 640 feet above the lowest point of its base (6,906 feet above the sea) with an average diameter of 2,000 feet below and 750 feet across the top. Its slopes are as steep as it is possible for such loose volcanic material to maintain at rest. The angles of the slope range from 30° to 37° according to size of the scoria and lapilli. They slide down under one's weight, so as to make the ascent, although but a few hundred feet, a matter of considerable fatigue.

The dull, somber aspect of the smooth, dark slope is greatly relieved by the carmine and orange-colored lapilli upon the southeastern side, so that when viewed from Snag Lake the cone presents the pleasing hues of a sunset. The strangeness of the scene is greatly enhanced by the almost complete absence of vegetation. Only two small bushes cling upon the outer slopes to give life to the barren cone.

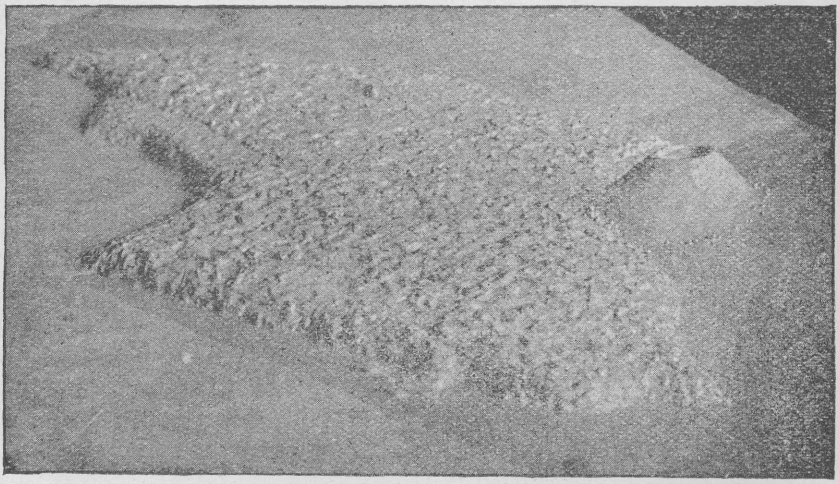


FIG. 2.—Model of lava field and cinder cone, looking southwest across Lake Bidwell.

The base of the cone is encircled by a multitude of volcanic bombs as shown in Pl. IV. These were hurled from the crater and, falling upon the steep slopes of the cone, tumbled to its base where they collected in great numbers. Many of the bombs are comparatively small, but a few attain a diameter of 8 feet. They are much jointed, often radially, and are falling to pieces under the influence of the elements. Externally they are cracked like septaria with a more or less ropy or pumiceous surface, often very rough, within they are dark and compact with a low degree of crystallization. Bombs of this sort with some effused lava may form a considerable portion of the lower part of the cone, but its chief mass is of lapilli ranging in size from that of a pea to 4 or 5 inches in diameter.

The summit of the cone is a well developed crater, as represented in Pls. V and X. The pit has a depth of 240 feet, with a narrow bottom and partially slaggy slopes so steep as to be scaled with difficulty. A peculiar feature is the double character of the crater. It has two rims one within the other separated by a shallow moat which encircles the great funnel-shaped depression in the center (Pl. X).

The Cinder Cone marks the position of the vent from which its material was ejected and a large mass of lava was effused. Only the ejected material passed out through the crater, for the pressure of the lava within the cone burst its walls and issued from its southeastern side at

VOLCANIC BOMBS AT SOUTHWEST BASE OF CINDER CONE.

an elevation of about 6,350 feet, forming an excresence which marks the path of easiest ascent. The upper crust of the lava tube which was left empty at the point of egress when the supply of lava ceased has broken in and partly filled with ice, in marked contrast to its igneous condition when the volcano was active.

THE ASH FIELD.

The volcanic sand and fine lapilli thrown out at the time of the eruption spread over a considerable area in all directions from the Cinder Cone.

The southern border of the ash field is seen near Juniper Lake, in the vicinity of Mount Harkness, eight miles from the cone. To the northeast it extends nearly to Poison Lake. In the opposite direction traces of the sand may be recognized in Hat Creek Valley, but it does not extend quite to Lassen Peak. To the north and northwest it reaches far beyond the summit of the prominent mountain at the base of which the Cinder Cone reposes. The outline of the field covered by the volcanic sand is approximately circular, with a radius of nearly eight miles, showing that at the time of the eruption there was no strong wind to modify the regular centrifugal distribution of the sand.

The maximum thickness of the sand at the base of the Cinder Cone could not be definitely ascertained. It is loose and flows easily so that a great deal of excavating is required to get through it where the layer has considerable magnitude, and the bottom was not reached by us at any point within a quarter of a mile of the base of the cone. It is evident, however, that its thickness rapidly diminishes in all directions.

The following table shows the thickness of the sand at various distances from the cone:

Thickness of fragmental material.

Direction from cone.	Distance from cone.	Thickness of sand.	Thickness of pumiceous fragments.	Total thickness.
	Miles.	*Inches.*	*Inches.*	
NE., N., and SW.	¼	52	30	82
N.	½	....	....	36
N.	¾	27	8	35
SW.	1	14	10	24
E.	1	10	10	20
SW.	1½	12	6	18
E.	1⅕	10½	5½	16
N.	1¼	....	....	15
SE.	1⅓	8	4	12
SE.	1½	5½	4½	10
W.	1¾	....	....	6
W.	2	2½	2½	5
SW.	2¼	....	....	4½

The sheet of fragmental material consists of two portions. The upper part is properly called volcanic sand; the lower part, however, is composed of small, light brown pumiceous fragments ranging in size from that of a pea to an inch in diameter. The fragments are very vesicular but still not sufficiently light to float on water like ordinary pumice. They are very rough and jagged with surfaces torn by the bursting cells once filled with eruptive gases. Some of them were produced by concussion. The pieces hurled violently into the air frequently struck others and all were partially pulverized as in a great mill. This sort of sediment is more abundant in the volcanic sand which overlies the pumiceous material and was therefore ejected at a subsequent stage of the eruption. Many of the sand grains are vesicular, but less so than the pumiceous fragments, and generally rounded. Other grains are angular and composed of compact lava with few vesiculæ. They are bounded by fracture surfaces, and were evidently produced by the violent concussion of larger fragments.

The sand exhibits irregular stratification due to the assorting action of the atmosphere upon the subsiding particles during the eruption. The thin layers are lenticular in shape and continuous for short distances only, not as sharply defined as beds laid down in water, but indicating a decided tendency to form beds under unfavorable conditions. This tendency is most clearly manifested a short distance away from the volcanic vent where the air was not so much disturbed by the violent current expelled from the crater.

The selective influence of the atmosphere may be seen not only in the imperfect stratification of the sand as exhibited in a vertical section, but also in its distribution upon the surface. Near the cinder cone the sand is coarse and the bed thick, but it becomes thinner and the sand finer and finer as the distance from the cone increases.

On the borders of the large circular field covered by the sediment thrown out from the crater the fine material is sand, and there is no evidence to show that any considerable amount of volcanic dust or material still finer than the finest sand was formed.

The almost complete absence of volcanic dust in this case is surprising when we consider the highly explosive character of the eruption, and it may be attributed in part, perhaps, to the viscous condition of the magma at the time of the outburst. Had the pumiceous fragments in the layer already referred to contained sufficient eruptible gases at the time of the ejection to blow them to atoms, considerable dust would doubtless have resulted.

The variety in the fragmental material ejected from the volcanic vent is not in size alone but also in form and structure. The larger fragments as well as the smaller particles violently hurled into the atmosphere while yet in a highly heated viscous condition show a tendency to assume a spherical form. Their vesicular structure renders them more brittle, so that in the violent collisions of the ascending and de-

THE CRATER OF THE CINDER CONE.

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

scending fragments many of them were reduced to smaller pieces which, although at first angular, may, as in the sand blast, become rounded by the frequent attrition of neighboring particles. In the sand the rounded forms, both original and abraded, as well as the angular chips and splinters, are abundant, with many intermediate grades.

The lapilli differ from the sand particles chiefly in size, but it is true in general, also, that they are more rounded and less vesicular, while the volcanic bombs, which are the largest fragments, found only at the base of the cinder cone, are all rounded and compact, excepting upon the periphery, where they may be more or less scoriaceous.

The vesicular covering of the bombs shows that their form is not due to the impact of neighboring particles, but to some earlier cause. Some of these bombs are over 8 feet in diameter, and it is difficult to believe that they became round and cool while flying through the air, for that would postulate an unreasonable rapidity of cooling. That they were solid when they struck the ground is evident because they did not flatten as did those ejected from the Mono Craters and many others. It appears probable that these large bombs were the first part of the lava to solidify, and were suspended in the magma before the eruption, when they were hurled out of the crater in their present form. This view of their origin explains also their compact structure as compared with the vesicular character of the other ejected material.

THE LAVA FIELD.

The tabular form of the lava field is illustrated in Figs. 1 and 2. It ends upon all sides abruptly like a terrace, frequently over a hundred feet in height. Plate VI shows its termination at the northwest corner of Snag Lake. Notwithstanding its general form, the lava field is full of irregular depressions, slight ridges and peaks, which are so extremely rough as to defy adequate description. Its surface is composed of sharp, angular blocks of lava loosely piled together so as to be completely impassable to many animals. The fragmental character of the lava field resulted from its extreme viscosity at the time of the eruption. The crust was repeatedly broken up by the friction and pressure of the moving viscous mass beneath and shoved along as a huge stone pile. Remnants of broken lava tubes may yet be recognized here and there in the lava field, often with hackly, jagged, steam-torn surfaces. (Pl. VII.)

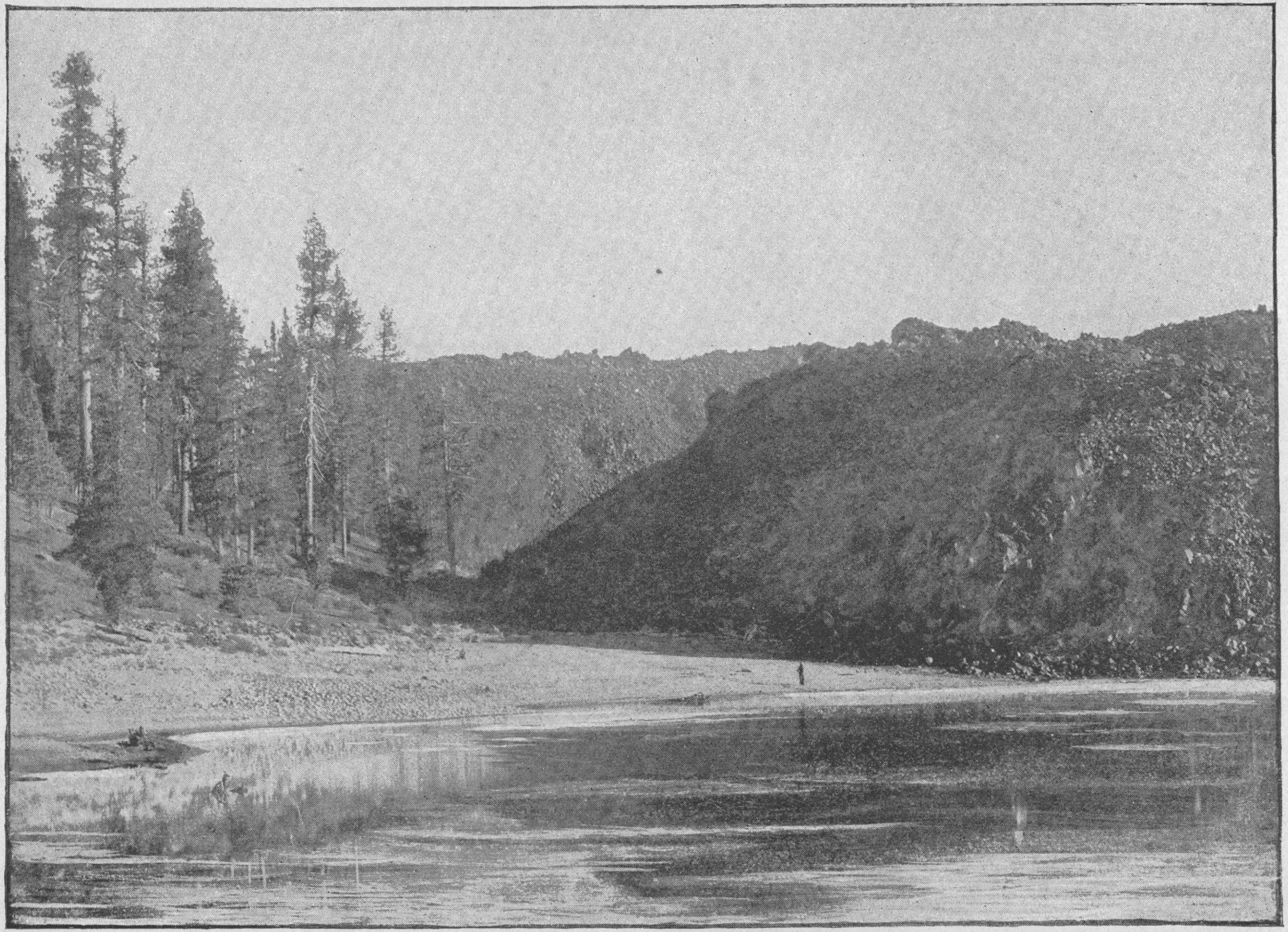
From the base of the cinder cone where the lava burst forth, by means of small ridges thrown up on the sides of the lava stream in a manner somewhat allied to that in which a glacier piles up its lateral moraines, as well as by the direction of the exposed lava tunnels and the flow-curves moved along on the surface of the current, its course can be traced first to the southeast, then bearing rapidly to the east, northeast, and north until finally part of the stream moved in a northwesterly direction, traversing a distance of not less than 3 miles, and yet at last coming to rest within one and a half miles of the vent. This was the route of the latest flow, and its course was greatly modified by the barriers formed of an older lava from the same vent.

A large part of the area now occupied by the lava field was once the site of a lake, which, by the encroachments of the lava, has been reduced to the present Lake Bidwell. At the time of the eruption the steam generated below by the hot lava coming in contact with the lake water burst up through the lava flow, forming miniature fragmental cones or covering the adjacent portion of the lava field with a thin sprinkling of volcanic sand or scoria. The best example of a cone of this sort is in the northeastern quarter of the lava field.

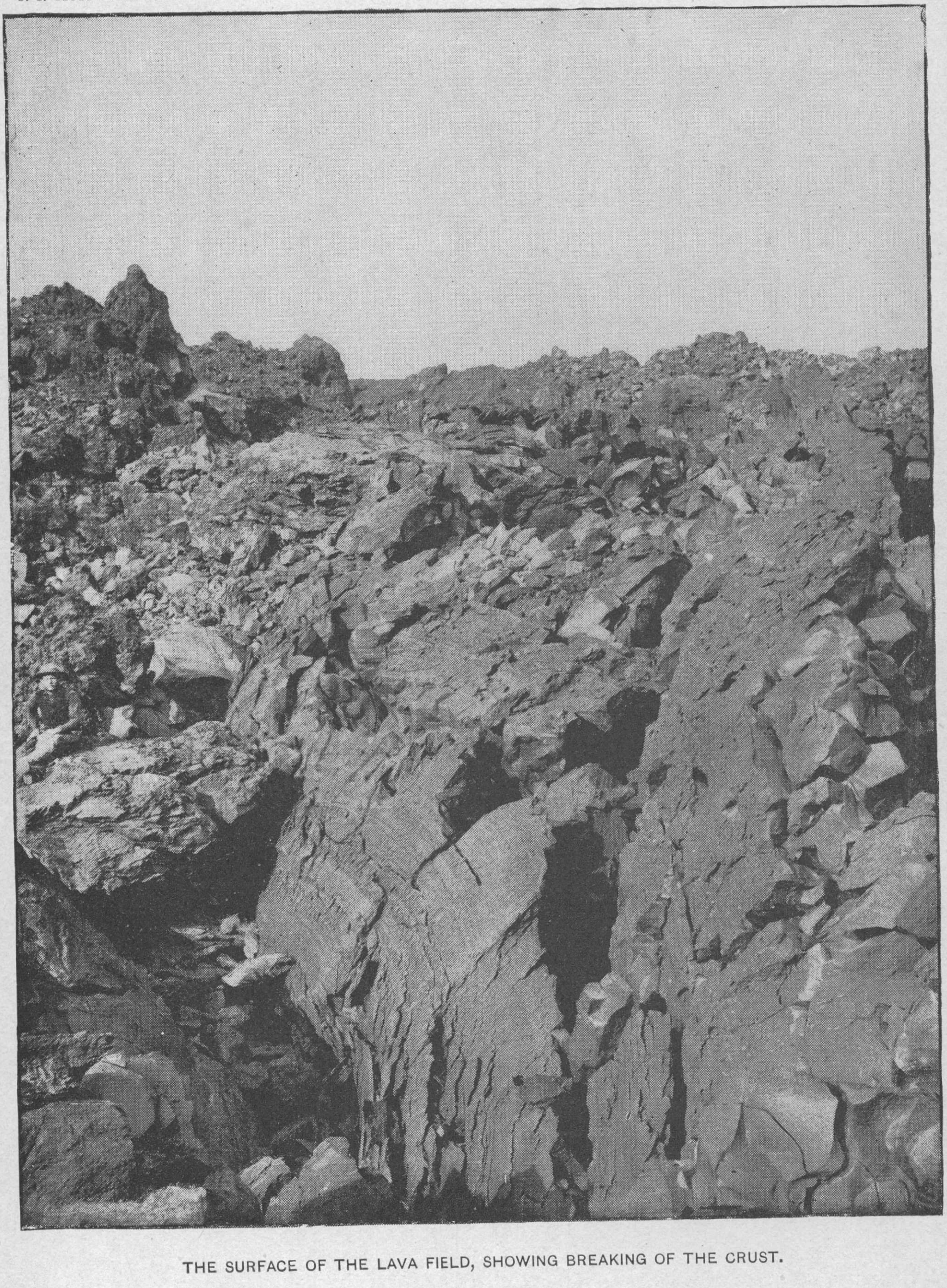
Everywhere in the lava field one is impressed with the idea that the lava moved slowly and with great difficulty, repeatedly breaking its crust and shoving along as a great stone pile, presenting an abrupt, terrace-like front upon all sides. It is a typical example of a lava field formed by the effusion of a viscous lava on gentle slopes. Had it been highly liquid like many of the other basalts in the same great volcanic field it would have found egress at the outlet of Lake Bidwell and stretched out down the little valley for miles northward.

The lava on the whole is decidedly compact as compared with others which are regarded as prominently vesicular, and yet in many parts it is full of small cavities. These cavities, however, are irregular in shape and with but little of the dense, often glassy, lining that generally surrounds the nearly spheroidal bubbles or vesicles in liquid lavas. These may have been filled with gas under high pressure, but of this there is little evidence to be found in the form or surroundings of the vesicles themselves. Perhaps this may be attributed to the highly viscous condition of the lava on account of which it was not susceptible of slight rearrangements in response to the pressure of the included gas. That the cavities were actually filled with gas under pressure is indicated by a study of the extremely rough, hackly surfaces of the lava tubes which were torn by the eructations of gas from such cavities. The liquidity of lavas has been frequently attributed to the presence of water, and perhaps the absence of a large amount of water in this case will explain its high degree of viscosity.

There is another consideration, however, to which attention must be given and that is the temperature. The temperature of lavas at the time of their eruption can be determined relatively only by studying the effects of their heat upon the adjacent rocks, the amount of contraction they have experienced in cooling, and their degree of crystallization. It is generally true that the lavas which were at the time of their eruption most liquid so as to spread far and wide over the country like sheets of water, as is true in many places in the great volcanic region of the northwest, are most crystalline, frequently holocrystalline and do not show, excepting at the upper surface, any evidence of the presence of considerable water or gases included in them. It is most



THE EDGE OF THE LAVA FIELD AT THE NORTHWEST CORNER OF SNAG LAKE.



THE SURFACE OF THE LAVA FIELD, SHOWING BREAKING OF THE CRUST.

commonly true, also, that the extravasation of the most liquid lavas is unattended by explosive eruptions which are the special manifestations of steam. It may be possible, therefore, that water has less to do than is generally supposed in producing (1) the high degree of liquidity in some lavas and (2) their effusion.

The holocrystalline basalts which at the time of their eruption were very liquid are commonly found upon close examination to have a decidedly cellular structure. The cells are interspaces left between the crystals by contraction in the process of cooling and are evidence that the liquid lavas had a very high temperature when effused. Other things being equal the higher the temperature of the magma the longer it will take to cool and the better it will crystallize. Thus the liquidity and the degree of crystallization of basaltic lavas are proportional to the temperature of their eruption. The lava from the Cinder Cone contains a large proportion of amorphous matter and exhibits no traces of cellular structure arising from contraction in the process of cooling.

As already stated there were two eruptions at the Cinder Cone. The earlier lava is mantled by a shower of sand but the latter is not. The surfaces of the two lava flows may be readily distinguished in Pls. VIII and IX. The depth of the lava varies somewhat in different parts of the field. It is frequently much over 100 feet and averages nearly that amount. The relations of the two lava flows, the mantle of sand by which they are separated, and the deposits of the ancient lake are illustrated in the accompanying section (Pl. X).

ANCIENT LAKE BED.

The ancient lake bed is exposed about the northern end of the lava field and upon the shores of Lake Bidwell, as illustrated on the map (Pl. XI). It connects directly with the present bottom of Lake Bidwell and the evidence indicates that the lake in which it was laid down covered a large part of the area now occupied by the lava field. There is no visible evidence to show clearly where its southern shore was, and before the eruption it may have extended nearly as far south as Snag Lake.

The bed is soft, white, and earthy, composed chiefly of infusorial earth intermingled with vegetable matter, such as grows on lake bottoms, and a small percentage of sediments washed in by little tributary streams. The thickness of the lacustrine deposit is at least 10 feet and it is well exposed at several points. That it immediately underlies the later lava flow is plainly seen upon all sides, and that it originated since the older lava is shown by the fact that it rests upon the volcanic sand which covers the older lava. There are several small areas of the old lake bed within the northern portion of the lava field, but accurate data for their location were not obtained.

To determine the relations of the old lake deposit to the sheet of volcanic sand a trench was dug across their junction near the west end of

Lake Bidwell and it was found that not less than 10 feet of lake deposit rested upon the sand.

Another feature of interest associated with the present lakes is the snags they contain. In Snag Lake (Pls. XII and XIII) they were once abundant but are now less so, many having been blown down and floated ashore. A few are found also near the east end of Lake Bidwell. The snags are evidently the trunks of trees killed by having their roots submerged. Near both ends of Lake Bidwell the old lake deposits rise above the present level of the lake, but at the point where the snags appear Lake Bidwell has advanced upon the forest and shows that the shore of the old lake was warped so that it does not lie parallel to the water surface of the present lake.

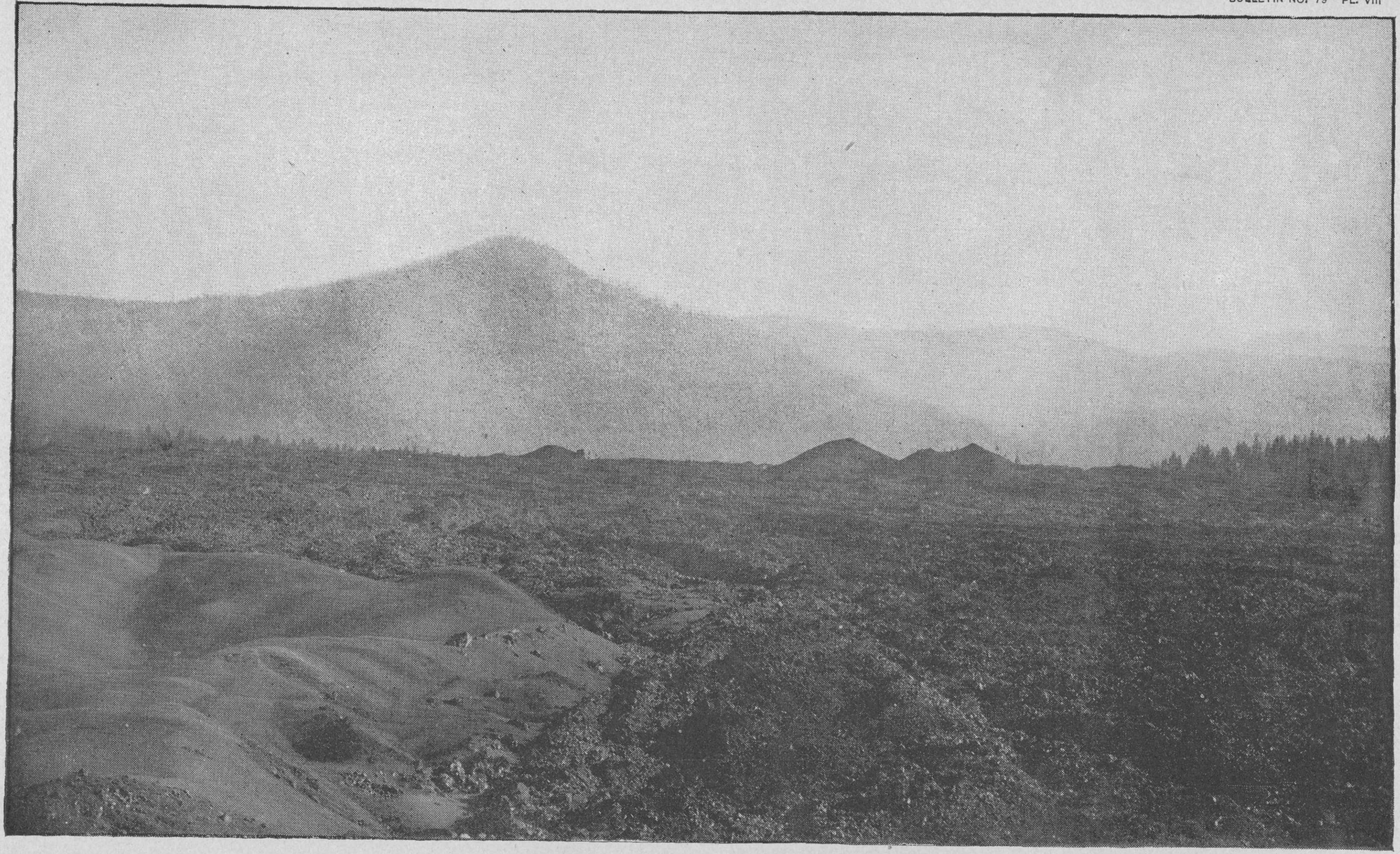
Lake Bidwell has a free outlet and rises during the rainy season only a few feet above low-water mark. On the other hand, Snag Lake has no free outlet and all its water, excepting that lost by evaporation, must escape through the lava field. During the rainy season, on account of the barrier which the lava imposes, the water of Snag Lake rises over a dozen feet. Upon its southwestern border the lava field forms two other small basins each of which contains a lake in wet weather.

HISTORY OF THE ERUPTION.

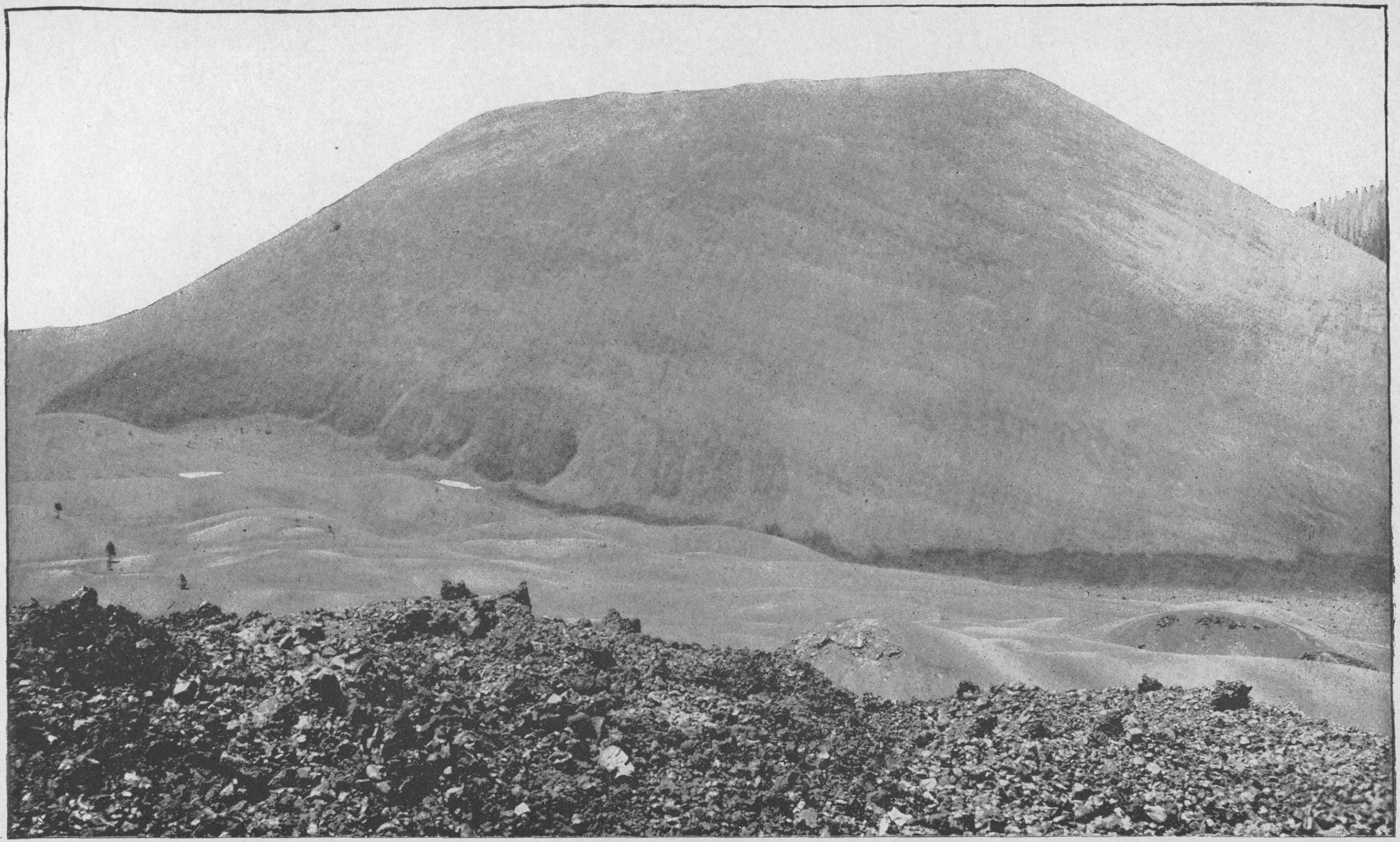
The history of this little volcano shows two periods of activity strongly contrasted in their phenomena and separated by a considerable interval of repose. The first period was characterized by violent explosive eruption, which formed the Cinder Cone and the ash field, and the second by the quiet effusion of a large mass of lava.

The first eruption began with the ejection of a great deal of light scoriaceous, almost pumiceous material, thrown out from the upper part of the magma, in which was stored a larger proportion than elsewhere of the highly expansible gases. When the passage to the surface was opened and the pressure relieved, this portion of the magma was much more highly dilated than any other. The expansion and disruption, however, were not sufficient to produce an appreciable amount of volcanic dust—a phenomenon which was a prominent feature of the late outburst at Krakatoa, sending its dust wafted on the winds for many hundreds of miles away. Succeeding the eruption of the pumiciform material, and continuous with it, came the volcanic sand, lapilli, scoria, and bombs from the next succeeding lower portion of the magma, containing a smaller amount of eruptible gases, but yet sufficient to tear it to pieces and hurl them into the air.

After the greater portion of the fragmental material had been ejected there was an effusion of considerable lava from the base of the Cinder Cone, and this effusion was accompanied and succeeded by a shower of sand which formed a thin coating over the lava already effused. Whether or not the effusion of the oldest lava and the succeeding



THE LAVA FIELD, LOOKING SOUTHEAST FROM THE CINDER CONE.



THE CINDER CONE, LOOKING WEST; OLDER AND NEWER LAVA IN THE FOREGROUND.

shower of ashes belong to the closing stages of the first eruption is not easily determined, but it is certain that all these preceded the long interval which separated the period of explosive eruption from the succeeding one of quiet effusive activity. During this interval of repose the old lake beds of infusorial earth and vegetable matter were laid down to a thickness of over 10 feet, and may represent a century or more of time.

This season of volcanic rest was again broken by the warping of the old lake bottom and the slow effusion of a great volume of very viscous lava from the southeastern base of the Cinder Cone. The new flow of lava developed the tabular lava field filling the shallow valley and forming the lava dam (Pls. XII and XIII) which gave birth to Snag Lake. A remarkable characteristic of the eruption was the entire absence of any explosion from the crater in connection with the effusion of so large an amount of very viscous magma, especially since the same vent at an earlier period had been the scene of violent ejection.

AGE OF THE ERUPTION.

The whole aspect of the Cinder Cone and lava field is so new that one at first feels confident of finding historic evidence of its eruption. To say that it was formed in the geologic yesterday, even, makes it too old, for it appears rather to belong to the early part of to-day. Some trees near the lava look as though they had been scorched by it at the time of the eruption, and visitors to the scene have conjectured that search would reveal volcanic ashes still clinging in the knot holes, crotches, and other lodging places among the adjacent forest trees. The investigation by Dr. H. A. Harkness, of San Francisco, concerning the age of the outbreak has been published,[1] and he infers, upon historic evidence of a very unsatisfactory character, that the eruption took place in January, 1850.

I have carefully sought among the earlier settlers, as well as among the Indians of that region, for positive historic evidence concerning the date of the eruption, but the only trustworthy testimony obtained is of a negative character. No white man or Indian now living is known to have been an eyewitness of the eruption, and it must be remembered that such an eruption would not leave the people of the region in doubt as to what was happening. What is now generally known in the Lassen Peak district as the Cinder Cone, was among the earliest settlers and trappers, as far back as 1845, called Black Butte. An old emigrant road yet in use passes by the very base of the Cinder Cone, and a number of individuals are living in the northern portion of the Sacramento Valley who crossed the trail in 1853, and report that the lonely bush growing near the summit of the cone was apparently as large then as now. Whatever may be the historical testimony as to

[1] Proc. Cal. Acad. Sci., Nov. 2, 1874, vol. 5, p. 408. See also article by Capt. C. E. Dutton, Science, July 17, 1885, vol. 6, p. 46.

the time of the eruption, the geologic evidence clearly demonstrates that it must have occurred long before the beginning of the present century.

Plate XIV shows the upper portions of a tree projecting from beneath the lava. The top has been broken off and lies upon the ground. The tree was pushed over by the advancing lava and apparently belongs to those killed at the first eruption when the Cinder Cone was formed. Two other trees of the older generation are seen in the view. The dead one on the left extends for a distance of more than ten feet down through the layer of volcanic sand to the original soil beneath, but the living trees in the neighborhood grow in the new soil upon the surface of the volcanic sand. They do not extend their roots more than three feet beneath the surface. The relation of the two distinct generations of forest trees is represented in Fig. 3. As the stumps of the trees killed at the time of the earliest eruption decay the sand caves in to take the place of the wood and forms a pit, as illustrated in the figure.

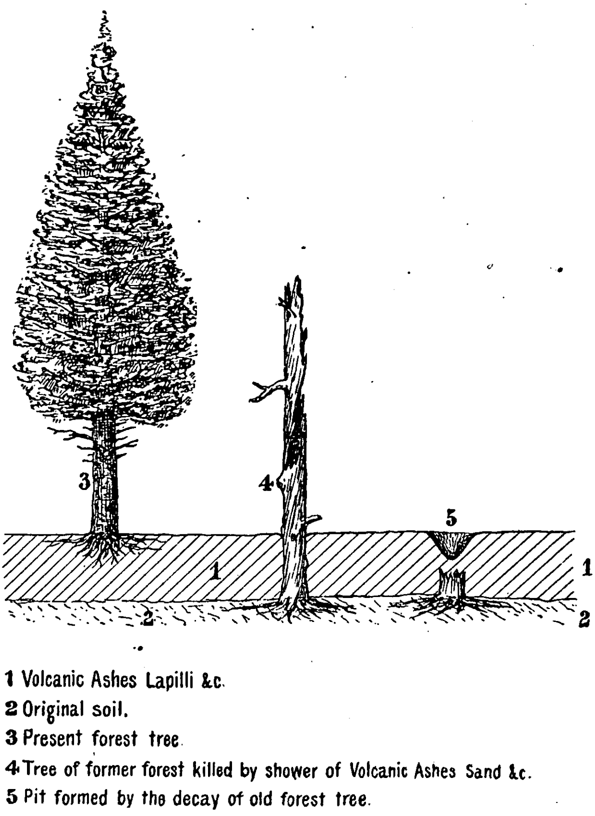
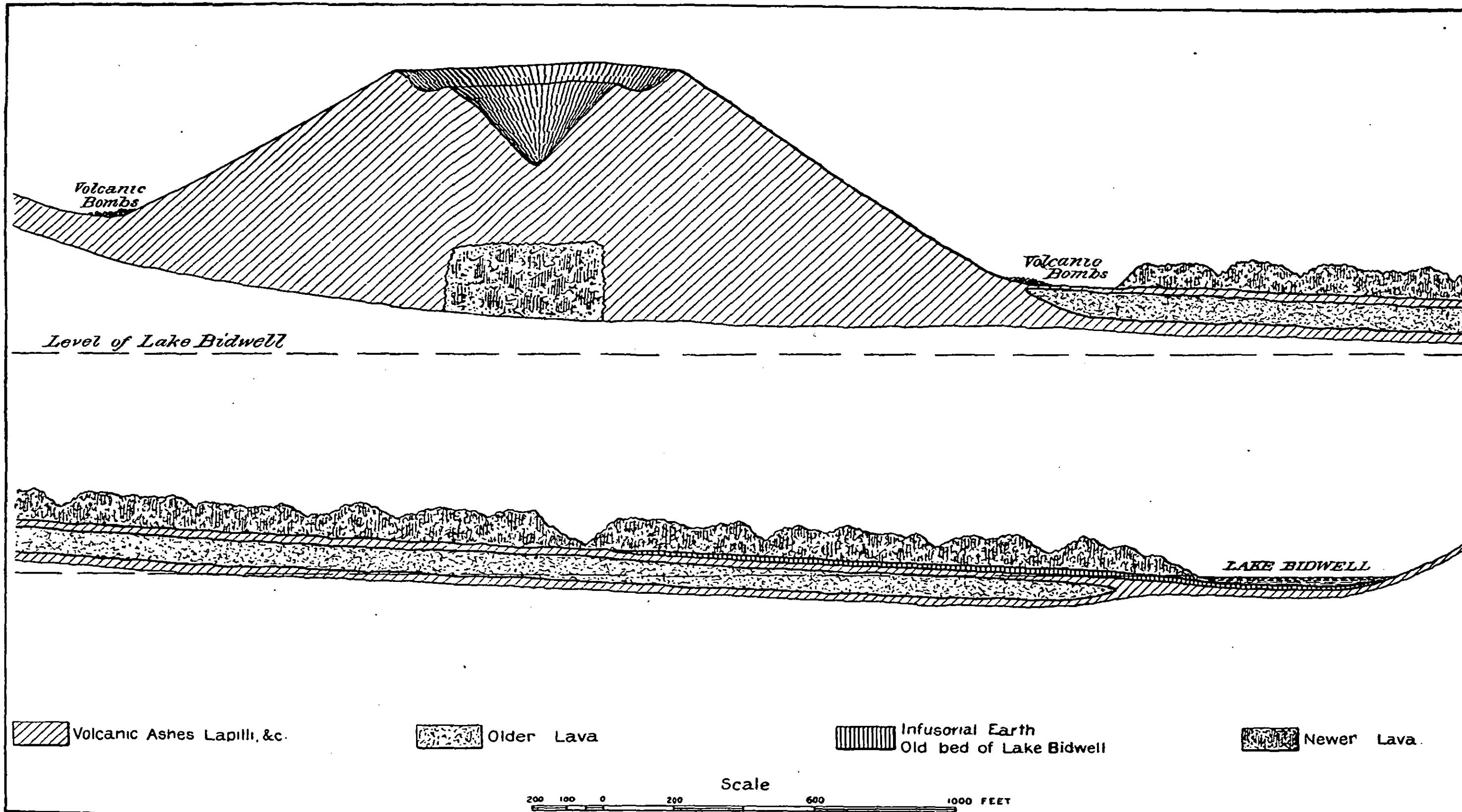


FIG. 3.—Relations of older and younger forests to volcanic sand.

These pits, often three feet deep, are numerous near the base of the Cinder Cone, and may be observed, at least to the southwest, for a distance of one and a half miles from the cone. The new forest has



SECTION THROUGH THE CINDER CONE, LAVA FIELD, AND LAKE BIDWELL.

attained its maximum growth for that region and there is no appreciable difference between it and the forest farther away from the Cinder Cone. Southwest of the Cinder Cone, however, as shown in Pl. xv, the new forest has a feebler development than elsewhere.

Several of the largest pine trees (*Pinus ponderosa*) in the vicinity of the Cinder Cone were measured two feet above the ground and found to be twelve feet in circumference, with a diameter, therefore, of forty-five inches and a thickness of solid wood of not less than forty-three inches. Not many miles to the westward from the Cinder Cone, where the climatic conditions are about the same, the heavy yellow pine is cut for lumber. The rings of growth were counted upon numerous stumps and it was estimated that the large pines near the Cinder Cone must have not less than 200 rings of growth. There is but one season of growth and one of repose for each year in that mountainous region, and there is good reason, therefore, for supposing that each ring represents a year's growth. If so, the trees by the cone must be about 200 years old. Presumably, as is well known to be true in other cases, the vegetation would take hold upon the volcanic sand very soon after the eruption, so that the age of the oldest trees may be taken as a rough approximation to the age of the first eruption, and we may with some reason conclude that it occurred nearly a century before the American Revolution. The second or effusive eruption occurred at a much later date, but certainly more than fifty years ago, and was of such a character as not to attract attention.

Upon the older portion of the lava southeast of the Cinder Cone a few pine trees have taken root. The largest has a diameter of one foot and over ninety rings of growth. Upon the newer lava near Lake Bidwell some scattered cottonwoods are growing. One shows over fifty rings of growth. It is interesting to note that dead pine trees, which are not usually supposed to maintain their form through more than thirty years of weathering, in this case have stood over 200 years. This may be attributed in large measure to the dry climate.

THE LAVA-QUARTZ BASALT.

The lava is readily recognized as basalt, one of the commonest of all types of late volcanic rocks, with hypocrystalline porphyritic structure. It has all the essential constituents of ordinary basalt, i. e., plagioclase feldspar, pyroxene, and olivine, together with accessory magnetite, and a large proportion of unindividualized material which is generally globulitic. In addition to all these common constituents of basaltic lava this basalt is remarkably anomalous in containing numerous grains of quartz.

The conditions under which the molten magma, erupted at the Cinder Cone, solidified to form the lava, were diverse at different places, and the physical features of the lava are varied accordingly. It ranges in structure from the highly vesicular in the pumiceous fragments spread beneath the sand to the very compact lava seen in some of the larger bombs and here and there throughout the lava field. Much the larger portion of the lava is somewhat vesicular, but the vesicles are small and irregular, so that the lava could not be classed among those which are prominently vesicular. The lava is wholly hypocrystalline, but ranges from almost completely amorphous to largely crystalline, and the degree of crytallization is in general inversely proportional to the vesicular structure.

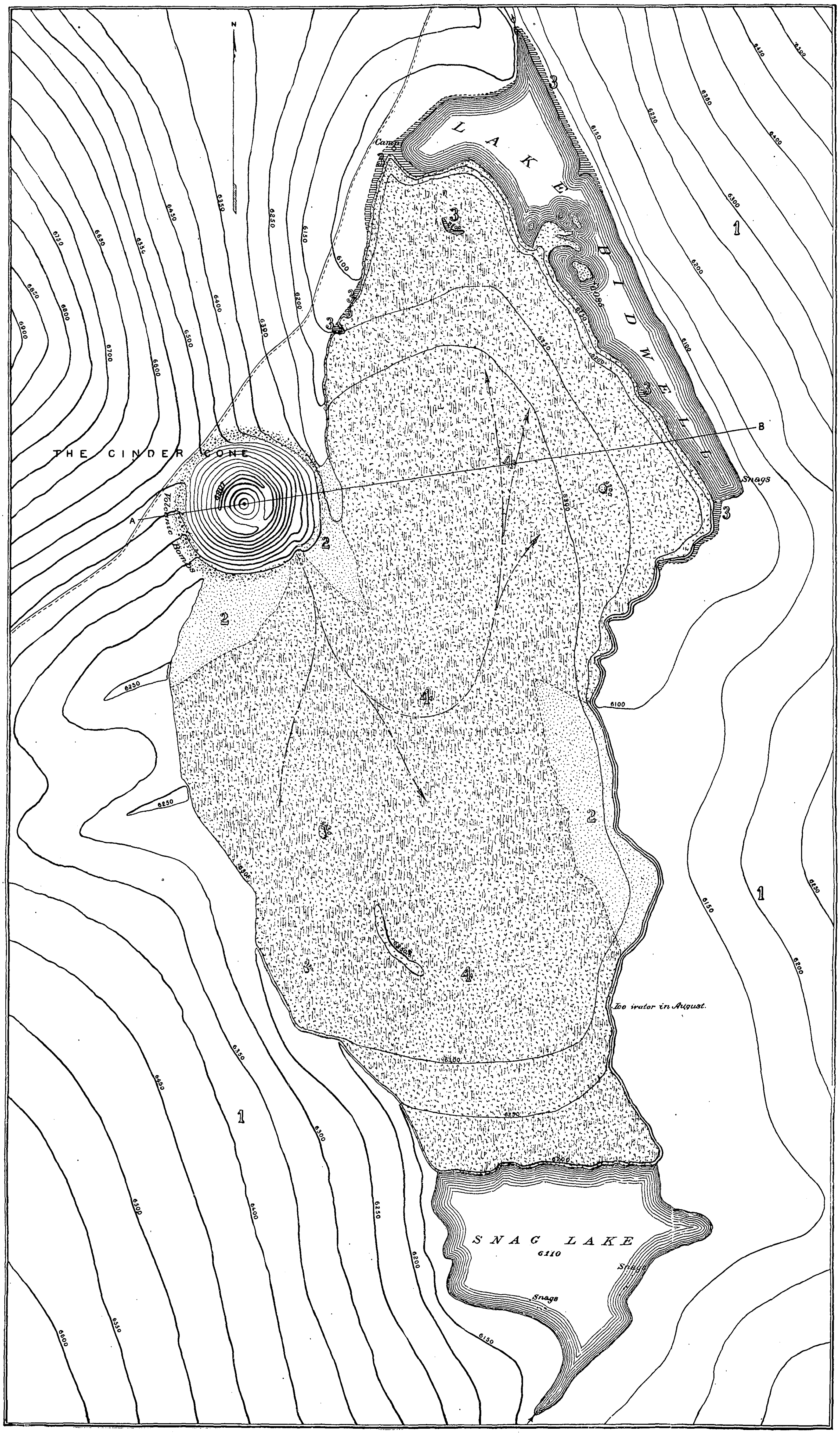
The light brown color of the pumiceous fragments is due to the presence of so much inflated glass whose color by transmitted light gives tone to the whole mass. Under the microscope it is seen that grains of olivine are numerous, some of them are well developed crystals and full of picotite. Rounded grains of quartz and clouded crystals of feldspar comparatively large are much less common. In the brownish glass are embedded a multitude of feldspar and augite microlites, occasionally having a stream-like arrangement about the minerals of the first generation. Many vesicles of various sizes are visible in the section and each one has a smooth, glassy lining. Of all the lava this was cooled the most suddenly. It contains the fewest products of crystallization, and indicates that in the upper portion of the magma, which was saturated with water under great tension awaiting the outburst, the olivine was already completely formed. The same is true of the quartz and the larger clouded crystals of feldspar, all of which have undergone partial resorption by the magma. On the other hand, while the eruption was in progress and the lava cooling many tiny crystals of feldspar and pyroxene were formed.

The lapilli are black and less vesicular than the pumiceous fragments, and differ from them chiefly in having a smaller amount of less glassy groundmass. The lath-shaped feldspars and grains of pyroxene have greatly increased in size and number so as to become conspicuous. The dark groundmass is full of colorless microlites mixed with minute black and cherry-red grains of iron oxide which are enveloped by a clear or clouded light brown occasionally globulitic base. The most vesicular portion of the lava cooled near the surface. It is extremely rough and cindery owing to the eructation of steam and other gaseous matter from the vesicles lying near the surface.

Although much less porous than the lapilli, it contains a much larger percentage of light brown glass and in this respect is very like the pumiceous fragments. A short distance beneath the surface the lava becomes more crystalline. The crystals and crystalline grains are larger, and the glassy base gradually arranges itself in minute spheres until it is completely replaced by a multitude of dark globulites.

The most highly crystalline lava was found along the southwest border of the lava field one-third of a mile south of the Cinder Cone. It is the portion best adapted for the study of its minerals.

Of the mineral constituents of the lava the feldspar is most abundant; then follows the pyroxene in a nearly equal amount with less olivine,



1 Volcanic Sand Lapilli &c

2 Oldest Lava and Lava partly covered by ashes &c.

3 Infusorial Earth. Old bed of Lake Bidwell.

4 Newest Lava.

Scale.

1000 500 250-100-0 1000 2000 FEET

GEOLOGIC MAP OF THE CINDER-CONE REGION.

and finally quartz. Abundantly scattered throughout the rock and filling the spaces between the minerals is a dark globulitic base, which makes up nearly 25 per cent of the mass.

Some of the olivine occurs in well defined crystals bounded by the usual prismatic and pyramidal planes, but by far the greater portion appears in round or irregular grains. It envelopes a large number of regular octahedral crystals and grains of a coffee-brown mineral, which is supposed to be picotite. Glass and liquid inclusions are also common, and the olivine is much fractured. That the olivine is one of the oldest minerals of the basaltic magma is clearly indicated by the fact that it is included in both feldspar and pyroxene. Granules of the latter sometimes appear to be most abundant upon the borders of the olivine in such a way as to recall a hypothesis advocated by Dr. M. E. Wadsworth[1], to the effect that a part of the pyroxene in basaltic rocks owes its genesis to the resorption of an earlier generation of olivine. Some of the olivine is so intercrystallized with the pyroxene as to indicate that both are in part of essentially the same age. The familiar black border which is a common feature of the olivine in many basalts is generally present in the central portions of the volcanic bombs, but has not been observed in any portion of the lava field.

The pyroxene is chiefly hypersthene, but augite also is sparingly present. The pyroxene is more abundant than the olivine, but less so than the feldspar, a feature which prevails among the andesitic basalts of the Cascade Range. The hypersthene is sometimes completely idiomorphic, but commonly only partially so, being allotriomorphic against the feldspar. The crystals are short, rather thick prisms less than two-tenths of a millimeter in length. As in the hypersthene andesites long ago pointed out by Dr. C. W. Cross,[2] the lateral pinacoids are largely developed and generally predominate over the prism planes. Obtuse pyramidal terminations were also observed. This hypersthene has a faint reddish yellow tone with perceptible pleochroism, which assists in distinguishing it from augite. It occasionally contains numerous irregular glass inclusions which permeate the interior portion of the crystal, but not so completely as in the first generation of feldspar. Some of the pyroxene is irregularly granular, and the system of crystallization is determined with difficulty. There are more or less completely developed crystals whose monoclinic character is evident, but much the larger number of grains appear to be orthorhombic. The most noteworthy feature of the monoclinic pyroxene is the granular borders which it forms about the grains of quartz. These are described and figured in connection with the quartz page.

The feldspar is of two sorts, and both are idiomorphic. The one occurs in relatively large, irregular crystals with clouded interiors; the other appears in sharply defined, lath-shaped polysynthetic twins, which predominate in rocks of this class and present no features worthy

[1] Bull. Mus. Comp. Zool., Cambridge, Mass., 1879, vol. 5, p. 279.
[2] Bull. U. S. Geol. Survey, No. 1, 1883.

of special mention. The irregularities of the clouded feldspars are due in part to crystallization and in part to the subsequent corrosive action of the magma which modified the original form. In some of them the interior is completely ramified by glass and globulitic inclusions. The outer zone of such crystals is usually clear and free from inclusions. These larger crystals are nearly all polysynthetic twins, with broad lamellæ, but their impure condition renders an exact determination impracticable.

Notwithstanding the strong contrast there is between the two sorts of feldspar in general, there are a few forms intermediate in size and general appearance so as to connect the generation of feldspars formed during the intratelluric period of the magma with those developed during its effusion.

THE QUARTZ OF THE QUARTZ BASALT.

The most interesting feature of this basalt is to be found in the remarkably large percentage of quartz which it contains, widely distrib-

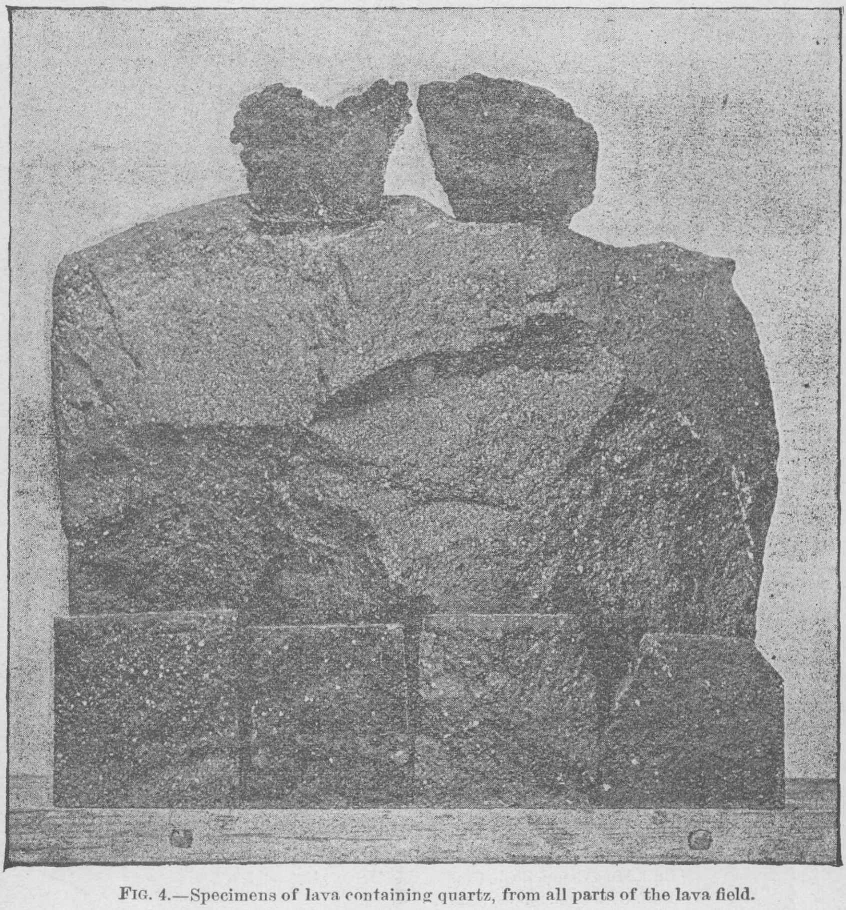
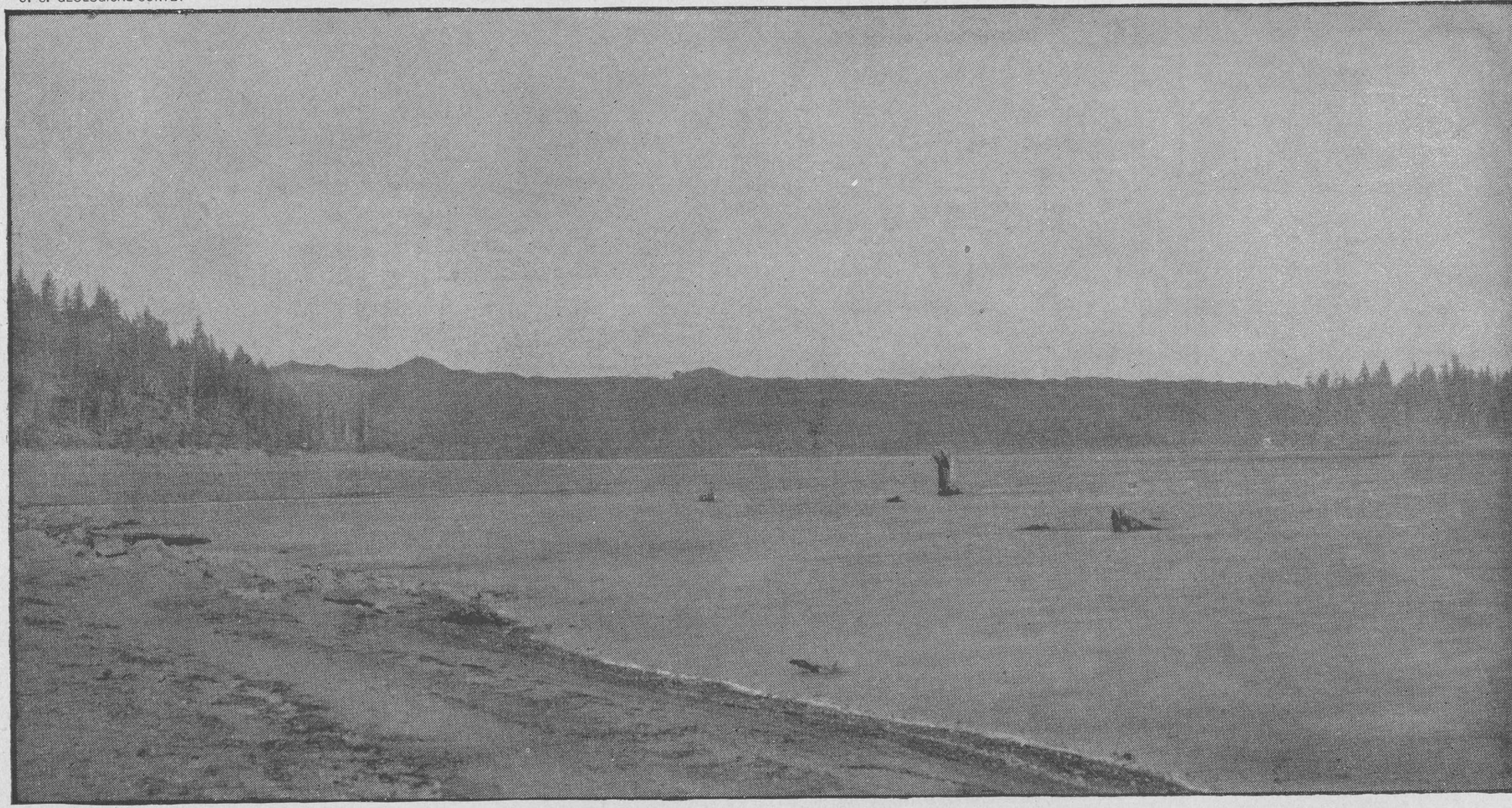
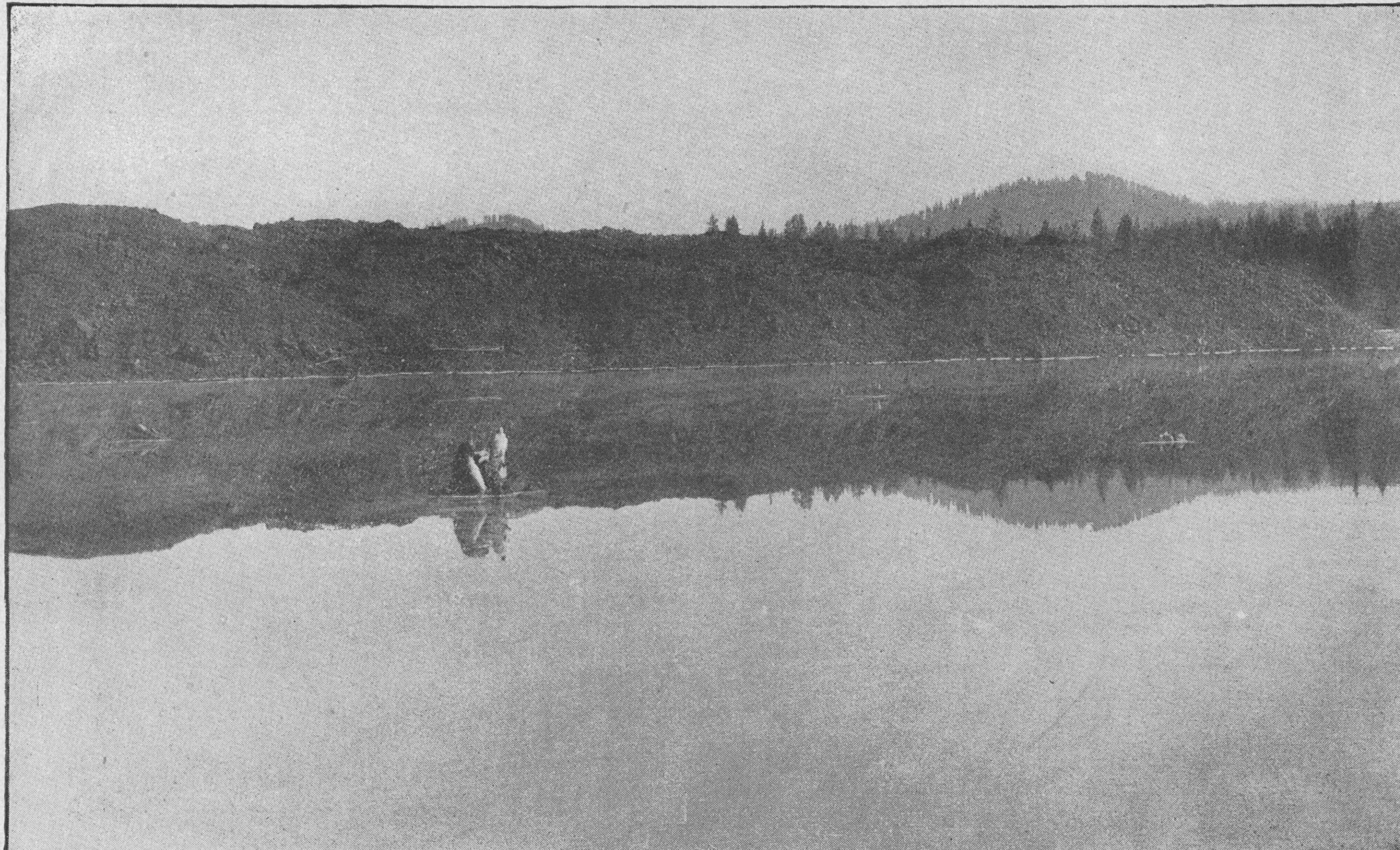


FIG. 4.—Specimens of lava containing quartz, from all parts of the lava field.



THE LAVA DAM AND SNAG LAKE.



THE LAVA DAM AND SNAG LAKE, NEAR VIEW.

uted through the mass. The quartz grains are in fact frequently so abundant as to impart a decidedly porphyritic structure to the mass, but generally they are so small as to be inconspicuous. Very rarely grains may be found over an inch in diameter. The average diameter is about one-thirtieth of an inch. Those lying near the surface of the lava flow are fractured, sometimes breaking into small prisms, but in the interior portion of the lava fractures are absent, a feature which suggests that they were produced by sudden cooling.[1]

The uniform distribution of the porphyric grains of quartz throughout the lava can be plainly seen in Pls. XVI and Pl. XVII, and also in Fig. 4, which represents fragments from all parts of the lava field. That the quartz is equally scattered in the lava is shown even more forcibly by the thin sections, of which over fifty distributed throughout the lava mass have been examined microscopically, and the presence of quartz is evident in nearly every section. The same fact is impressed by the chemical analyses not only of the lava from various portions of the lava fields, but also of volcanic bombs and sand at different distances from the Cinder Cone.

The quartz grains are irregular in shape, frequently angular, but generally rounded and embayed as the phenocrystic[2] quartz in other lavas. Notwithstanding the large number of sections examined, not a single idiomorphic crystal of quartz was found. All have been greatly modified apparently by the corrosive action of the magma. From a hand specimen, however, one crystal was obtained, which, although somewhat rounded, yet retains distinct traces of its former bipyramidal form. It is probable, therefore, that originally a large number of the included grains of quartz may have been dihexahedral crystals just as in other eruptive rocks.

Each grain of quartz, excepting those in the pumiceous fragments, is encircled by a shell of granular, acicular augite, which is separated from the quartz by a film of glass. In Pl. XVII, Nos. 1 and 2, such quartz grains are represented. The irregular grains of quartz in the center are surrounded by glass, which is darkened in the figures, and outside of this is the more or less radially granular or acicular augite. The borders of glass and augite are constant features of the quartz, and appear to be reactionary rims resulting from the corrosion of the quartz by the magma.

The resorption of the quartz is partial only. The great majority of the grains have only their outer portions removed, but there are many others which have nearly or completely disappeared. In Pl. XVII, Nos. 3 and 4 represent grains of quartz which have almost disappeared. Only small portions of the original quartz remain imbedded in the glass. In No. 5 the quartz has entirely disappeared, and in No. 6 the glass has gone also, leaving a group of augite crystals to tell the story. In

[1] Rosenbusch, Mik. Physiographie, vol. 2, p. 356.

[2] For the use of the term "phenocryst," see Mr. J. P. Iddings's paper on the Crystallization of Igneous Rocks, Phil. Soc. of Washington, D. C., Bulletin, vol. xi, p. 73, foot-note.

this way are produced structures which appear in most cases at least to be identical with the so-called "augite eyes" (Augitaugen[1]) which are well known in a number of European basalts.

The quartz is colorless and transparent with few liquid or gas inclusions. Glass inclusions are more abundant but are rarely dihexahedral. They are most common in deeply embayed grains, and appear in many cases to be of secondary origin like those described by Crustschoff.[2] In its essential features the quartz in the basalt is identical with the phenocrystic quartz of the dacites and rhyolites and differs decidedly from granitic quartz and that of the crystalline schists.

The glass border with which the quartz grains are surrounded is generally colorless and transparent, but occasionally it is brown. In the highly vesicular lava the glass rims generally contain bubbles. These are sometimes so numerous as to render the glass pumiceous. Among the lapilli of the Cinder Cone and in the volcanic sand small fragments of white pumice are not uncommon, and upon examination some of them are found to be almost wholly pumiceous glass containing remnants of quartz and feldspar.

A chemical analysis of one of these enveloped fragments of white pumice is given in column 10, p. 29. Whether the fragment is an inclusion or an early secretion which has been fused and inflated is not easy to determine.

The pyroxene of the border about the quartz may be well crystallized or irregularly granular. Rather long thin crystals are most numerous and frequently converge, penetrating the glass toward the disappearing quartz in such a way as to indicate the direction of their growth.

The small crystals have a large angle of extinction and evidently belong to the monoclinic pyroxenes. They have much stronger double refraction than the hypersthene.

The pyroxene border is epigenetic, and it formed during the effusion of the lava, for it is certainly one of the latest developments in its own neighborhood, and the fact that it is sometimes absent about quartz grains in the pumiceous fragments clearly shows that the sudden eruption and cooling of that portion of the magma prevented its development.

This long thin monoclinic form of pyroxene appears to be found only in groups and owes its existence to the destruction of quartz. It may, perhaps, be closely related to the so-called porricin of the Eifel lavas.

Only four hypotheses suggest themselves in explanation of the origin of these quartz grains in the basalt. They may be regarded (1) as remnants of a rock from which the basalt may have been derived deep in the earth by fusion; (2) as included fragments picked up by the way as the lava was passing from the interior of the earth to its present position; (3) as products of crystallization in the magma itself; and

[1] Rosenbusch, Mikroskopische Physiographie d. Massigen Gesteine, 2d ed., vol. 2, p. 727.

[2] Tschermak's mineralog. und petrog. Mittheil., 1882, vol. 4, p. 473.

TREE PUSHED OVER BY ADVANCING LAVA.

(4) as secondary products resulting from metasomatic changes in the lava since its eruption.

The lava is absolutely fresh and unaltered, so as completely to negative the view which regards the quartz as a product of metasomatic changes.

Concerning the first hypothesis, it may be said that there are many prominent geologists who incline to the belief that eruptive rocks originate in the fusion of deeply buried sediments. As already indicated, in unaltered eruptive rocks there are two petrographic types of quartz. The oldest generation of quartz crystals in eruptive rocks is characterized by idiomorphic or corroded outlines and glass inclusions often dihexahedral like the host, with some liquid inclusions. Quartz of this sort always occurs as phenocryst in the rock, and its associations clearly demonstrate that it crystallized out of a molten magma at great depths within the earth.

The quartz in a normally developed granite is the last product of crystallization, filling out the spaces between the crystals of other minerals. It differs from phenocrystic quartz in being allotriomorphic, without glass inclusions, and in containing in general a greater abundance of liquid inclusions. It is the characterizing quartz of granitic rocks, and on that account Rosenbusch has designated it as granitic quartz.[1]

Granitic quartz is closely allied to vein quartz, and that which occurs in metamorphic rocks and bears the impression of having been deposited under condition more of aqueous solution than of igneous fusion.

The quartz of the basalts is not of the granitic phase which pervades sedimentary rocks, but wholly of the phenocrystic type, whose pyrogenic crystallization is evident, and its essential features decidedly negative the view which regards it as the unfused remnant of a sediment.

As to the second hypothesis, which surmises the quartz grains to be included fragments picked up by the lava along the walls of the volcanic chimney or upon the surface of the earth during its effusion, the considerations already mentioned are of great weight. The quartz is not of the type which prevails in sedimentary rocks through which the magma passed on its way to the surface, but of the type whose origin is intratelluric, the very source of the lava itself.

Besides the quartz basalt, the only other lava of the Lassen Peak district that contains phenocrystic quartz is dacite. It is true that the dacites are all older than the quartz basalt, and that the latter may have reached the surface by breaking through the dacites from which perhaps the phenocrystic quartz could be derived. Quartz is more abundant in the basalt than in the dacite, and the amount of dacite that would have to be ransacked to raise quartz sufficient to stock the quartz basalt would be much larger than the mass of the quartz basalt itself.

[1] Rosenbusch, Mikrosk. Physiog., 2d edition, vol. 1, pp. 340–342.

Veritable inclusions in the quartz basalt have been diligently sought for and almost in vain. Only one small fragment of dacite was found in the basalt. It was a fragment picked up upon the surface and showed no tendency whatever to yield up its quartz to the basalt. Furthermore, there are in the same region numerous cinder cones and flows of basaltic lava which have penetrated the same formation to reach the surface as did the quartz basalt, and if the quartz grains are inclusions, all the basalts of that immediate vicinity ought to be quartziferous.

It has been urged that the envelope of pyroxene encompassing the grain of quartz characterizes them as included fragments. All the quartz grains in the magma, whether native (indigenous) or foreign (included) to the lava at the time of its effusion, would be subjected to the same conditions. All would be corroded by the magma and each have its reactionary rim of pyroxene formed, so that the presence of such a border can not be used as a means of distinction. This envelope is absent from the phenocrystic quartz in the quartz porphyries, rhyolites, and generally also in the andesitic rocks; but the above is true also of quartz inclusions in the same lavas. The presence or absence of an envelope of pyroxene is not determined by the source of the quartz, but by the chemical composition of the basic magma which corrodes it.

The uniform distribution of the quartz grains throughout the lava is an insuperable objection to regarding them as inclusions. They are found not only in all parts of the lava field, but everywhere in the Cinder Cone and throughout the volcanic sand. Their distribution is universal, like that of the olivine, pyroxene, and feldspar, and it is impossible to satisfactorily explain their omnipresence on any other hypothesis than that they are indigenous to the lava and crystallized out in place, belonging to the basalt and forming an essential part of it, just as much as the olivine, feldspar, and pyroxene.

OLDER LAVA, ASH FIELD, AND LASSEN PEAK, FROM THE SOUTH BASE OF THE CINDER CONE.

Chemical analyses of volcanic product.

	1	2	3	4	5	6	7	8	9	10
SiO_2	56.18	57.25	54.56	56.70	56.53	55.93	57.59	56.51	56.58	79.49
TiO_2	} 16.59	0.60	0.53	0.65	0.54	} 17.34	16.49	0.48	0.77	} *11.60
Al_2O_3		16.45	16.04	15.75	17.50			18.10	14.88	
Cr_2O_3	......	....	trace.	trace.	trace.	....	....	trace?	trace?	....
Fe_2O_3	1.51	1.67	0.95	1.29	1.35	1.50	1.22	4.26	2.31	0.32
FeO	5.51	4.72	6.07	5.32	5.03	5.20	4.89	2.68	3.04	0.49
MnO	undet.	0.10	0.17	0.19	0.12	undet.	undet.	0.11	0.16	none.
CaO		7.65	8.89	7.67	8.07	8.04	....	8.15	8.69	......
SrO	} 7.61	trace.	trace.	trace.	trace?	....	} 7.40	0.04	....	} 1.64
BaO		0.03	0.03	0.03	trace.	(?)		0.04	0.07	
MgO	7.26	6.74	8.71	7.16	5.94	7.29	7.72	4.52	3.76	0.09
K_2O	1.47	1.57	1.18	1.56	1.55	1.35	0.99	1.15	2.18	1.52
Na_2O	} 3.58	3.00	3.05	3.36	3.51	3.32	} 3.62	3.23	3.36	} 4.04
Li_2O		none.	trace.	trace.	trace.	(?)		trace.	CO_2 2.32	
H_2O	0.42	0.40	0.28	0.30	0.27	0.26	0.86	0.69	2.12	0.68
P_2O_5	with Al_2O_3	0.20	0.18	0.20	0.15	with Al_2O_3	with Al_2O_3	0.14	0.15	....
	100.16	100.38	100.64	100.18	100.56	100.23	100.78	100.10	100.39	99.88

* Contains P_2O_5 if any present.

1. Lava from west end of Lake Bidwell. Analyst, W. F. Hillebrand.
2. Lava near Cinder Cone. Analyst, W. F. Hillebrand.
3. Lava from point ½ of a mile south of Cinder Cone. Analyst, W. F. Hillebrand.
4. Volcanic bomb. Cinder Cone. Analyst, W. F. Hillebrand.
5. Lapilli. Cinder Cone. Analyst, W. F. Hillebrand.
6. Volcanic sand. One-half mile NE. of Cinder Cone. Analyst, W. F. Hillebrand. Sand from 10 miles NE. of Cinder Cone contains 54.15 per cent of silica. Another sample, ½ mile, contains 54.96 per cent, SiO_2. Determined by E. L. Howard.
7. Lava from Silver Lake, Cal. Analyst, W. F. Hillebrand.
8. Lava from north base of Lassen Peak. Analyst, W. F. Hillebrand.
9. Lava from Mytilene. Analyst, T. M. Chatard. This specimen contains also CO_2=2.32, H_2O at 105°=.69, at red heat, 1.43°.
10. White pumiceous fragment enveloped by lava at the base of the Cinder Cone.

The chemical analyses of quartz basalt given in the accompanying table were made in the laboratory of the U. S. Geological Survey. The first six are of various sorts of material ejected and effused from the Cinder Cone 10 miles northeast of Lassen Peak, California, and they show the remarkable uniformity in the distribution of the silica. The percentage of SiO_2 is high in all of them. The one from the north base of Lassen Peak as well as that from Mytilene is poor in olivine and somewhat andesitic and the latter is considerably altered. Mr. J. P. Iddings demonstrated by chemical analyses of some New Mexican quartz basalts[1] that the presence of phenocrystic quartz in the basalts is not determined by a high percentage of silica in the magma, as one might be led to infer from the analyses in the table above.

The important lesson to be learned from this remarkable basalt is that quartz and olivine in abundance have actually crystallized in the same magma before its eruption. The relative ages of these two min-

[1]Am. Jour. Sci., Sept., 1888, vol. 36, p. 220.

erals are not at first evident, for neither is ever found included in the other. They are not congregative. The quartz is wholly free from mineral inclusions and has been deeply corroded by the magma; on the other hand the olivine contains many crystals of picotite and has suffered comparatively little from the caustic action of the mother liquor. These facts indicate with a high degree of probability that the quartz is older than the olivine. If the amount of corrosion a mineral has experienced may be taken as an index of relative age, it is certain that phenocrystic quartz is one of the very oldest minerals of the lava in which it occurs.

Quartz basalt holds the same relation to the general group basalt as dacite does to andesite and quartz trachyte (rhyolite) to trachyte. Quartz trachytes are very abundant as compared with trachytes. In the basalts, however, the other extreme is reached: the quartz-bearing members are rare while ordinary basalts are the most abundant and widely distributed of all lavas. In the andesites the quartz-bearing and quartzless members are more nearly equal.

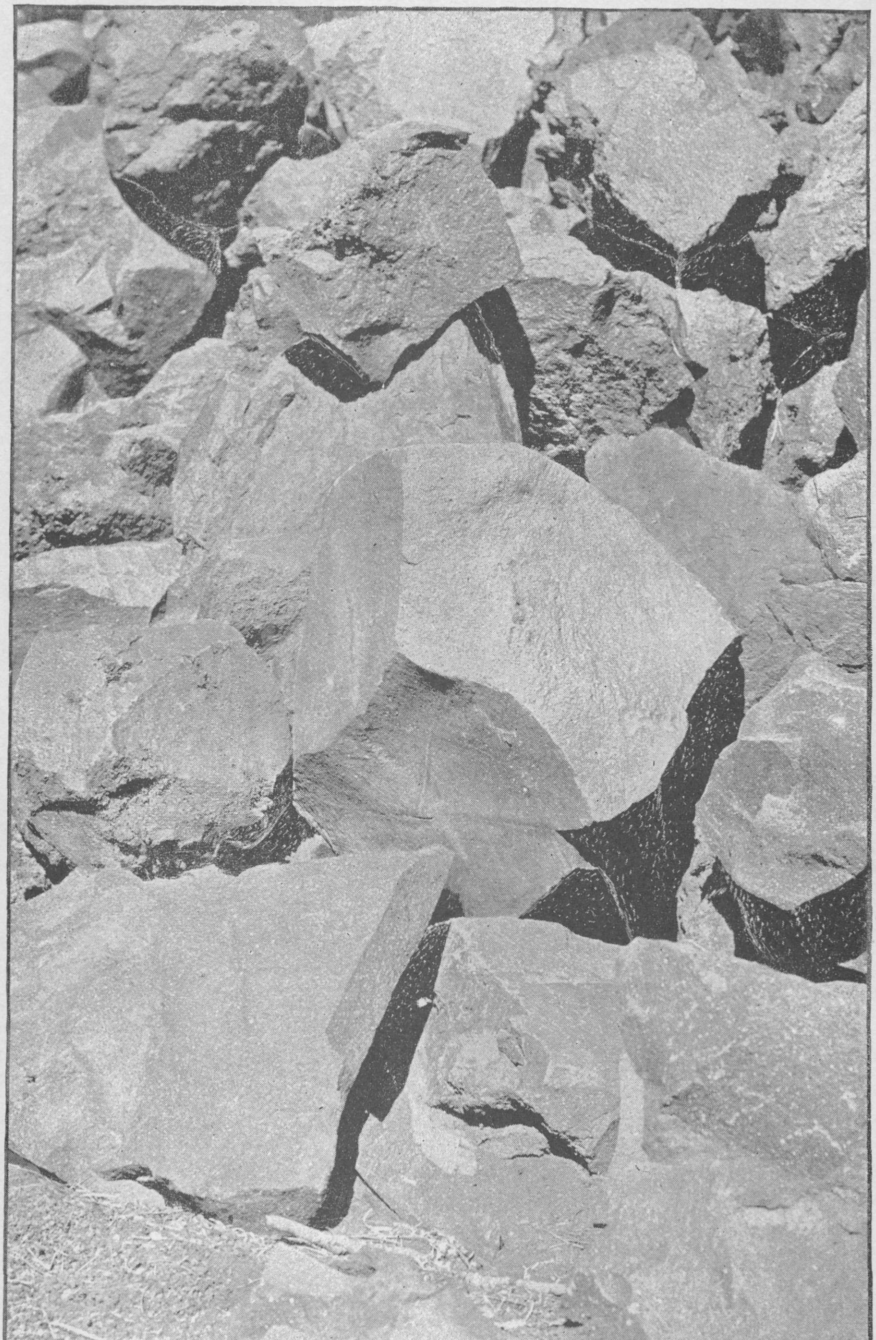
DISTRIBUTION OF QUARTZ BASALT.

When the quartziferous character of the basalt at the Cinder Cone was discovered it was regarded as almost unique, but subsequent investigation has revealed the fact that such basalts are by no means as rare as formerly supposed.

In the Lassen Peak district alone they have been effused from four different volcanic vents. At Silver Lake, 25 miles northwest of Lassen Peak, the outburst, although not so recent as that just described, is a late flow, younger than any of its neighbors, and was very viscous at the time of its eruption, forming a lava field nearly equal to that at Snag Lake.

Near the northwestern base of Lassen Peak, northeast of Chaos, at an elevation of about 8,000 feet, there is a small outcrop of quartz basalt, chiefly fragmental, the source of which has not been definitely determined. East of north from Lassen Peak about twenty miles, bordering the valley of Hat Creek upon the east, is an edge of a platform which is well known in that region as Hat Creek Hill. It was formed by a north and south fault and is capped by a basalt which contains occasional grains of quartz. A microscopical examination reveals a number of groups of acicular pyroxene crystals (Augitaugen) which represent resorbed quartz, and it is evident that the magma was once full of quartz crystals which have almost completely disappeared.

At the time of its eruption the lava was very fluent—spreading far and wide almost as level as a sheet of water. It is not vesicular and almost holocrystalline and has a decidedly diabasic structure. In all of these features it is strongly contrasted with the quartz basalt of the Cinder Cone. Both rhombic and monoclinic pyroxene are present. The former is the older and idiomorphic; the latter is allotriomorphic and



NEAR VIEW OF LAVA

The white grains are quartz.

largely predominates. Olivine is not abundant and is wholly granular. From the four examples of quartz basalt already discovered in the Lassen Peak district it is very probable that others will yet be found in the same region.[1]

The finding of quartz as a constant ingredient in some of the basalts of the Lassen Peak district has led me to examine many other American lavas of the same class.

While studying the Grand Cañon region, Capt. C. E. Dutton made an extensive collection of basaltic lavas, which are of interest on account of the evidence they furnish concerning the resorption of minerals developed early in the crystallization of the magma. In the newest lava nodules of olivine are abundant, ranging in size from a few inches to a foot in diameter. Corroded crystals of hornblende, quartz, and feldspar are not uncommon. In a few of the sections from the older lavas of Mounts Trumbull and Logan the characteristic augite eyes, both with and without quartz in the center, have been observed.

At the Ice Cave Buttes and Tabernacle Crater, 10 miles west of Fillmore City, Utah, there is a volcanic field described by Mr. G. K. Gilbert.[2] The numerous lava flows are of basalt, which frequently contain quartz scattered throughout the mass. The quartz appears to be most abundant in the newest lava.

In a collection made by Capt. Dutton in the vicinity of Mount Taylor, New Mexico, there are numerous basalts, and among them are specimens containing augite eyes as well as a few grains of corroded quartz, besides rounded and embayed grains of oxide of iron and augite. The most interesting of these late quartz-bearing lavas is in the immediate vicinity of Grant station, on the Atlantic and Pacific R. R. Recently a number of sections prepared from the basalts which form the volcanic necks east of Mount Taylor have been examined, and in some of them there are eyes of pyroxene with here and there a trace of phenocrystic quartz, but in the great majority of basaltic lavas of that region, all of which have passed through the same formations to reach the surface, there is no trace of primary quartz.

Mr. Iddings read a paper before the Philosophical Society of Washington in which he described several specimens of basalt collected by Maj. J. W. Powell and Mr. W. H. Holmes in Northern New Mexico.[3]

These basalts contain numerous grains of phenocrystic quartz, which Mr. Iddings described in detail, and in all essential features they are identical with those in the quartz basalt at Snag Lake. Analyses of the lavas from New Mexico show that in chemical composition they are normal basalts, clearly demonstrating, Mr. J. P. Iddings argued, that

[1] Dr. M. E. Wadsworth informs me by letter (March 26, 1887) that in studying the basalts of California he has found a number of them to contain quartz. In his writings he frequently refers to this interesting phenomenon in other basalts also. "Classification of Rocks," Bull. Mus. Comp. Zool., Cambridge, Massachusetts, vol. 5, pp. 276, 281, 286. "Geology of Iron and Copper District of Lake Superior Region," 1880, p. 48. Proc. Boston Soc. Nat. History, 1881, pp. 266, 267; 1883, pp. 418, 419.

[2] Mon. U. S. Geol. Survey, vol. 1, Lake Bonneville, pp. 320-325.

[3] Am. Jour. Sci., Sept., 1888, vol. 36, p. 208. See also U. S. Geol. Survey Bull. No. 66.

the presence of the quartz is not determined by the chemical composition of the magma. He regards the quartz as primary and indigenous to the basalt, and advances a hypothesis to account for its crystallization in such a basic magma, attributing it chiefly to the action of superheated steam under considerable pressure. He calls attention also to several quartz-bearing basalts in the fortieth parallel collections,[1] and more especially to some found in Arizona and Colorado, as well as near Eureka, Nevada[2].

In connection with the Assos expedition in 1882, the writer collected specimens of quartz basalt upon the outskirts of the city of Mytilene, northwest of Smyrna. The lava is andesitic basalt, which contains numerous grains of quartz associated with brown glass and a border of pyroxene. Traces of phenocrystic quartz were observed in basalts of the Troad, near the plain of Troy, and in all cases there is no doubt as to the primary character of the quartz.

The investigations of Bleibtrau,[3] Lasaulx,[4] vom Rath, Zirkel,[5] Rosenbusch,[6] and especially of Lehmann,[7] have rendered the basalts of Jungfernberg, Petersberg, Oelberg, Niedermendig, and other places in the valley of the lower Rhine, celebrated for the quartz they contain.

The basalts contain inclusions which, according to Lehmann, have been fused. Quartz and a host of other minerals have been identified as crystallizing out of the fused mass chiefly in cavities. I have examined about a dozen thin sections of basalts from the localities named, including one from Gerolstein, and find rings of augite (Augitaugen) with or without grains of quartz in the center clearly marked in all of them. In nearly every respect the quartz I have seen closely resembles that in the lava at the Cinder Cone, and it is probable that much of it has the same history. It must be borne in mind that, according to Lehmann, there are two phases of quartz in many of the basalts in the lower Rhine Valley: (1) Quartz inclusions, which are small grains and more abundant than all other kinds of inclusions; each grain is corroded and surrounded by an envelope of augite; (2) well developed crystals of quartz (pyrogenous quartz), which crystallized out in cavities as a consequence of the fusion of siliceous (but not quartz) inclusions. Perhaps many of the simple grains of quartz which Dr. Lehmann, largely for theoretical reasons, regards as inclusions may be indigenous to the lava.

Rosenbusch mentions the occurrence of "Augitaugen" in the basalts of the Vogelgebirge. Lehmann writes that quartz grains occur in the

[1] Noted also by Zirkel (Geol. Explor. Fortieth Parallel, vol. 6, p. 251) and King (Geol. Explor. Fortieth Parallel, vol. 1, pp. 655 and 656), and Wadsworth (Bull. Comp. Zool., vol 5, No. 13, p. 286).

[2] Mr. Arnold Hague, in the Ann. Rept. of the Director U. S. Geol. Survey for 1881 and 1882, pp. 279 and 280, calls attention to the quartz grains in the Eureka basalt.

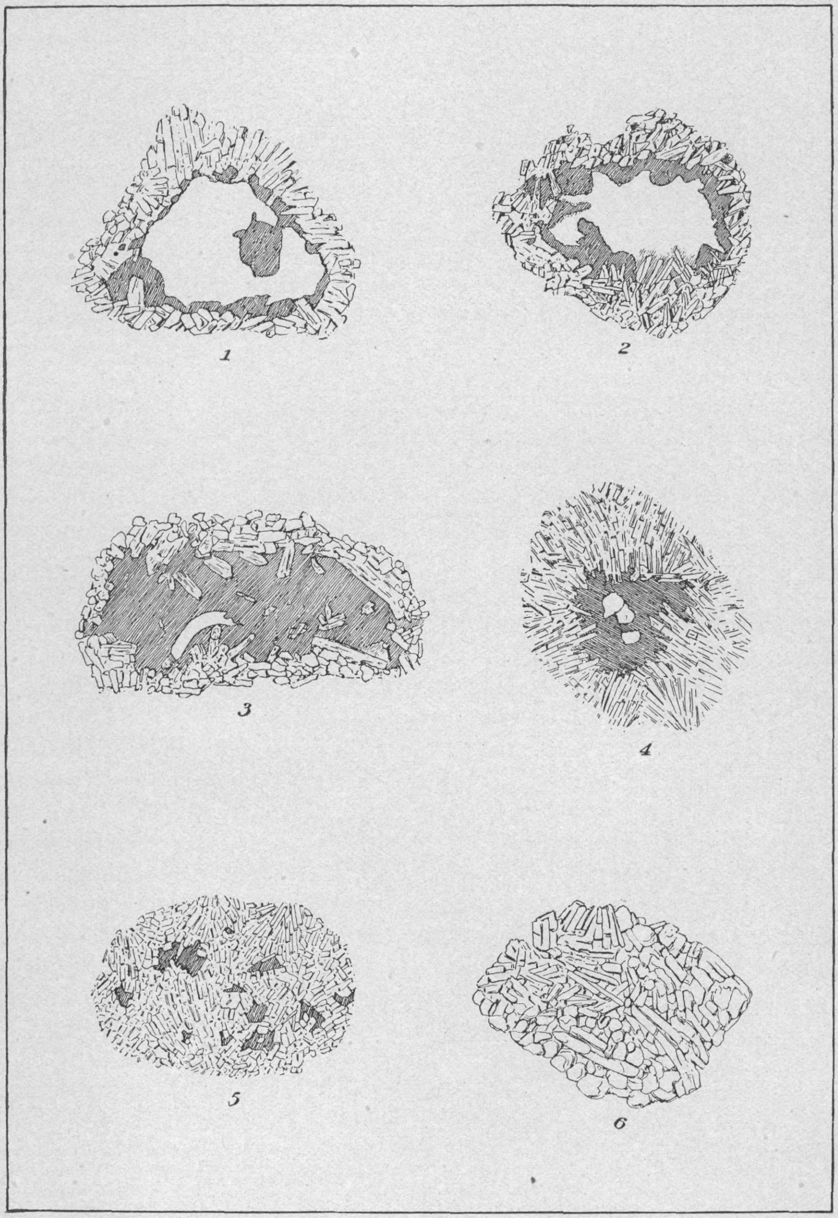
[3] Zeit. deutsch. geol. Gesellsch., 1883, vol. 35, p. 489.

[4] Elemente der Petrographie, p. 237.

[5] Lehrbuch der Petrographie, vol. 2, p. 285.

[6] Mikroskop. Physiog. der Min. und Gesteine, 2d edition, vol. 2.

[7] Verh. des naturh. Vereins der preus. Rheinl. u Westfalens, 1877, p. 203.



SECTIONS OF QUARTZ GRAINS AND SURROUNDING SHELLS OF GLASS AND AUGITE.

basalts of Bernsteingebirge bei Striegau, and Scrope[1] calls attention to them in a basalt of the Auvergne. In a specimen of basalt from Tannenbergthal,[2] Erzgebirge, obtained from Stürtz, of Bonn, corroded grains of quartz with pyroxenic rims occur.

Prof. J. W. Judd and the late deeply esteemed vom Rath both called my attention to the celebrated basalt at Detunata Siebenbürgen, and to Professor Judd I am greatly indebted for a fragment of the rock which he collected years ago. Professor Judd informs me that dihexahedral crystals of quartz occur in this rock, but by those who have visited the locality they are regarded as inclusions having been picked up from the dacite through which the basalt passed on its way to the surface.

Phenocrystic quartz, as we have seen, is widely distributed in regular basalts. It has been discovered also in closely related diabases, according to Rothpletz[1] and Stecker.[2]

In this country, Haworth[3] has just described an interesting example in Missouri, and Prof. B. K. Emerson has found a similar occurrence in the Connecticut Valley near Mount Holyoke, yet to be described. In diabasic rocks the pyroxene border may be inconspicuous or entirely absent. Notwithstanding the fact that occurrences of this sort have been described as anomalous and due to inclusions, there is much reason to believe, as Haworth has urged, that they are not only primary but indigenous.

I do not mean to assert that all of the grains of quartz in all of the rocks enumerated above are products of crystallization in the magma deep within the earth. It seems highly probable that such is not the case, but a careful consideration of the quartz basalt of the Snag Lake region leads me to suspect that much more of the quartz is indigenous than is generally supposed.

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[1] Geology of the Extinct Volcanoes of Central France, p. 109.
[2] Neues Jahrbuch für Mineralogie Geologie u. Paläontologie, 1876, p. 400.
[1] Zeit. deutsch. geol. Gesellsch. 1878, vol. 30, pp. 554-556.
[2] Stecker: Min. u. petrog. Mittheil. v. G. Tschermak, Wien, vol. 9, p. 145.
[3] American Geologist, June and July, 1888, vol. 1, pp. 363 et seq.