



Geological Survey Professional Paper 3

The Geology and Petrography of Crater Lake
National Park

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THE GEOLOGY AND PETROGRAPHY OF CRATER LAKE NATIONAL PARK

BY
JOSEPH SILAS DILLER and HORACE BUSHNELL PATTON



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The Geology and Petrography of Crater Lake National Park

INTRODUCTION

By JOSEPH SILAS DILLER.

Twenty years ago Crater Lake was unknown to the general public, but since then a knowledge of its remarkable features has been spread abroad through the press, and Congress recognized its worth as an educational feature and made it a national park by the act approved May 22, 1902.

As defined in the bill, the park is "bounded north by the parallel forty-three degrees four minutes north latitude, south by forty-two degrees forty-eight minutes north latitude, east by the meridian one hundred and twenty-two degrees west longitude, and west by the meridian one hundred and twenty-two degrees sixteen minutes west longitude, having an area of two hundred and forty-nine square miles."

The Ashland sheet of United States Geological Survey, on the scale of 4 miles to 1 inch, includes the area lying between meridians 122° and 123° and parallels 42° and 43°. This map includes the region between Ashland and Crater Lake. On account of the great scientific interest of Crater Lake a special map, known as the Crater Lake special sheet, was prepared on the scale of 1 mile to an inch, including the country immediately adjacent to Crater Lake, between meridians 122° and 122° 15' and parallels 42° 50' and 43° 4'. From these two maps the accompanying map of the Crater Lake National Park (Pl. 1) has been prepared.

The two papers published here refer practically to the whole region included in the National Park. The one, Part I, treats primarily of the geology, the development of the great volcano, Mount Mazama, and its collapse, which gave birth to) Crater Lake; the other, Part II, deals with the petrography, and gives a special description of the various rocks occurring in the park.

Origin of the name Mount Mazama.^a—A great impetus to the spread of information concerning Crater Lake was given by the Mazamas of Portland, Oreg., who held a meeting at the lake in August, 1896, which attracted many visitors. The principal features in the history of the lake had previously been made out, and the Mazamas, recognizing the fact that the great peak which was nearly destroyed in preparing the pit for the lake had no name, gave it the name of their own society. Upon the rim of the lake are a number of small peaks, each having its own designation. The term Mount Mazama refers to the whole rim encircling the lake. It is but a mere remnant of the once lofty peak, the real Mount Mazama, which rose far into the region of eternal snow. To get a basis for reconstructing the original Mount Mazama it is necessary to study in detail the structure and composition of its foundation, now so attractively displayed in the encircling cliffs of Crater Lake.

^aAn account of the discovery of Crater Lake and reference to its literature will be found in Mazama, vol. I, No. 2, Crater Lake number, 1897; National Geographic Magazine, Vol. VIII, p. 33, and the Annual Report of the Smithsonian Institution

for 1897, p. 369.

ROUTES TO CRATER LAKE.

Crater Lake is deeply set in the summit of the Cascade Range, about 65 miles north of the California line. It can be reached only by private conveyance over about 80 miles of mountain roads from Ashland or Medford, on the Southern Pacific Railroad, in the Rogue River Valley of southern Oregon (see fig. 1, p. 18), or from Ager, on the same railroad, in northern California, by way of Klamath Hot Springs and Klamath Falls.

Rogue River Valley marks the line between the Siskiyou Mountains of the Klamath group on the west and the Cascade Range on the east. The journey from the railroad to Crater Lake affords one a good opportunity to observe some of the most important features of this great pile of lavas. The Cascade Range in southern Oregon is a broad irregular platform, terminating rather abruptly in places, especially at the western border, where the underlying Cretaceous and Tertiary sediments come to the surface. It is surmounted by volcanic cones and streams of lava, which are generally smooth, but sometimes rough and rugged. The cones vary greatly in size and are distributed without regularity, a feature which is well illustrated in Pl. II. The photograph was taken across the western edge of Crater Lake. The sharp peak on the right is Union Peak and in the distance is Mount Pitt. Each conical hill has been an active volcano. The fragments blown out by violent eruption have fallen about the orifice from which they issued and built up cinder cones. From their bases have spread streams of lava (coulees), raising the general level of the country between the cones. At some vents many eruptions, both explosive and effusive, have built up large cones, like Pitt, Shasta, and Hood. Their internal structure is revealed by the walls of the canyons carved in their slopes, and they are found to be composed of overlapping layers of lava and volcanic conglomerate. This type of structure is well illustrated in the base of Mount Mazama.

The Dead Indian route from Ashland, Oreg.—The journey from Ashland by the Dead Indian road crosses the range where the average altitude is less than 5,000 feet, and affords a fair view of the low part of the range traversed by the Klamath River. A much better general view of the larger features of the range, and especially of the Crater Lake region, may be obtained from Mount Pitt (elevation 9,760 feet), which lies within a two days' trip from this road at Lake of the Woods. The road skirts Pelican Bay of Klamath Lake, famous for its fishing, and after running northward for about 20 miles along the eastern foot of the range it ascends the slope along the canyon of Anna Creek to the rim of Crater Lake.

The Klamath Falls route from Ager, Cal.—The approach from the east may be made also by a longer route, leaving the railroad at Ager, Cal., and traveling by stage road along the Klamath River, through the Cascade Range to Klamath Falls and Fort Klamath, from which point Crater Lake is only 20 miles distant by way of the Anna Creek road, already noted. The older tilted lavas of the Cascade Range dipping to the east are well exposed on this route at many points along the Klamath River road between Ager and Klamath Hot Spring.^a Across the edges of these lavas, nearly 1,000 feet above the present river bed, is an ancient wide valley of the Klamath River, associated with gentle topographic relief at higher levels. Later lavas have crossed the range in this wide old valley and the Klamath River has cut a deep canyon in them. Within this young canyon, north of Bogus post-office, there has been a volcanic eruption, forming a dam across the Klamath and a consequent ponding of the river, in which a mass of white diatom earth was formed. The products of this eruption are much younger than any others known to the writer in the neighboring portion of the Cascade Range.

^aThis celebrated health resort has a good hotel, fine scenery, hunting, and fishing.

The Rogue River route from Medford, Oreg.—From Medford the road by way of Rogue River, although 75 miles in length, is somewhat the shortest route. It affords some fine views of the canyons and rapids of that turbulent stream and of the high falls, where it receives its affluents, especially Mill Creek, below Prospect. A few miles below the mouth of Union Creek is a remarkable natural bridge of lava, but some distance from the main road. Striking features along the roads on both sides of the mountain, within 20 miles of the lake, are the plains developed upon a great mass of volcanic detritus filling the valleys. Across these plains Anna Creek and Rogue River have carved deep, narrow canyons with finely sculptured walls, which the roads follow for some distance.

The main road, whose grade is in general very gentle, crosses the summit 3 miles south of Crater Lake, and from the western slope near this point the crest of the rim is reached by a road with several heavy grades. There are good camping grounds with plenty of pasture on Castle Creek beyond the forks of the road and within 2-1/2 miles of the lake. At the end of the road, on the rim of Crater Lake, the camping places are fine, but pasture and water are not so abundant nor so easily obtained. There are as yet no hotels nor permanent accommodations for travelers at the lake, but during August and September, the most favorable months for visiting the lake, temporary accommodations should be provided and travel encouraged.

EXCURSIONS ABOUT CRATER LAKE.

By far the most impressive and, to the geologist, most important trip about Crater Lake is by boat from Eagle Cove along the western and northern shore of the lake to Cleetwood Cove and Rugged Crest, returning by way of the crater capping the cinder cone in Wizard Island. It can be made in a day, but may require hard rowing. The rare opportunity of travelling about in the interior of a volcano could hardly be anything else than intensely interesting. The descent by the trail and cruise along the shore disclose the alternately overlapping sheets of andesitic lava and conglomerate of which the rim is composed. These are cut by dikes—a prominent one is at Devils Backbone, and smaller ones occur beneath Llao Rock. Some of these are andesite, but others dacite. The great flow of Llao Rock, over 1,200 feet thick in places and tapering to thin edges on the sides, is dacite. It is younger than the andesites of the rim and fills an old valley. At Pumice Point layers of pumice and streams of dacite overlie platy andesite which was glaciated before the dacites were erupted, and at Cleetwood Cove is seen the inflowing dacite from Rugged Crest and the caved-in lava tunnel to the northward. The latest flow of the rim is the tuffaceous dacite along the northeast crest from Pumice Point to the Wineglass, but later even than this is the excellent example of a little volcano which forms Wizard Island, with its cinder cone capped by a perfect crater summit, marking the vent from which the cinders were blown. From the island and the boat the glacial notches in the southern rim of the lake and the dacite flows of Cloud Cap and the eastern rim may be seen to greatest advantage.

The most instructive day's walk from the rim camp (Camp 1 on map), but a rather hard one, is along the western crest to Llao Rock. Glacial striae are best displayed along this portion of the rim. Andesites are exposed all the way to the Llao Rock flow, which near the edge may be examined both above and below. The inflow of Cleetwood Cove is clearly visible from a distance, and an excellent view of the crest of the Cascade Range may be obtained.

Those who may wish to make a camping trip around the lake are advised to take a pack train and devote a number of days to the trip, as the distance around the crest of the rim is over 20 miles and over much of the route traveling is difficult. There is no definite horse trail around

the rim, but a practical pack route, with camping places indicated by numbers, is marked upon the map (Pl. I).

The canyon of Sun Creek is difficult to cross, as its western wall is precipitous. Near the notch there is pasture and good camping, but lower down, where the trail crosses, feed and water are scarce. At Camp 2, on the west fork of Sand Creek, there is plenty of both. Camp 3 has many attractions besides the fine firs and flowers. The great cliffs are inspiring, and the rustling of numerous little cascades gives a life to this inclosed camp that is not to be found elsewhere about the lake.

The ascent of the east side of Sand Creek Canyon is steep and somewhat difficult, but the fine views of the lake from the eastern rim in the morning abundantly pay for the special exertion necessary to attain them.

Camp 4 has some pasture and snow water. Beneath the large cliffs just north of the camp water was obtained for the animals. To the northeastward about 3 miles, in the line of the canyon heading at Cloud Cap, are fine springs and a cascade 50 feet in height. There is considerable pasture here, but on the whole the place is less inviting for camping than locations close to the crest. From this camp the descent to the lake may easily be made at the "wine-glass"-shaped slide of Grotto Cove.

At the head of Cleetwood Cove the crest is very rugged and somewhat difficult to cross with animals, but elsewhere travel along the northern rim of the lake is easy. Near the foot of Red Cone there is good camping by a spring. At many points along the lower slope of the western rim of the lake there are fine camps, plenty of grass, wood, and water, but in the past the sheep have greatly injured the pasture. Near the crest cliffs and rough talus slopes make traveling difficult and dangerous for animals. The easy and safe but longer route lies west of the cliffs to Camp 6, which is the main pasture camp of the region, with fine water.

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National Park

THE GEOLOGY OF CRATER LAKE NATIONAL PARK

By JOSEPH SILAS DILLER.

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Nisqually Glacier, Mount Rainier National Park,
Washington

THE PETROGRAPHY OF CRATER LAKE NATIONAL PARK

By HORACE BUSHNELL PATTON.

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THE GEOLOGY OF CRATER LAKE NATIONAL PARK

By JOSEPH SILAS DILLER.

INTRODUCTION.

The geological record of this country from the earliest epochs to the present time is replete with volcanic phenomena. but the climax appears to have been reached in the earlier portion of the Neocene, when one of the largest known volcanic fields of the world was vigorously active in our Northwestern States. This area of volcanic activity stretches from the Rocky Mountains to the Pacific, embracing a large part of Wyoming, Montana, Idaho, Washington, Oregon, and California, and presenting a great variety of volcanic phenomena concerning which, notwithstanding a copious literature, there has been as yet but a small amount of detailed investigation.

The central feature in the geology of the Crater Lake National Park is the wreck of Mount Mazama. and in order to describe this more clearly, it is necessary to consider briefly the general relations of the Cascade Range.

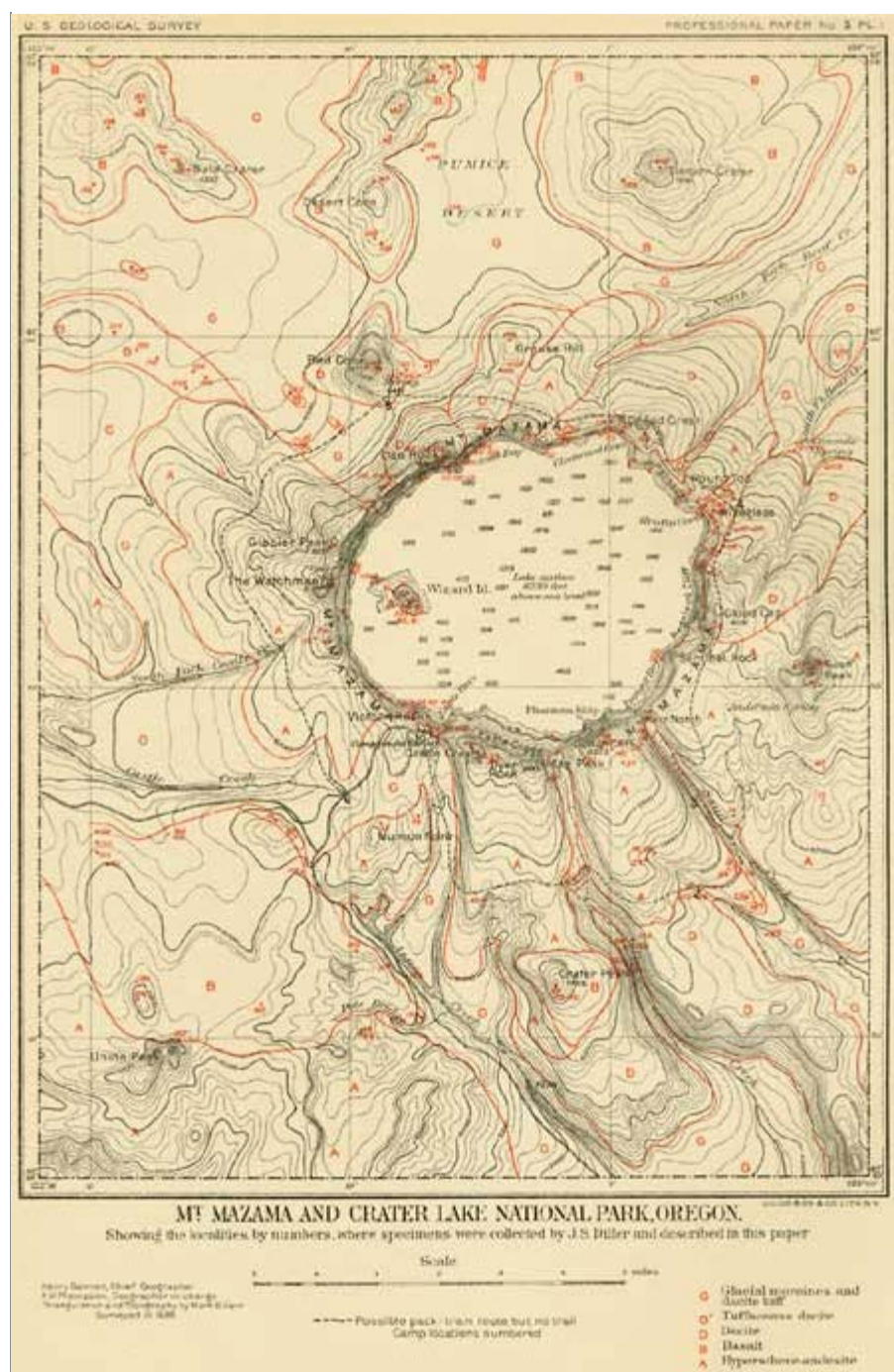


Plate I.—MT. MAZAMA AND CRATER LAKE NATIONAL PARK, OREGON.
(click on image for an enlargement in a new window)

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CASCADE RANGE.

LIMITS OF THE CASCADE RANGE.

The western limit of the great volcanic field is likewise the western border of the Cascade Range, which is made up at least largely, if not wholly, of volcanic material erupted from a belt of vents extending from northern California to central Washington. Lassen Peak marks the southern end of the Cascade Range, and Mount Rainier is near the northern end. Beyond these peaks the older rocks rise from beneath the range and form prominent mountains, the range itself occupying a depression in these older terranes.

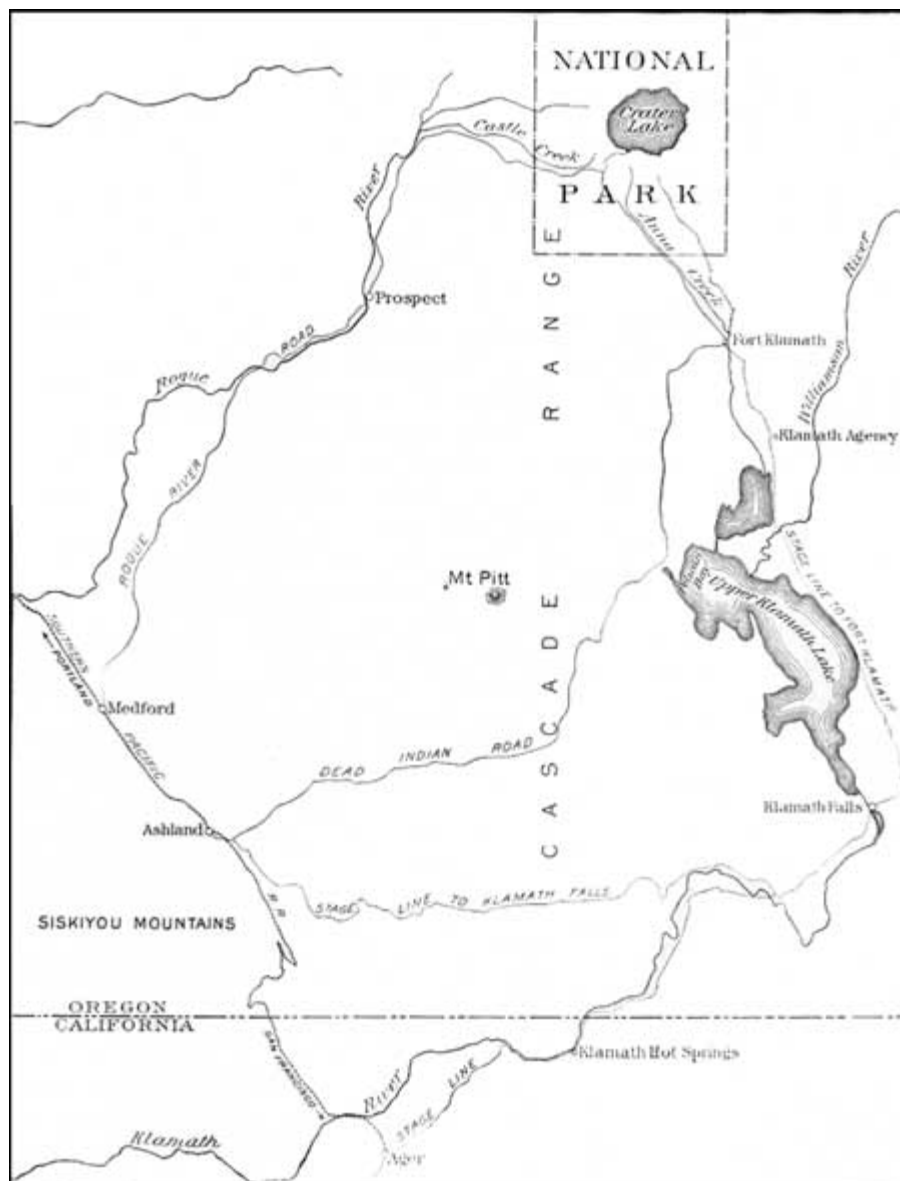


Fig. 1.—MAP SHOWING ROUTES TO CRATER LAKE.
(click on image for an enlargement in a new window)

FOUNDATION OF CASCADE RANGE.

A clearer conception of the development of the Cascade Range may be gained by considering the geography of the region during the later portion of the Cretaceous. At that time the coast of northern California, Oregon, and Washington was subsiding with reference to sea level, causing the sea to advance upon the land. In California the sea reached the western base of the Sierra Nevada and covered a large part, if not the whole, of the Klamath Mountains. In Washington it beat upon the western base of the range near the coast north of Mount Rainier, and in Oregon it extended far into the interior. Marine deposits of this period occur along the base of the Blue Mountains in eastern Oregon, as the Cascade Range did not then exist in Oregon to shut out the open sea from that region. East of the Klamath Mountains, as shown by the position and distribution of the Cretaceous rocks and fossils of marine origin, the open sea connected directly with the sea in the Sacramento Valley. The Cascade Range throughout a large part of its extent rests upon Cretaceous rocks, and is associated in Oregon and California with a depression in the older rocks between the Klamath Mountains on the one hand and the Blue Mountains and Sierra Nevada on the other. This depressed area beneath the lavas of the Cascade Range must not be regarded primarily as a region of subsidence, as

its chief movement since time Cretaceous has been upward, above the sea. The Klamath and Blue Mountains, as well as the Sierra Nevada, however, have been elevated so much more than the base of the Cascade Range that it would appear on the surface as a depression were it not filled with lava. The depression is so deep where the Cascade Range is cut across by the Klamath and Columbia rivers that the bottom of the lavas forming the bulk of the range is not reached. However, at the ends of the range the older rocks rise to form a more or less elevated base for those parts of the range, and at Mount Shasta. as well as on the divide between the Rogue and Umpqua rivers where an arch of the older rocks extends northeasterly from the Klamath Mountains toward the Blue Mountains of eastern Oregon, the Cascade Range gets so close to the western side of the depression that the lavas lap up over the arch of older rocks rising to the westward. At various points of the range granolitic rocks, such as gabbro and diorite, occur; but the deep erosion at these points may have reached the granolites corresponding to the lavas of the upper portion of the range.



Plate II.—CONES ON SUMMIT PLATFORM OF CASCADE RANGE.

The sharp peak on the right is Union Peak; in the distance is Mount Pitt; in the foreground are Wizard Island and Crater Lake.

EOCENE HISTORY OF CASCADE RANGE.

There can be no reasonable doubt that fossiliferous Cretaceous rocks of marine origin are widely distributed beneath the Cascade Range from Lassen Peak to the Columbia, and that during the Chico epoch the whole area was beneath the sea. At the close of the Cretaceous, important changes occurred in the distribution of land and sea. Northern California, as well as southern Oregon, was raised above the sea excepting the Coast Range region north of Rogue River, which remained beneath the sea during the early part of the Tertiary. The marine deposits of the Eocene period in the vicinity of Roseburg run under the Cascade Range, but have not yet been found on the eastern side. The conglomerates of the Eocene, like those of the Cretaceous, contain many pebbles of igneous rocks, but they are of types common to the Klamath Mountains and are rare or unknown among the lavas exposed in the Cascade Range. During the Eocene there was vigorous volcanic activity^a in the Coast Range of Oregon, but the record of such activity has not yet been found in the Cascade Range. That volcanoes were active along the range during the Eocene is rendered more probable, although not yet beyond question, by Dr. J. C. Merriam's discovery of Eocene volcanic deposits in the John Day region.^b

^aSeventeenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, p. 456.

^bBull. Dept. Geol. Univ. California, Vol. II, No. 9, p. 285.

MIOCENE HISTORY OF CASCADE RANGE.

There can be no doubt, however, that during the Miocene^a the volcanoes of the Cascade Range were most active and the greater portion of the range was built up, although it is equally certain that volcanic activity continued in the same region at a number of points almost to the present time. While it may be surmised that the volcanoes of the Cascade Range are extinct, there are many solfataras, hot springs, and fumaroles, showing that volcanic energy is not yet wholly dissipated. All the peaks of the Cascade Range were once active volcanoes, and from them came most of the lava of the range. Each great volcano was surrounded within its province, at least during the later stages, by numerous smaller vents from which issued the lava that filled up the intervening spaces and built up the platform of the range.

^aTwentieth Ann. Rept. Rept. U.S. Geol. Survey, Part III, 1900, p. 32.

All of the great volcanoes of the range probably had their beginning in the Miocene. Many of them, like Lassen Peak and Mount Shasta, continued their activity into the Glacial epoch, and have suffered much erosion since their last eruptions. In this manner important structural differences have been brought to light among the peaks about the headwaters of the Umpqua, Rogue, and Klamath rivers, and these may be noted as throwing some light upon the history of Mount Mazama.

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UNION PEAK.

Union Peak (elevation 7,881 feet.) is on the summit of the Cascade Range, in Oregon, about 50 miles north of the California line and 8 miles southwest of Crater Lake. It is a sharp, conical peak (Pl. III, A) rising about 1,400 feet above the general level of the crest of the range. About the base upon the east and west sides, as well as upon its summit, are remnants of the original tuff cone, but the mass of the peak exposed on all sides is of solid lava. The molten material did not sink away after the final eruption. The volcanic neck resulted from the cooling of lava within the cinder-cone in the top of the volcanic chimney. Union Peak to-day shows us the neck stripped of its cinder-cone.



Plate III.—A. UNION PEAK

MOUNT THIELSEN.

Mount Thielsen (elevation 9,250 feet), the Matterhorn of the Cascade Range, is 12 miles north of Crater Lake and rises about 2,000 feet above the general level of the crest of the range. It is built up of bright-red, yellow, and brown layers of tuff, interbedded with thin sheets of lava, and is cut by a most interesting network of dikes radiating from the center of the old volcano. No trace of a volcanic neck is present—the peak is but a remnant carved out

of the lava and tuff cone surrounding the vent. After the final eruption the molten material withdrew from the cone before consolidation, so as to leave no volcanic neck corresponding to that of Union Peak. The subsidence within the chimney of Mount Thielsen after eruption must have been over 1,000 feet, for the sheets of lava effused from that vent reach more than 1,000 feet above the exposed throat of the old volcano.

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MOUNT MAZAMA.

On the rim of Crater Lake there once stood a prominent peak to which the name Mount Mazama has been given. Mount Mazama is practically unknown to the people of Oregon, but they are familiar with Crater Lake, which occupies the depression that resulted from the wreck of the great peak. The remnant of Mount Mazama is most readily identified when referred to as the "rim of Crater Lake." The wrecking of Mount Mazama was the crowning event in the volcanic history of the Cascade Range, and resulted from a movement similar to that just noted in Mount Thielsen but vastly greater in its size and consequences. This volcanic activity culminated in the development of a great pit or caldera, which for grandeur and beauty rivals anything of its kind in the world.

GENERAL FEATURES.

The rim encircling Crater Lake, when seen from a distance from any side, appears as a broad cluster of gently sloping peaks rising about 1,000 feet above the general crest of the range on which they stand. A good view is obtained from the road along Anna Creek, where the southern portion of the rim appears as shown on Pl. III, *B*. Here Castle Crest and Vidae Peak are the most prominent features, with the canyon of Anna Creek in the foreground. The topographic prominence of Mount Mazama can be more fully realized when it is considered that it is close to the head of Rogue, Klamath, and Umpqua rivers. These are the only large streams breaking through the mountains to the sea between the Columbia and the Sacramento, and their watershed might be expected to be the principal peak of the Cascade Range.



Plate III.—B. RIM OF CRATER LAKE ACROSS CANYON OF ANNA CREEK

In the foreground is the canyon of Anna Creek; in the background Castle Crest is seen on the left and Vidae Peak on the right.

To one arriving by the road at the crest of the rim, the lake in all its majestic beauty (Pl. IV) appears suddenly upon the scene, and is profoundly impressive. The eye beholds 20 miles of unbroken cliffs, the remnant of Mount Mazama, ranging from over 500 to nearly 2,000 feet in height, encircling a deep, blue sheet of placid water in which the mirrored walls vie with the original slopes in brilliancy and greatly enhance the depth of the prospect. The lake is about 4-1/4 miles wide and 6-1/4 miles long, with an area of nearly 20-1/2 square miles.

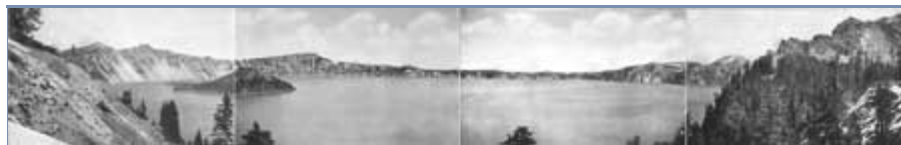


Plate IV.—PANORAMIC VIEW OF CRATER LAKE.

(click on image for an enlargement in a new window)

From the wooded slope a short distance within the rim at Victor Rock, an excellent general view of the lake may be obtained. The first point to catch the eye is Wizard Island, lying nearly 2 miles away, near the western margin of the lake. Its irregular western edge and the steep but symmetrical truncated cone in the eastern portion are very suggestive of volcanic origin. We can not, however, indulge our first impulse to go at once to the island, for the various features of the rim are of greater importance in unraveling the earlier stages of its geological history.

On the left is the western border of the lake shown in Pl. IV, with the Watchman, Glacier Peak, and Devils Backbone opposite Wizard Island, and Llao Rock beyond. These features, with Victor Rock in the foreground instead of the Watchman, are much more clearly shown in Pl. V, from an excellent photograph by Mr. Cunningham. On the right is the southern border of the lake. Castle Crest, Kerr Notch, Scott Peak, Sentinel Rock, and Cloud Cap appear in the distance along the rim. The boldest part of the southern rim is cut off from this view by Castle Crest. A more complete general idea of Crater Lake and its surroundings may be obtained from the map, Pl. VI. The broad, gentle outer slope, with an inclination ranging from 10° to 15°, is in strong contrast with the abrupt inner slope, with its many cliffs. This difference is well expressed by the relative position of the contours in the map. The vertical interval of the contours is 100 feet. On the inner slope the contours are crowded close together to show an incline so steep that one needs to travel but a short way to descend 100 feet, while on the outer slope the contours are so far apart that one needs to travel a

considerable portion of a mile to descend the same distance. The outer slope at all points is away from the lake; and as the rim rises at least a thousand feet above the general level of the crest of the range it is evidently the basal portion of a great hollow cone in which the lake is contained.



Plate V—WESTERN BORDER OF CRATER LAKE FROM VICTOR ROCK TO LLAO ROCK.

In addition to the strong contrast between the outer and inner slopes of the rim the map shows the occurrence of a number of small cones on the outer slope of the great cone. These adnate cones have peculiar significance when we come to consider the volcanic rocks of which the region is composed. The rim is ribbed by ridges and spurs radiating from the lake, and the head of each spur is marked by a prominence on the crest of the rim. The variation in the altitude of the rim crest is 1,460 feet, with seven points rising above 8,000 feet. The crest generally is passable, so that a pedestrian may follow it continuously around the lake, with the exception of short intervals on the southern side where the sharpest portion of the rim occurs in Castle Crest. At many points around the rim of the lake the best route is on the inner side, where the open slope, generally well marked with deer trails over beds of pumice, affords an unobstructed view of the majestic sheet of water.

The best way to get a comprehensive view of the base of Mount Mazama is to travel around the crest of the rim, but the structure is seen to greatest advantage from a boat on the lake.

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Geological Survey Professional Paper 3

The Geology and Petrography of Crater Lake National Park

THE GEOLOGY OF CRATER LAKE NATIONAL PARK

By JOSEPH SILAS DILLER.

CRATER LAKE.

TEMPERATURE OF CRATER LAKE.

Among those who visited Crater Lake with the Mazamas in 1896 was Dr. Barton W. Evermann, of the United States Fish Commission, who made some observations on its temperature. He reported that on "August 22, at a station about 2-1/4 miles east from the southeast corner of Wizard Island * * * the surface temperature was 61°; at a depth of 555 feet, 39°; at 1,040 feet, 41°; and at 1,623 feet, which was at the bottom, 46°."^a He further remarks that "If there be no error in our observations, it seems certain that the waters of Crater Lake are still receiving heat from the rocks upon which they rest."^b His observations were made with a Negretti-Zambra deep-sea thermometer, tripped by means of a propeller. Dr. Evermann says:^b

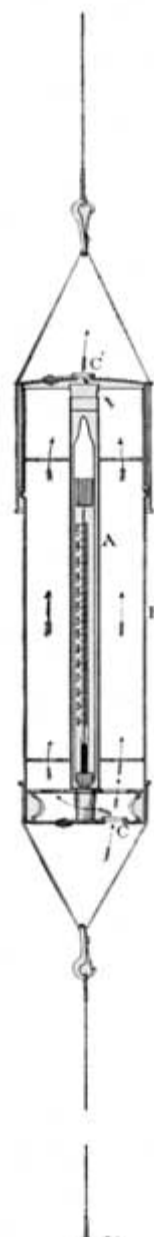
"The only possible source of error which has yet suggested itself is that the propeller may not always have worked properly. It is possible that, in some cases, when we began hauling up the thermometer, the propeller failed to reverse until some moments later, in which case the reading would be that for some depth other than the one desired. This is a possibility, though it seems to me improbable. The observations should be carefully repeated before the conclusions suggested by the results should be accepted."

^aMazama, Vol. I, No. 2, p. 232.

^bOp. cit., p. 234.

The volcanic rocks of Wizard Island, although recent, are sufficiently old to have completely cooled off. There are no visible fumaroles or hot springs anywhere about the lake to indicate local remnants of volcanic heat, and it was not expected that the bottom water would be warmer than the main body of the lake. Dr. Evermann's observations suggest that the point of latest volcanic activity on the floor of the lake is now beneath its surface and possibly near one of the two cones located by the soundings. He made only one series of observations to depths beyond 500 feet.

To settle this matter, if possible, several thermometers of the common form,



but with thick glass jackets to withstand pressure, were obtained from James Green, of Brooklyn, and a reel having a rapid winding attachment was prepared for their manipulation. Hard-drawn tinned-steel wire, No. .042, was found best suited to the work. Each thermometer was placed in a protecting brass tube (A in fig. 2), closed by a perforated rubber cork, and placed in a cylindrical bucket B, 3-1/4 inches in diameter, having an upward opening valve C at each end to allow the water to pass through while the bucket was descending, but to hold it confined while ascending, and thus not only preserve the temperature of the thermometer but at the same time to furnish a sample of the water from any depth desired. The stone D and double hook E were released from the suspending bar F at the end of the wire when the bottom was struck. Loops were placed on the wire at intervals of 500 feet, so that several thermometers could be sent down at the same time. After lowering the thermometers they were moved vigorously up and down for a few minutes to fill each cylinder with water. They were allowed to remain there for half an hour to make it sure that the thermometer in each ease had acquired the temperature of the place. The thermometers were raised as rapidly as possible and read at the surface. The thermometer from a depth of over 1,900 feet reached the surface and was read in less than 4 minutes. Experiments showed that by changing the water in the cylinder as noted above the thermometer readily acquired the water's temperature, but with valves closed and water confined in the cylinder, as when ascending rapidly, the thermometer was amply protected from the influence of the higher temperature of the surface waters.

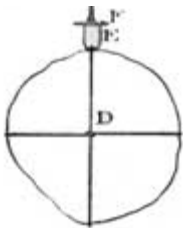


Fig. 2.—
Thermometer
and
attachments
used at Crater
Lake.

In order to eliminate the chances of failure as far as possible we obtained from the United States Fish Commission, through the kindness of Dr. Evermann, a Negretti-Zambra deep-sea thermometer, tripped by a messenger sent down the wire. He furnished us also the necessary apparatus for using the thermometer. This thermometer and the ordinary form noted above were sent down together a number of times, and invariably agreed when brought to the surface. The Negretti-Zambra several times allowed the messenger to pass the clip without reversing, but when registered there is no danger of change by surface temperature. The two forms of thermometers were generally used on the same wire 500 feet apart.

Observations were made at three widely separated points to a depth of over 1,300 feet, and the results are given in the accompanying table. The temperature of the lake everywhere below a depth of 300 feet is approximately 39°, and the bottom contains no appreciable volcanic heat.

Temperature of Crater Lake.

Depth.	1.	2.	3.	4.	5.
<i>Feet.</i>	<i>Degrees.</i>	<i>Degrees.</i>	<i>Degrees.</i>	<i>Degrees.</i>	<i>Degrees.</i>
1	48	50	51	50	52
100					b42
200					a40.5
300					b39.5
400					a39.5
500	a39	a39		b39	b39
972					b?
1,000				a39	
1,306			a39 (Bottom.)		
1,442				b38.5	
1,472					a39 (Bottom.)

1,942				^a 38.5 (Bottom.)	
-------	--	--	--	--------------------------------	--

^aCommon form of thermometer with thick glass jacket inclosed in brass tube and suspended in bucket 3-1/4 by 12 inches.

^bNegretti-Zambra deep-sea thermometer.

No. 1. July 8, 1901, 8 a. m., 1/2 mile toward island from Eagle Cove. Thermometer down 30 minutes; raised from 500 feet in 2 minutes.

No. 2. July 8, 1901, 9.40 a. m., 1/2 mile toward island from Eagle Cove. Both common form and Negretti-Zambra sent down, but messenger failed to trip Negretti-Zambra. Down 30 minutes; raised in 4 minutes.

No. 3. July 8, 1901, 10.50 a. m., 1/4 mile toward island from Eagle Cove. Thermometer down 30 minutes; raised in 5 minutes from 1,306 feet.

No. 4. July 17, 1901, 8.40 a. m. Near deepest part of lake, where line from Dutton Cliff to Cleetwood Cove crosses line from top of Cinder Cone, on Wizard Island, to Cloud Cap. Put common form at end of wire and Negretti-Zambra 500 feet higher. Sent common form down first to 1,000 feet; left down one-half hour and raised in 4 minutes; then sent to bottom—1,942 feet—with Negretti-Zambra at 1,442 feet, and bottom one came up in 8 minutes.

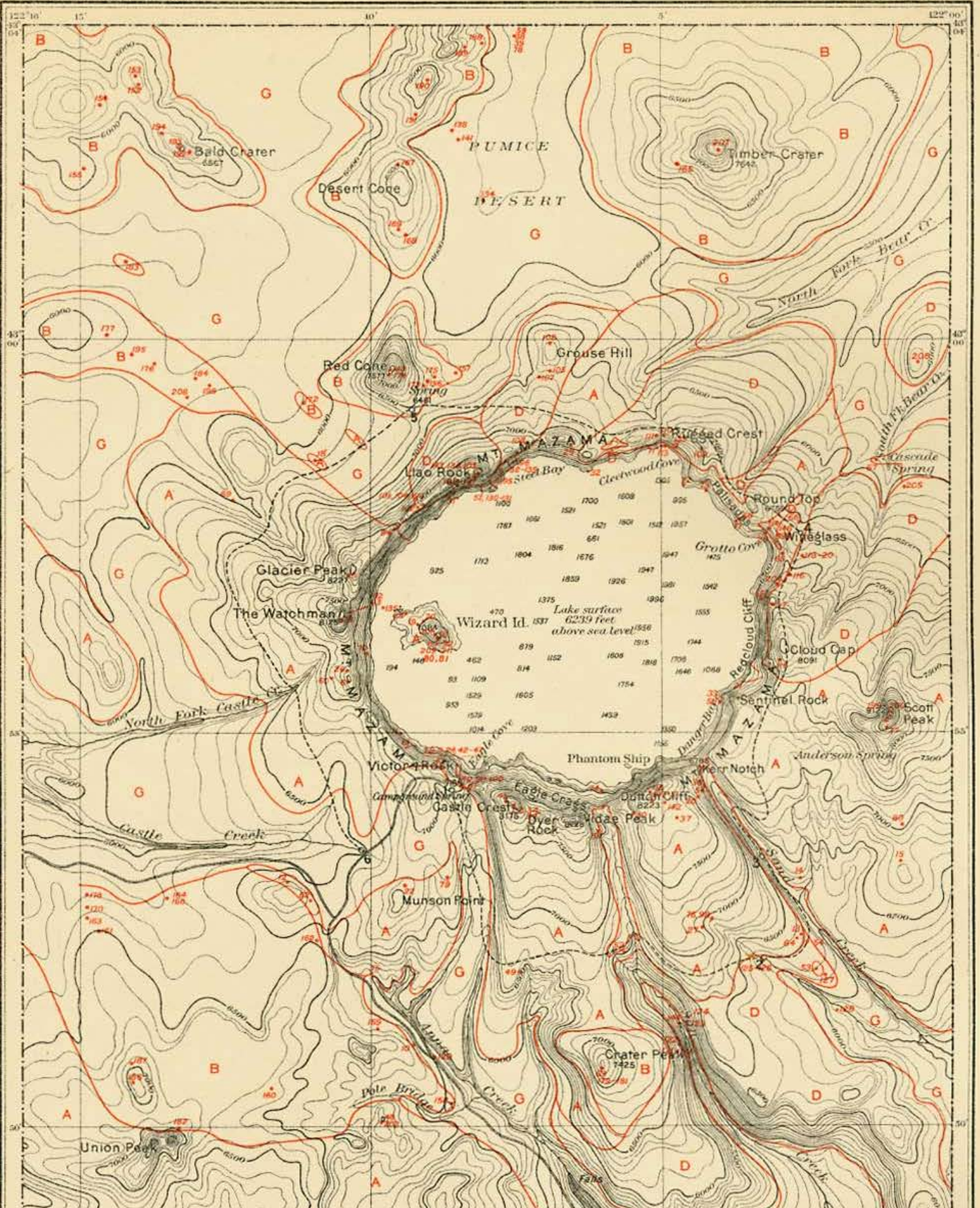
No. 5. July 19, 1901, 9.10 a. m., 1/4 mile south of Cleetwood Cove. Surface temperature, 52°; but at 10.40 it was raised to 54°. At 972 feet Negretti-Zambra failed to trip and register. This last series was observed by James Storrs and E. W. Herchberger.

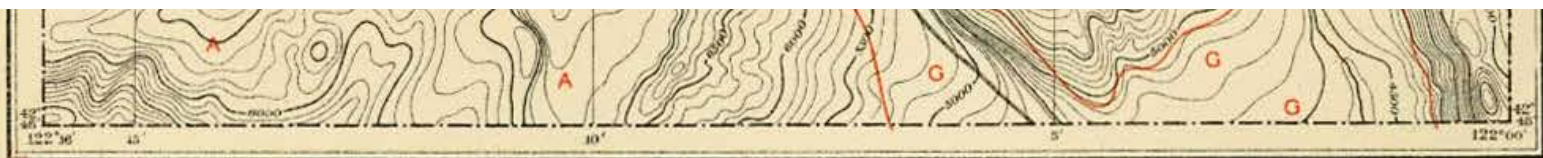
It may be noted also that Crater Lake, although over 6,000 feet above the sea, does not freeze over in winter, as do the Klamath lakes, at a much lower level, upon the eastern side of the mountain. Mr. E. W. Herchberger, a trapper, saw Crater Lake March 15, 1895, without ice. The winter was very cold. At the same time Diamond Lake and the Klamath lakes were covered with thick ice. He saw the lake half a dozen other times in the depth of winter from the east and never noted any ice. On February 18, 1900, he saw the lake from the west and noted ice over the shallow water between the island and the west shore, but none elsewhere. Although the lake is always open, Mr. Herchberger never saw any water birds on the lake in the winter.

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MT MAZAMA AND CRATER LAKE NATIONAL PARK, OREGON.

JULIUS BIEN & CO. LITH. N. Y.

Showing the localities, by numbers, where specimens were collected by J. S. Diller and described in this paper

Scale

1 0 1 2 3 4 5 miles

Henry Gannett, Chief Geographer
A. H. Thompson, Geographer in charge
Triangulation and Topography by Mark B. Kerr
Surveyed in 1886

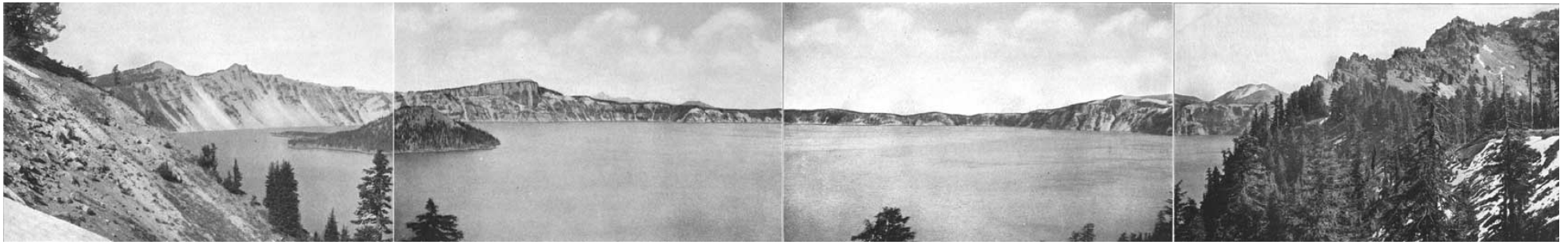
----- Possible pack-train route, but no trail
Camp locations numbered

- G Glacial moraines and dacite tuff
- D Tuffaceous dacite
- D Dacite
- B Basalt
- A Hypersthene-andesite

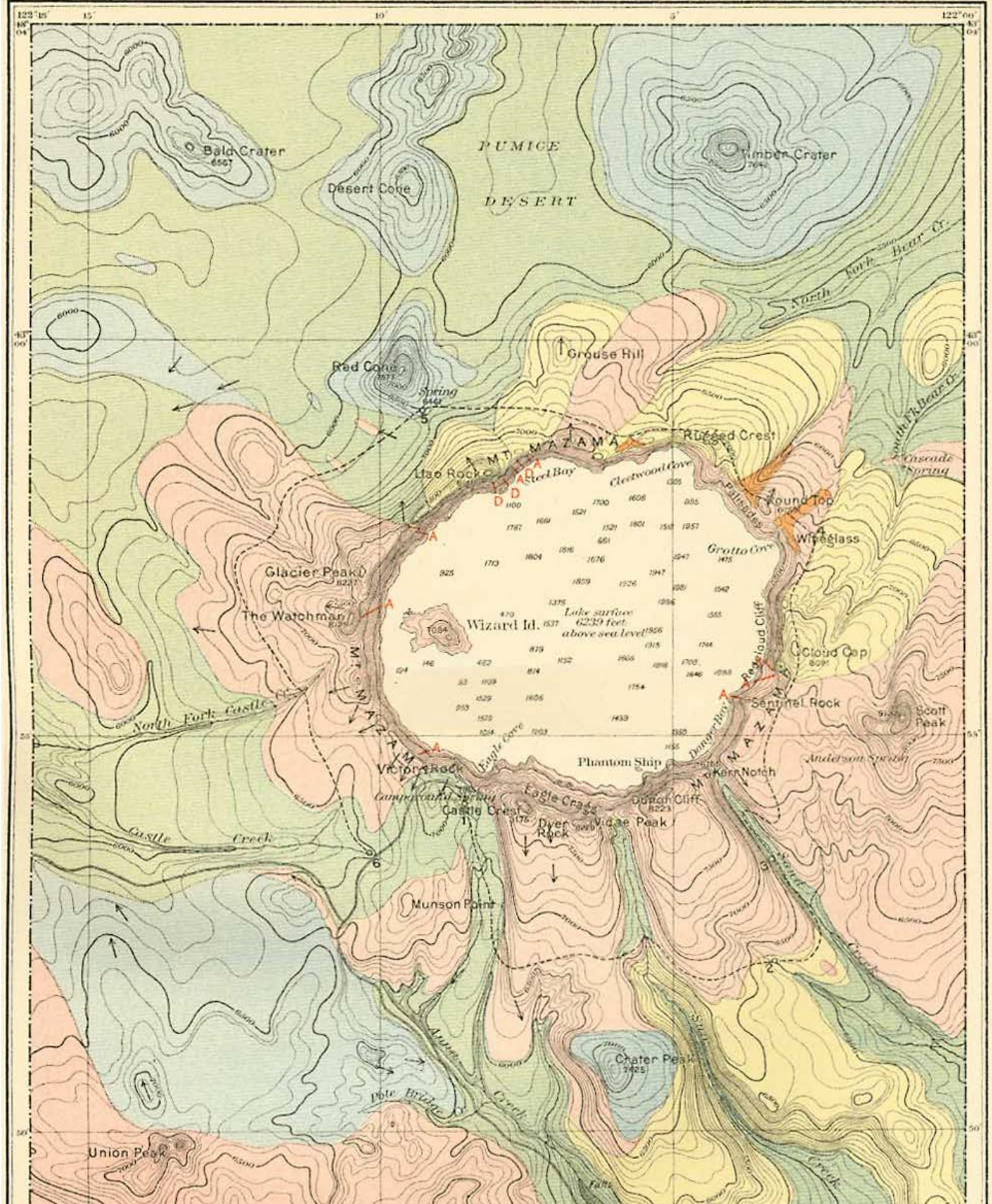












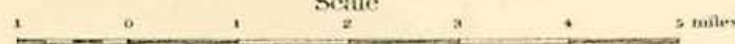


GEOLOGICAL MAP OF MT MAZAMA AND CRATER LAKE NATIONAL PARK, OREGON.

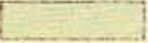
BY J. S. DILLER

Triangulation and Topography by Mark & Kerr
Surveyed in 1885

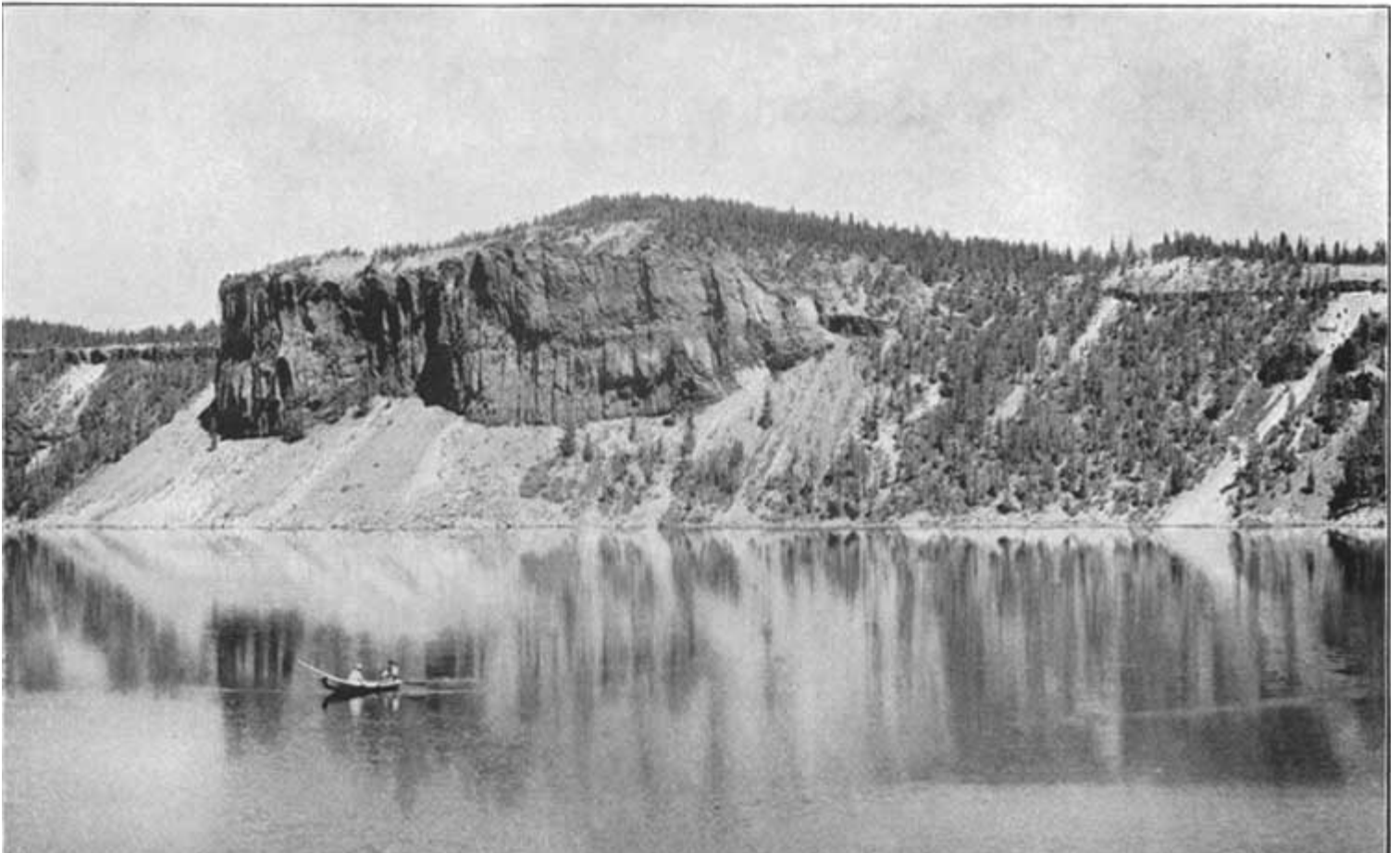
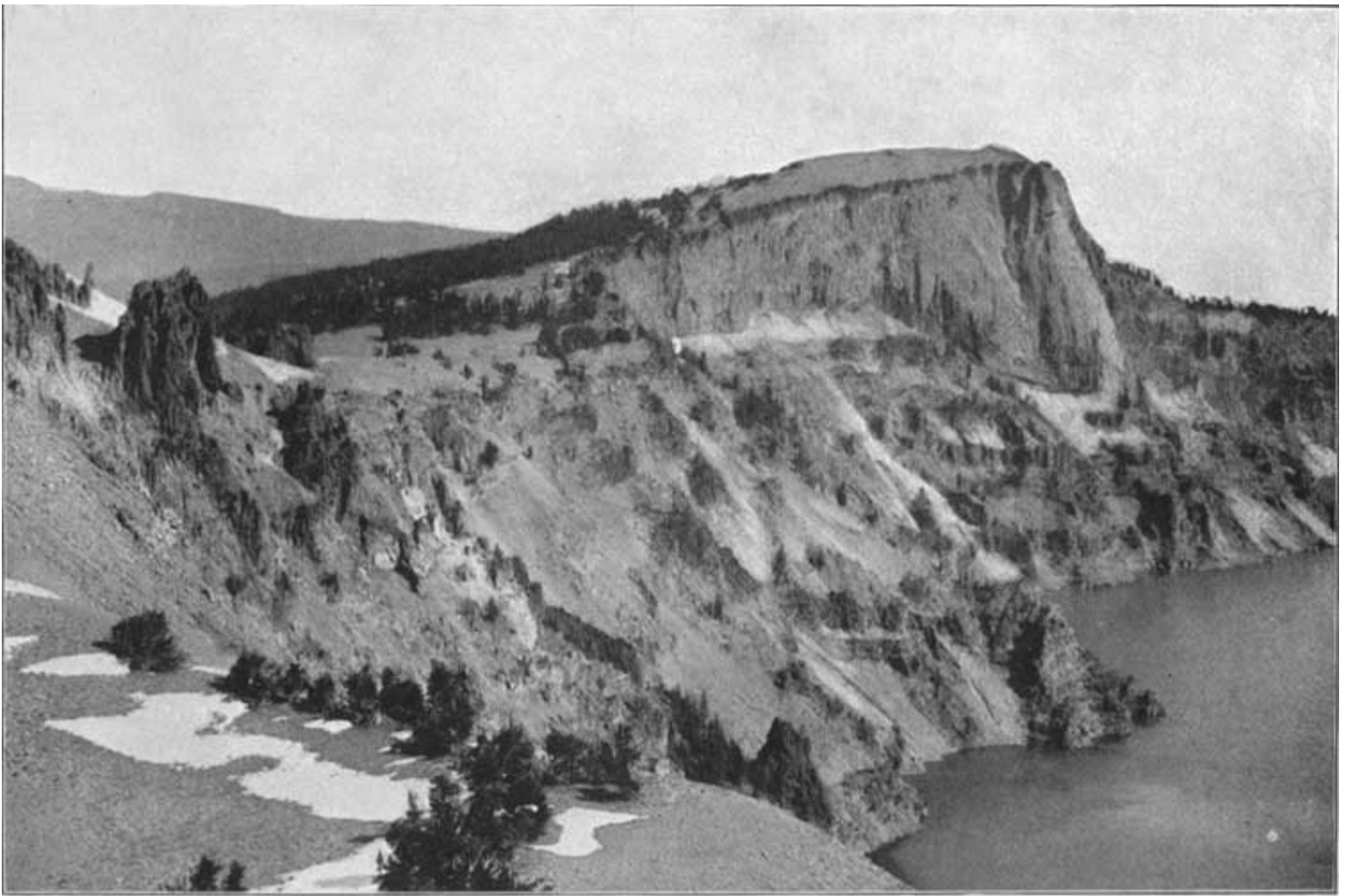
Scale



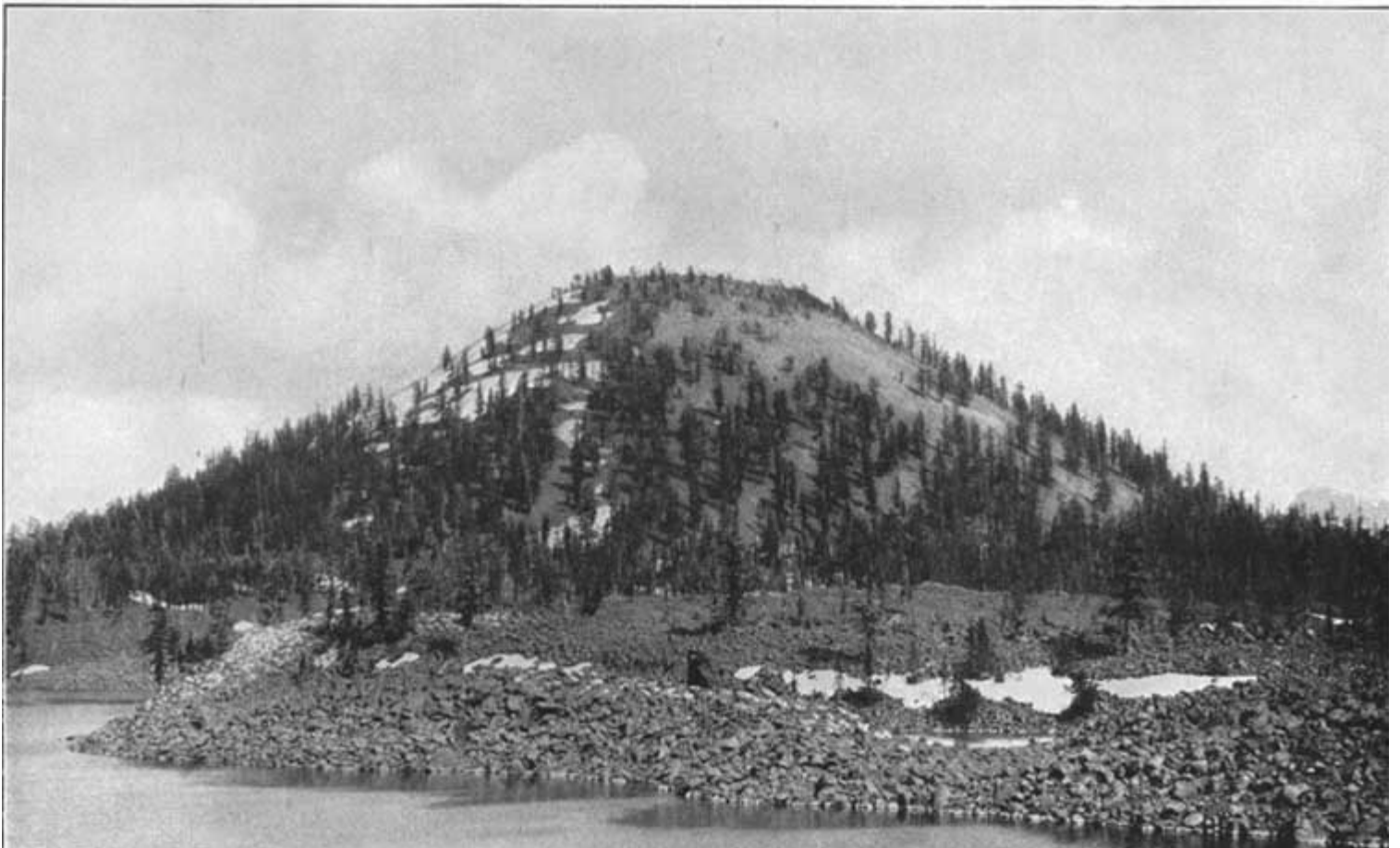
LEGEND

- | | | | | |
|--|---|---|---|---|
|  |  |  |  |  |
| Glacial moraines and
dacite tuff | Tuffaceous dacite | Dacite | Basalt | Hyperssthene-andesite |
|  Glacial striae | |  Hyperssthene-
andesite dikes |  Dacite dikes | |

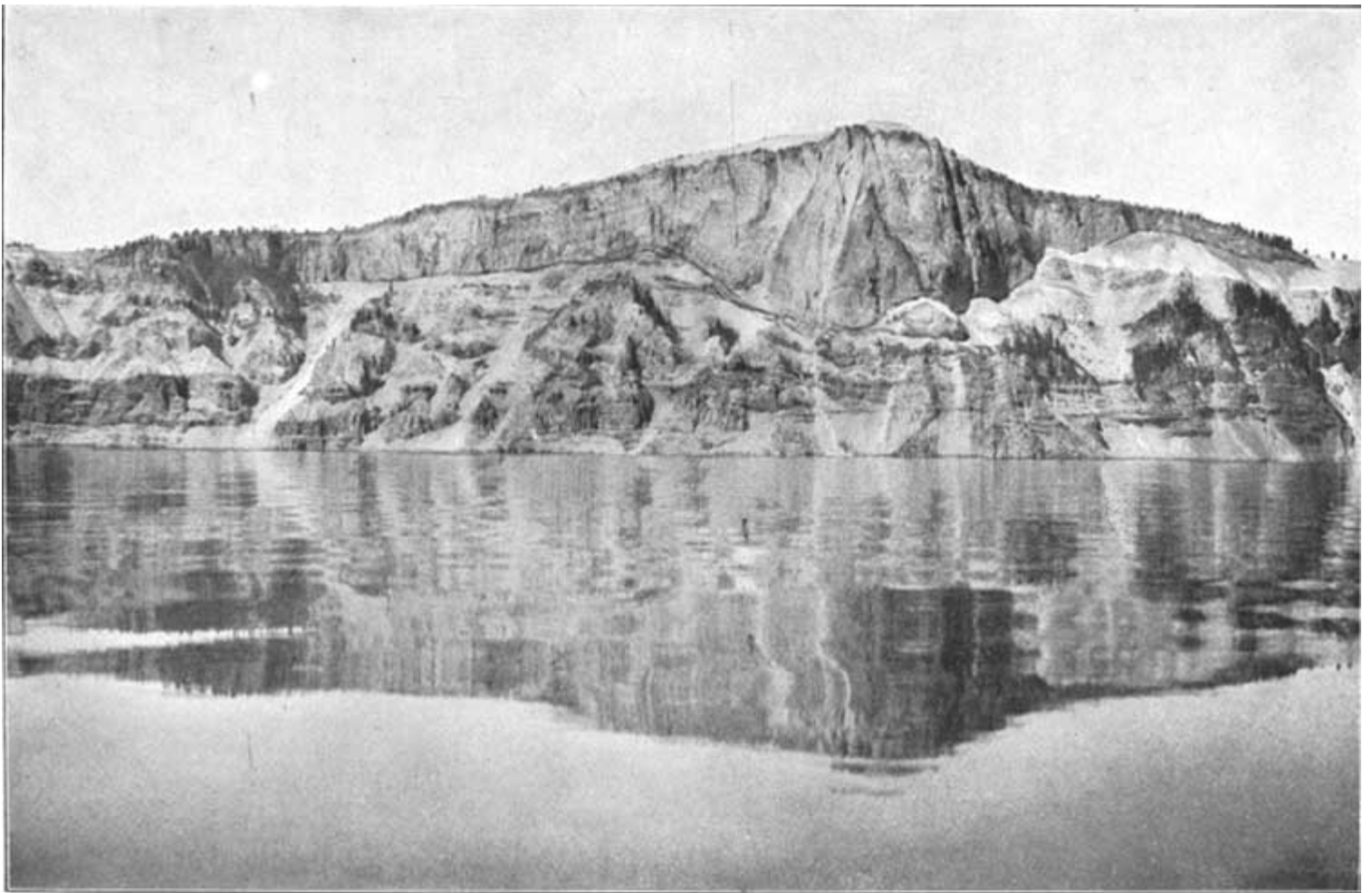
JULIUS BIEN & CO. LITH. N.Y.







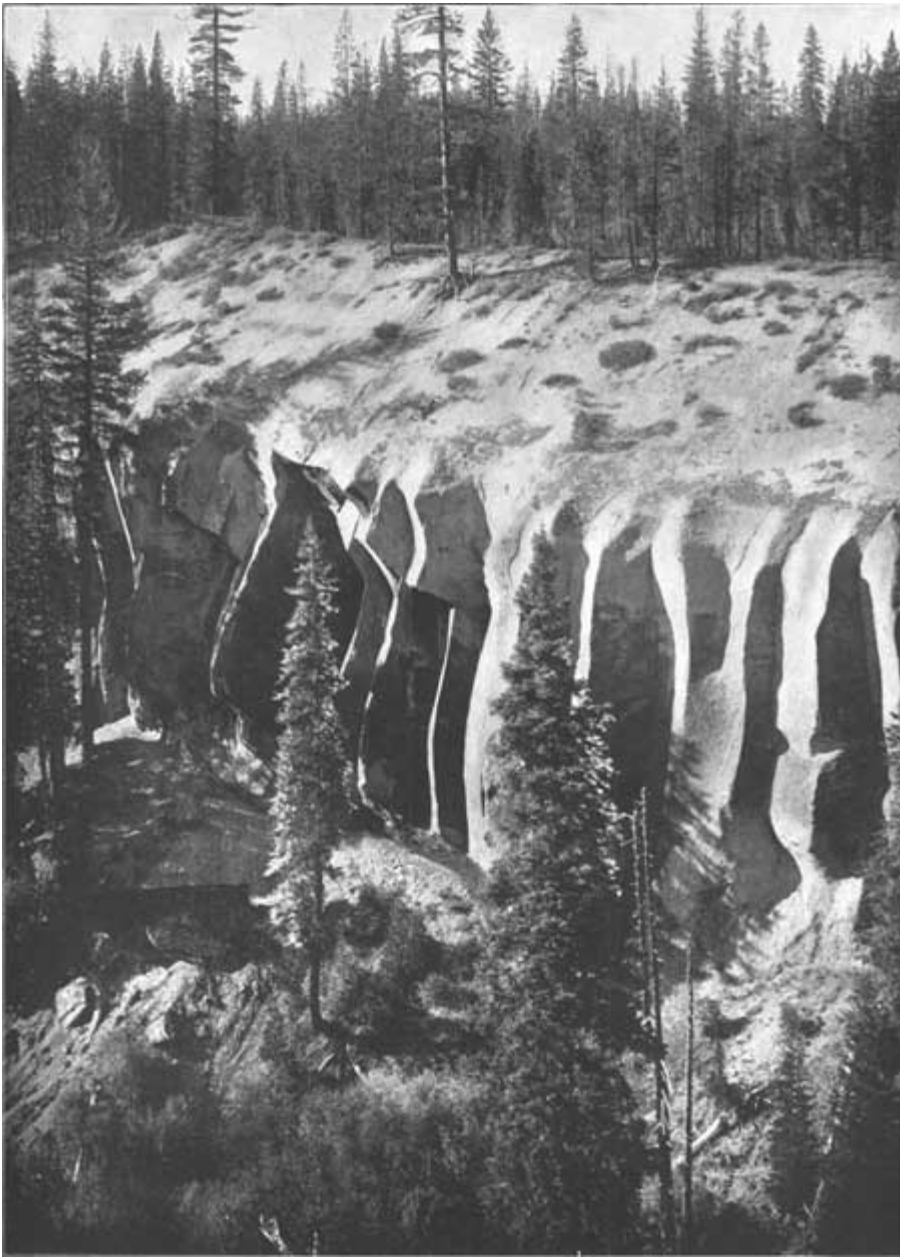


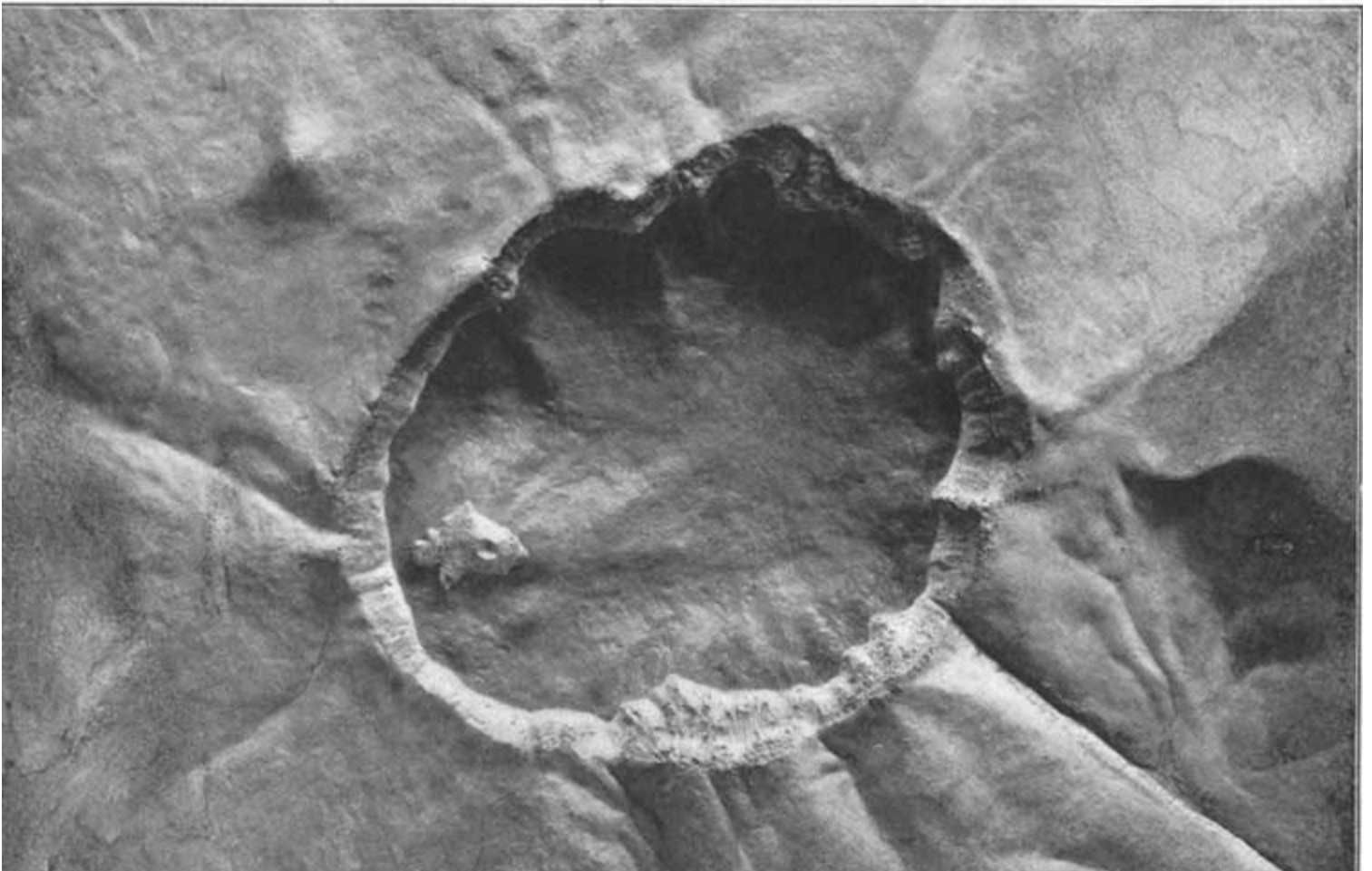




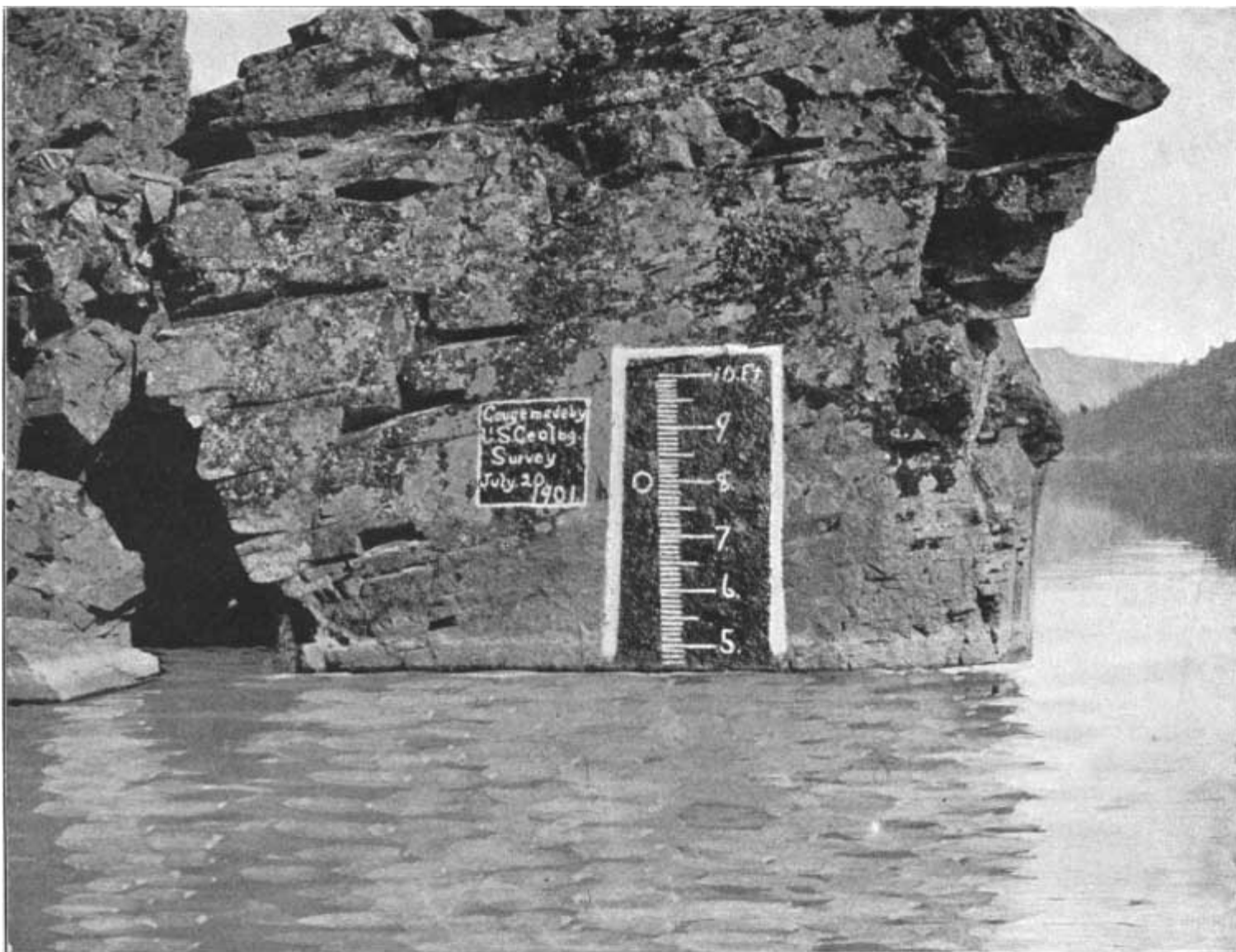


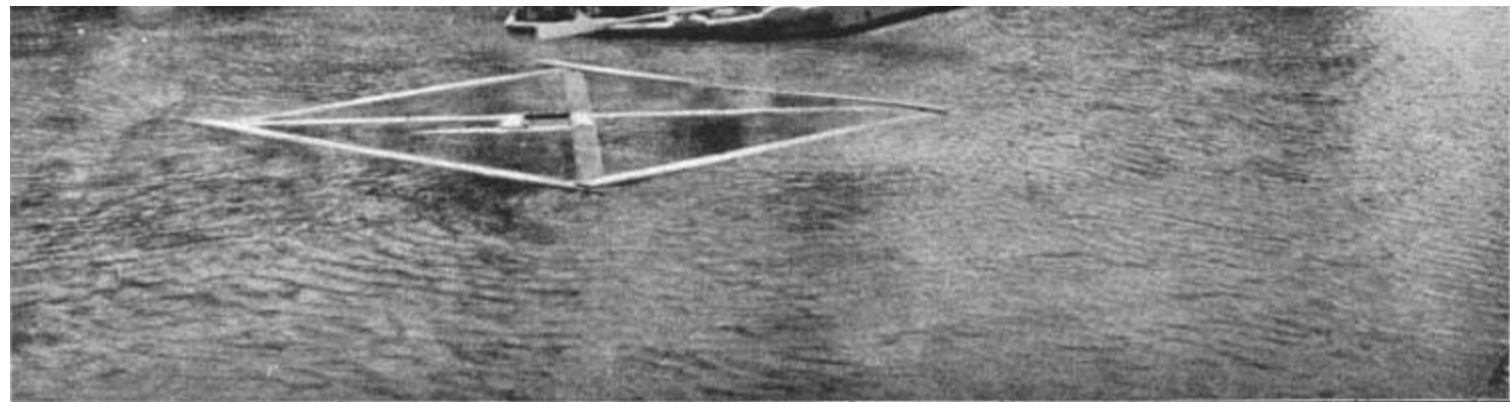


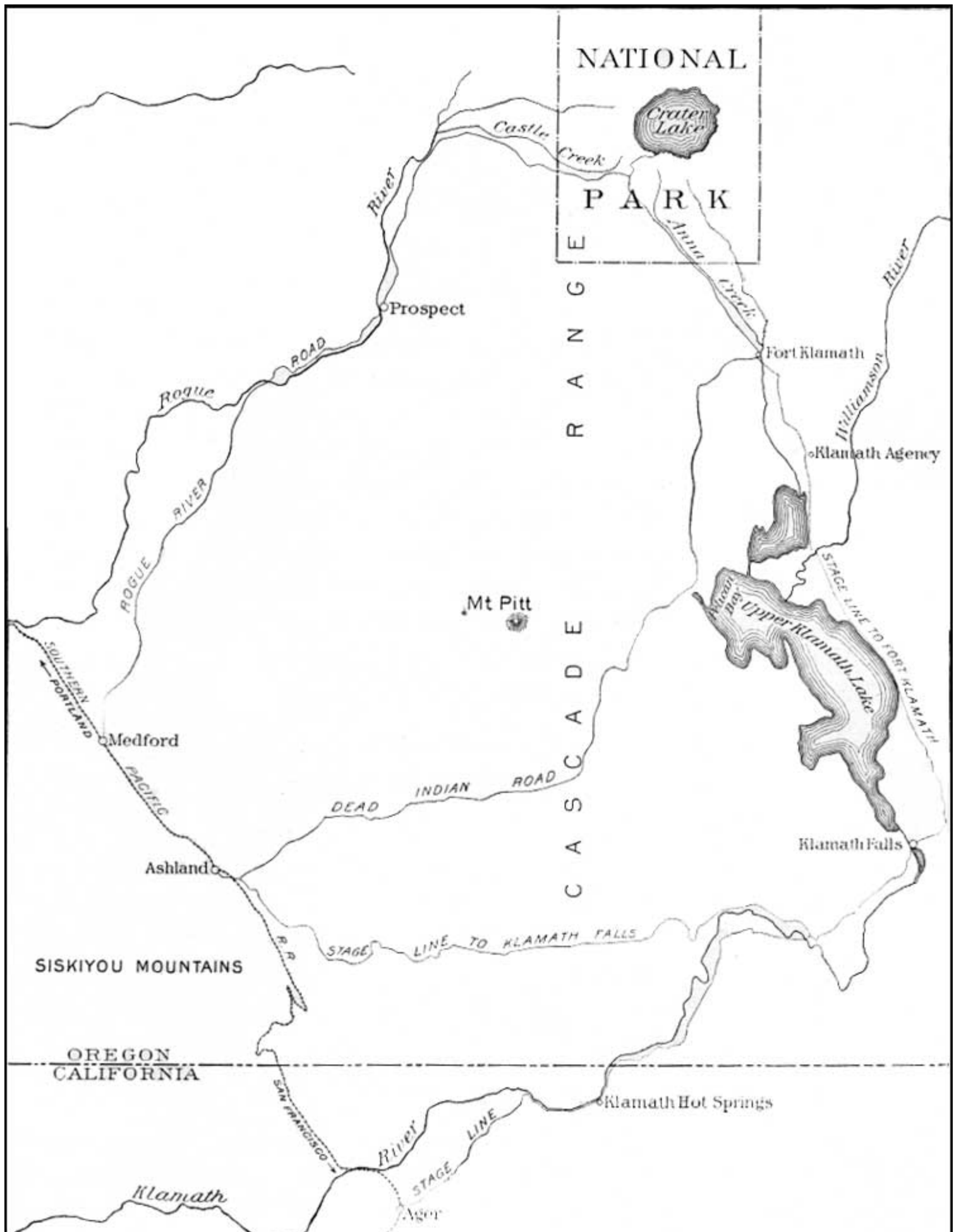




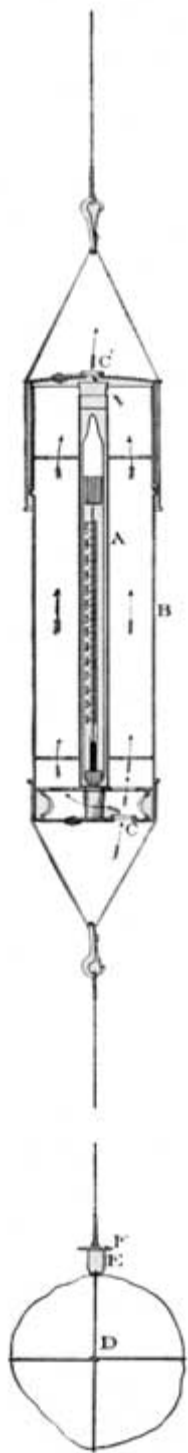














Geological Survey Professional Paper 3

The Geology and Petrography of Crater Lake
National Park

THE PETROGRAPHY OF CRATER LAKE NATIONAL PARK

By HORACE BUSHNELL PATTON.

HYPERSTHENE-ANDESITES.

The andesites are the oldest of the volcanic rocks of Crater Lake and form the great bulk of the exposed rocks. They are all hypersthene bearing, and may therefore be classified as hypersthene-andesites. But in spite of the fact that they may all be placed under this one head, there is a remarkable diversity in their external appearance, inasmuch as they vary in color from black to light gray or light drab and in texture from vitrophyric to holocrystalline. This diversity of texture and color is confined, however, to the groundmass; that is to say, the phenocrysts, although they may show many and varied distinctions, do not appear to be dependent in their variations upon the character of the groundmass to any very great extent. In the following description of these rocks the phenocrysts will be first considered, as they occur in all the andesitic varieties, while the groundmass will be described in connection with the discussion of the different varieties, which depend entirely on the variations of the groundmass.

MINERAL COMPONENTS.

The phenocrysts of these rocks are basic plagioclase, hypersthene, augite, and magnetite. The last-named mineral, to be sure, does not appear as a phenocryst in the hand specimen, but it is always present and belongs in part to the crystallizations of the first generation. To the above should be added olivine and hornblende, which are very seldom present.

PLAGIOCLASE.

As a phenocryst plagioclase occurs usually in stout crystals with sharply developed faces and rather numerous crystal forms, such as have been repeatedly described as characteristic of andesites in general. The most prominently developed form is usually the brachypinacoid (010), the habit of the crystal being thick-tabular parallel to this form. The next most prominent form is the basal pinacoid (001), in addition to which may usually be found a macrodome, probably (101), and the two partial prisms (110) and (110). This habit causes sections parallel to the brachypinacoid to have hexagonal shape and sections cut perpendicular to this face to have very often rectangular or five- or six-sided shapes. The plagioclase crystals usually measure 1 or 2 millimeters in longest diameter. At most the dimensions reach 3 or 4, but not infrequently are considerably less than 1 millimeter. They are nearly always abundant, but macroscopically are conspicuous only in case of the dark-colored specimens with glassy groundmass (2, 3, 17). In the hand specimen these plagioclases are nearly always perfectly fresh and glassy. They can not readily be distinguished from sanidine, owing to apparent absence of cleavage and twinning striations.

In a few cases twinning appears to be entirely absent, even in thin sections, but usually the customary albitic twinning is very pronounced. This may be developed in a few broad bands or in many thin ones that may or may not extend across the crystal. Not infrequently twinning striations at right angles to the first and produced by the application of the pericline law of twinning are to be seen. Crystals thus twinned may be still further complicated by the presence of twinning after the Carlsbad law.

Maximum extinction angles measured to the right and to the left of the trace of the albitic twinning plane on sections cut at right angles to the brachypinacoid indicate in almost every case that these plagioclase phenocrysts are very basic and are to be classed as anorthite. Out of a large number of such measurements the following may be given as indicating fairly average results. In each case the angle given is the largest that was noticed in the specimen referred to.

Maximum extinction angles of plagioclase.

No. 41	24°
Nos. 9, 43	26°
No. 44	27°
No. 65	28°
Nos. 11, 24, 31, 35	30°
No. 66	31°
Nos. 2, 8	33°
Nos. 3, 42	35°
No. 79	38°

It is not to be inferred from the above that the smaller number of degrees necessarily gives the actual maximum extinction, inasmuch as it is not always possible to find a crystal cut so as to give such angles.

Almost invariably these phenocrysts show a well-developed zonal structure. This is very much more marked in sections parallel to the brachypinacoid than in those cut perpendicular to that face. The general rule in such cases seems to hold true here also, namely, that the extinction angles near the margin of a crystal are less than near the center. In No. 79 the crystal whose extinction angle is given above as 38° for a section cut at right angles to the brachypinacoid gave at the margin an extinction angle of only 30°. This difference of eight degrees for such sections, while perhaps not rare, is larger than ordinary. In very many cases the difference in such sections is not marked. The different extinction zones sometimes gradually shade into each other; sometimes, however, the transition is abrupt, or relatively so. Not infrequently a narrow margin will show a notably smaller extinction angle than does the rest of the crystal. In still other cases the crystal may be divided into very irregular patches that show either undulous extinction or somewhat different appearing zonal banding in the different parts. A recurrence or alternation of bands that show respectively greater and smaller extinction angles in the same crystal is by no means rare.

As is customarily the case in andesitic rocks, these plagioclase phenocrysts are often characterized by inclosures. These embrace glass, augite, hypersthene, magnetite and apatite, as well as other not well-characterized substances. With the exception of glass these inclosed substances are only occasionally met with, and then any one or more or even all of them may be seen in the same crystal. Even glass, which is so often characteristic of andesitic plagioclase, is by no means always present. In some cases none of the plagioclase phenocrysts contain such inclosures; in other cases some phenocrysts may contain none while

others may be filled or perhaps contain only scattered inclosures. These glass inclosures are usually very irregular in form, but they may also be simply spherical, or oval, or polygonal. In color they are sometimes a clear deep brown and are either absolutely free from any crystalline matter (17), or else in inclosures of the same brown color there may be seen microlitic inclusions of augite and magnetite, exactly the same as are to be found inclosed in the brown glass base of the groundmass (16, 6), or, again, a minute gas bubble (6, 26, 17). Such gas bubbles are apparently much more apt to occur in brown glass inclosures in the plagioclase phenocrysts than in the colorless glass inclosures referred to below. Brown glass inclosures are confined mainly to those andesites that have an abundant brown glassy base and that belong to the hyalopilitic type. But exceptions to this rule have been noted (42) where a somewhat paler glass occurs inclosed in plagioclase phenocrysts that are embedded in a hypocrySTALLINE groundmass in which little or no glass base can be readily identified. In this case it is of interest to note that a pale-brown glass of the same color as that of the inclosed glass, and practically free from microlitic or other crystals, occurs in more or less isolated areas formed by the meeting of several phenocrysts of plagioclase or of other minerals. Brown glass inclosures occur nearly always isolated or sparingly scattered through the crystal and not conspicuously parallel to the outlines of the phenocryst. There are, however, a few cases where this brown glass thickly crowds the crystal or a part of it, or occurs in a zone intermediate between a clear center and a clear margin, exactly analogous to what is described below as more characteristic of the colorless glass inclosures in feldspar.

Colorless glass inclosures of very irregular shape and fair size thickly crowding the mass of the feldspar so as to leave the latter in a sort of skeleton form are by no means rare, but they can not be said to be so characteristic as are similar occurrences that will be described in connection with the dacites of Crater Lake. Usually colorless glass inclusions are very minute in size and are densely crowded together so as to give the feldspar a clouded appearance. Such glass inclusions, however, are almost never free from crystalline matter, but contain more or less well-defined material similar to that seen in the groundmass of the hypocrySTALLINE andesites. Owing to this crystalline matter of the glass inclusions the feldspars are rendered not only cloudy but appear dirty, as though fine emery dust had been ground into them. These very minute glass inclusions are not always fresh, but may contain at times ill-defined doubly refracting decomposition matter. The distribution of these beclouding glass inclusions is extremely varied. Sometimes they fill the whole of the crystal mass, although they nearly always leave a clear outer margin. At other times they are aggregated in the central part of the crystal, while still again they may occur in an intermediate zone, leaving both the center and the margin clear. In the last case this clouded zone may be rather broad and not sharply defined either toward the center or toward the margin, or it may be narrow and then more sharply delimited. In general the outer edge of this zone is apt to be more clearly defined than is the inner edge.

These thickly crowded glass inclosures are not to be found in all the plagioclase phenocrysts of the same thin section, nor even in all the phenocrysts of the same general habit. Sometimes they are to be seen in only two or three, while the rest are entirely free from such inclosures. Their occurrence seems to bear some sort of relationship to the character of the groundmass, more particularly to the amount of the glass present in the groundmass. As will appear later, the andesites of Crater Lake will be treated under several heads, based upon the nature of the groundmass. Of these there are three main types, namely: 1, Those with holocrystalline groundmass; 2, those with hypocrySTALLINE groundmass; 3, those with hyalopilitic groundmass. The last-named type contains an abundance of brown glass, the second considerable, but not so evidently developed glass, and the first no glass at all. The relationship of these dense inclosures to the amount of glass may be indicated by the following comparison, which is confined to those phenocrysts that show well-characterized inclosures of thickly crowded glass with a clear margin of feldspar outside: Out of sixteen thin sections of andesite with holocrystalline groundmass, only two, or 12-1/2 per cent, contain such inclosures; out of

twenty-one sections of the hypocrystalline type, eleven, or 52-1/2 per cent, contain such inclosures; and out of twenty-one sections of the hyalopilitic type, thirteen, or 62 per cent, contain plagioclase of this description. It would seem, therefore, that the presence of glass in the groundmass has something to do with the crowding of certain of the feldspars with glass inclusions. It should further be stated that plagioclase crystals that have suffered partial resorption, so as to appear in more or less rounded forms, have a stronger tendency to contain such crowded glass inclusions than have those crystals that do not show such resorption. It should also be stated that the above comparison does not take into account the very abundant, but larger and more isolated, inclusions that do not have a marked tendency to occur in an intermediate zone. No such law seems to apply to such inclusions.

The mineral inclosures in plagioclase are not often very abundant. Magnetite occurs in the customary small octahedrons or in grains and apatite in sharp needles or slender prisms. Augite and hypersthene are usually to be seen in roundish grains that have the same color and general appearance as when not inclosed. At times there is to be seen a slightly greenish, finely and irregularly granular mineral, associated with the glass inclusions, that appears to resemble augite more than any other mineral unless it be epidote; but the great freshness of these rocks would seem to exclude the last-named mineral. Another inclosed mineral, that occurs in roundish or oval form and has a slightly yellowish color with rather strong refractive powers, may be zircon, but no sharply formed crystals of zircon were noted.

Resorption phenomena are very common in connection with these plagioclase phenocrysts. They are seen in the rounding of the corners or in the further eating into the feldspars so as to leave them in round grains or in the form of embayments. Such corroded feldspar crystals, as stated above, are peculiarly liable to be filled with glass inclusions to such an extent that there seems to be but a skeleton of feldspar filled with glass. These corroded crystals almost invariably show a clear margin of later growth. The formation of an intermediate zone of glass inclusions is also very strongly developed, and in this case the outlines of the clouded zone are clearly parallel to the outer edge of the newly extended crystal, except where, occasionally, the clear margin has developed new crystal faces. In discussing this well-known phenomenon Professor Rosenbusch says:^a

"Evidently a period of resorption of the already crystallized feldspars is followed by one of rapid addition of new feldspar substance, during which the glass inclosures which are taken up in great quantity on account of the rapid growth must arrange themselves parallel to the deformed periphery. Then came a period of slow growth, with the consequent freedom from interpositions, and the effort to produce regular crystallographic restoration."

^aMikroskopische Physiographie, 3d edition, Vol. II, 1896, p. 867.

This explanation is plausible and is possibly strengthened by the fact above noted—that the development of this intermediate zone seems in some way dependent on the amount of glass present in the groundmass. It would seem that the period of resorption was followed, in case of those andesites that have developed a holocrystalline groundmass, by a period of slow cooling, which was not favorable to the incorporation of numerous glass inclusions and which continued practically uninterrupted until the whole rock became solidified. Still it does not seem clear just why this phenomenon should be dependent on the present condition of the groundmass, for both the holocrystalline and the partially glassy groundmasses must have been fluid during the period of resorption which is common to both. Another fact often observed in studying these rocks does not seem to fit in with Professor Rosenbusch's explanation. It is this: That the inner line of these intermediate zones is not always as sharp as is the outer one. In fact, it may be quite irregular and not sharply defined, as it should be. In

such cases it more closely resembles the gradual encroachment of alteration products upon a clear and unaltered interior. Such feldspar crystals have the appearance of having been honeycombed in the process of resorption, the pores thus produced being filled with the surrounding glass. Such a honeycombing, if possible, would not necessarily advance into the interior of the crystal equally in all directions nor leave always a perfectly sharp line of separation.

The above-mentioned glass inclosures in plagioclase phenocrysts, as well as some of the resorption phenomena and subsequent new growth, are brought out in figs. A, B, C, and D of Pl. XIV (page 76) and in the photomicrographs presented as figs. A, B, and D of Pl. XV (page 80). Figs. A, B, C, and D of Pl. XIV illustrate the distribution of glass inclusions similar to the groundmass also the clear margins of later growth, free from such inclusions. The glass inclusions are rendered black and often opaque through included magnetic dust.

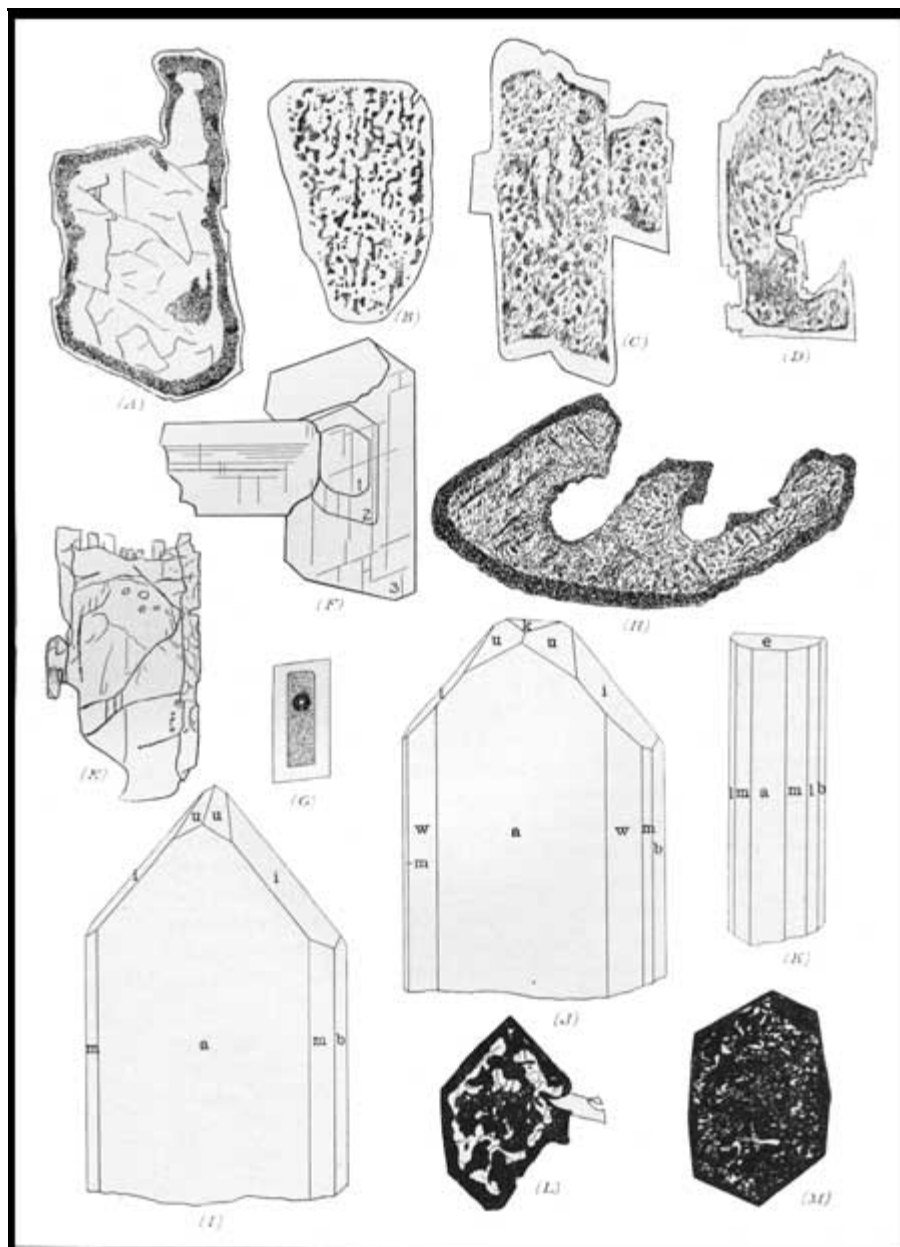


Plate XIV.—CRYSTALS IN ANDESITE, DACITE, AND BASALT.

FIG. A.—Plagioclase in hyalopilitic andesite from Sand Creek. Magnified 30 diameters. Specimen No. 5. The glass inclusions are mainly confined to a narrow zone near the margin. Has undergone partial resorption and secondary enlargement.

FIG. *B*.—Plagioclase in hyalopilitic andesite from Anna Creek. Magnified 60 diameters. Specimen No. 10. Glass inclusions are uniformly distributed in rather large and irregular patches. Has undergone resorption and slight secondary enlargement.

FIG. *C*.—Plagioclase in hypocrystalline andesite from water's edge under Llao Rock. Magnified 60 diameters. Specimen No. 31. Glass inclusions uniformly and thickly distributed throughout the original crystal. Has undergone secondary enlargement without resorption.

FIG. *D*.—Plagioclase in hypocrystalline andesite from Grotto Cove. Magnified 30 diameters. Specimen No. 55. Glass inclusions uniformly and thickly distributed, original crystal partly resorbed, and a secondary enlargement pronounced.

FIG. *E*.—Andesite at water's edge west of Eagle Cove. Magnified 60 diameters. Specimen No. 11. Shows a phenocryst of augite surrounded in part by a rim of parallel growing hypersthene. See page 82.

FIG. *F*.—A plagioclase phenocryst. From the vitrophyric dacite of Llao Rock. Magnified 60 diameters. Specimen No. 102. Polarized light with crossed nicols. Shows distinct zonal structure and two directions of cleavage, the basal parallel to the small face near to the figure 3 and the prismatic parallel to the longest side. The section is cut nearly parallel to the brachypinacoid. The intermediate shell 2 is more basic than is the center. See page 101.

FIG. *G*.—A minute feldspar crystal containing a large inclosure of brown glass with outlines parallel to the sides of the crystal. From the vitrophyric dacite of Llao Rock. Magnified 400 diameters. Specimen No. 101. This glass inclusion contains a single gas bubble which appears like a broad black ring. See page 106.

FIG. *H*.—Corroded hornblende crystal with resorption rim of augite and magnetite. From the dacite of Grouse Hill. Magnified 200 diameters. Specimen No. 105. See page 111.

FIGS. *I*, *J*, *K*.—Crystals found in the cavities of basalt from the base of Red Cone, No. 156. Figs. *I* and *J* are hypersthene and fig. *K* is pseudobrookite. See pages 146 to 148.

FIG. *L*.—Olivine phenocryst. From the basalt of Desert Cone. Magnified 65 diameters. Specimen No. 169. Alteration product is like that of fig. *M*, but alteration is not so far advanced. Contains a plagioclase crystal projecting into the side. See page 153.

FIG. *M*.—An olivine phenocryst almost completely altered to an opaque mass of which magnetite appears to form the bulk. From the basalt on the inside of the crater of Red Cone. Magnified 110 diameters. Specimen No. 174. See page 155.

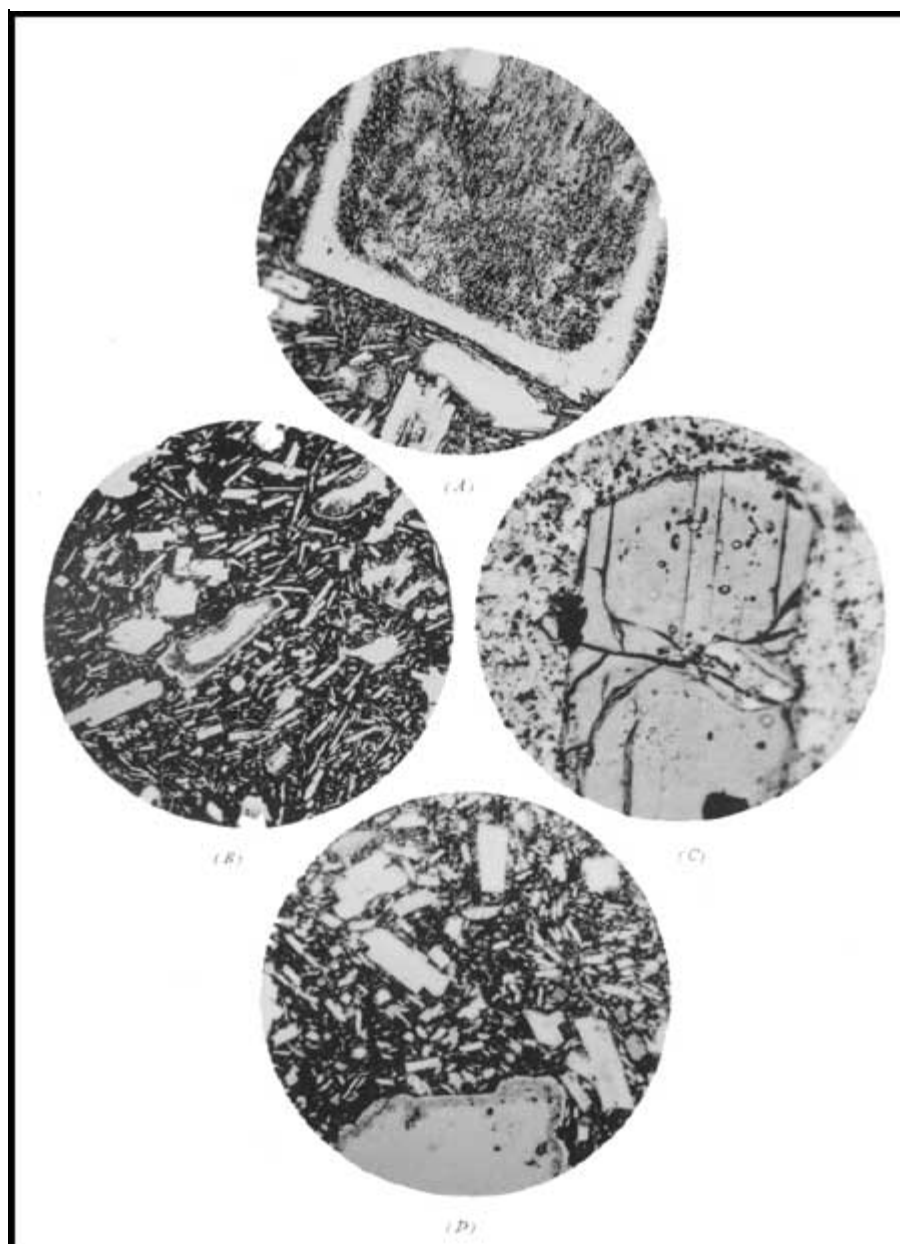


Plate XV.—THIN SECTIONS OF ANDESITE.

FIG. A.—Andesite from the south rim of the caldera. Magnified 94 diameters. Specimen No. 1. A photomicrograph in white light. Shows a plagioclase of the first generation, with the center extremely spongiform and crowded with brown glass. The structure thus developed bears a close resemblance to the intergrowth of feldspar and glass in the light-colored granophyric secretions among the dacitic ejectamenta. See page 132.

FIG. B.—Andesite of the hyalopilitic type from east of Sand Creek. Magnified 20 diameters. Specimen No. 15. A photomicrograph in white light. Shows plagioclase crystals of two well-defined types. In the center is a phenocryst of the oldest generation with clear margin and clear center, corroded on one side, and showing an intermediate zone of brown glass inclusions. For descriptions see pages 74 and 84.

FIG. C.—Andesite from the rim south of The Watchman. Magnified 86 diameters. Specimen No. 60. A photomicrograph in white light. Shows a crystal of hypersthene containing small inclosures of glass, with a bubble in each inclosure. Two of these may be seen above the center and to the right and left of the two conspicuous cleavage cracks. See page 81.

FIG. D.—Hyalopilitic andesite from the water's edge west of Eagle Cove. Magnified 20 diameters. Specimen No. 11. A photomicrograph in white light. The section illustrates the occurrence of plagioclase in three generations. First, the oldest, large phenocrysts with glass inclusions, in this case near the margin; second, phenocrysts without glass inclusions and that have mostly rectangular forms; third, small laths of the groundmass feldspar that are

mostly too small to be conspicuous in the photograph. See page 77.

In addition to the plagioclase crystals already described, there is very often present a phenocrystic plagioclase that occurs in long to short rectangular sections with square, diagonally extinguishing cross section. These are crystals elongated parallel to the crystallographic axis, and similar, therefore, to the microlitic plagioclases of the groundmass of andesites and basalts. In most cases they are entirely distinct from the groundmass plagioclase, as well as from the above-described phenocrysts. They sometimes form the only plagioclase phenocryst present, but at other times they occur together with the first-described kind and form a second generation of phenocrysts. This type of plagioclase is characteristic of the lavas of Wizard Island (19, 20, 25, 30, 95), but is not confined to that locality. In No. 21, from Sentinel Rock, this type of feldspar is represented, one crystal of which was noticed cutting clearly through a small hypersthene phenocryst. As hypersthene is one of the oldest ingredients in these andesites, this would indicate that these plagioclase crystals can not be considered as part of the groundmass. This is exceptional, however, as in most cases the plagioclase is distinctly younger than hypersthene. They do not appear to be much less basic, if at all, than the plagioclases of the first generation (20 gives maximum extinction angles on sections perpendicular to the brachypinacoid of 30° and 33°). They are usually free or nearly free from inclusions, but they may contain glass inclusions and even be crowded with the same.

From the above it appears that, taking into consideration the plagioclase of the groundmass, this mineral occurs in many of the Crater Lake andesites in three distinct generations. The two generations among the phenocrysts are usually quite sharply defined and readily recognized, but this is not equally true as between the second generation and the third or that occurring in the groundmass. These two are apt to shade into each other. In certain instances it is more than possible that still another generation may be present. Three generations of plagioclase are brought out in fig. *D* of Pl. XV, which also illustrates a more or less pronounced transition between the plagioclase of the groundmass and that of the second generation. In this case the groundmass feldspars are mostly too small to be readily discernible in the illustration.

The plagioclase of the groundmass varies greatly in size and habit in accordance with the degree of crystallization. In the more glassy andesites it is very apt to assume distinctly microlitic form, so that the microlitic laths may not measure more than 0.005 millimeter in diameter; but more customarily they are considerably larger than this and develop long and short lath forms that gradually pass into the smaller phenocrysts, so that a distinction between the two is not always easily made. Usually these plagioclase laths show extinction angles that are not very much smaller than those of the phenocrysts. For instance, one rock that shows symmetrical extinction angles of 28° and 30° among the phenocrysts contains groundmass laths with extinctions of 24° , 26° , and 27° . The polysynthetic twinning is not always distinguishable, but where this is apparently absent an undulous extinction is very common. In certain of the holocrystalline andesites two generations of feldspar are to be seen in the groundmass—first, an older, lath-shaped variety with developed twinning striae, and, second, an irregularly developed residual feldspar that usually does not show twinning, but which has an undulous extinction. This last-named variety is commonly in irregular, allotriomorphic patches of considerable size, shows simultaneous or nearly simultaneous extinction, and incloses the other minerals of the groundmass, such as plagioclase laths, augite, and magnetite. This residual feldspar will be more fully considered in connection with the description of the holocrystalline andesites. An excellent example is No. 73.

PYROXENE.

Both orthorhombic and monoclinic pyroxenes are characteristic ingredients among the

phenocrysts, the former being hypersthene and the latter augite. These two minerals are nearly always abundant, but are never large enough to become prominent in the hand specimen. In general, they are both of about the same size, sometimes one and sometimes the other being the larger. They are not often over 1 millimeter and never more than 2 millimeters in greatest diameter, and from this they may sink to microscopic dimensions. In the hand specimen they can not be distinguished from each other. They have a greenish to brown and brownish-green color and distinctly resinous appearance. They are perfectly fresh, and break without apparent cleavage in roughly conchoidal fractures. Although frequently bunched together, so as to appear larger than they really are, they require a magnifying glass to be clearly seen. Although both of these pyroxenes are almost always present, they vary greatly in their relative abundance. For instance, in a series of six specimens collected along the path descending from the camp ground to the water's level—a vertical distance of about 800 feet—we have hypersthene the more abundant in Nos. 8, 9, and 24, while the reverse holds for Nos. 7, 42, and 44. In general, however, hypersthene is the more abundant (2), although it may become scarce (16). Augite, on the other hand, is rarely more abundant than hypersthene, and is often either scarce (40) or even almost completely wanting, so as to be represented by only one or two roundish grains in a thin section (30, 56).

HYPERSTHENE.

The hypersthene phenocrysts usually occur in well-developed crystals that appear in short to long prismatic habit, seldom in very slender prismatic habit. The forms nearly always present are the brachypinacoids and macropinacoids (100) (010), and the prism (110). The pinacoids are equally developed, and nearly always are more prominent than the prism. This gives to the cross section either a squarish form with truncated corners or an octagonal form. The terminal faces are not so easily determined, but they appear to be a flat pyramid or equally flat domes. In some cases this mineral may occur in more or less irregular grains. This is not apt to be the case when it occurs isolated, but it occurs in this manner when it forms nests, either alone or with augite and magnetite (2). Usually the hypersthene is older than augite, but at times the two appear to have been formed simultaneously.

In not very thin sections hypersthene appears strongly pleochroic, and is then distinctly greenish parallel to the vertical axis and reddish or brownish red at right angles to this axis. These rocks are so fine grained that they require rather thin sections, so that the hypersthene shows much paler colors; but even in the very thin nest sections one can recognize the distinctive pleochroism, as rays vibrating parallel to the vertical axis are always greenish, while those vibrating at right angles to the vertical axis are faintly reddish or yellowish. The three elasticity axes agree with the three crystal axes, as follows: $a=a$, $b=b$, $c=c$. In convergent light sections cut at right angles to the vertical axis give a positive bisectrix and large optical angle, while sections cut parallel to the macropinacoid give a negative bisectrix and a much smaller optical angle. In longitudinal sections the parallel cleavage lines are usually well developed, as is also a cross fracture, but the customary prismatic and pinacoidal cleavages are not often sharply defined in horizontal sections unless the section is unusually thin or the crystals larger than common.

Mineral inclosures in hypersthene are confined to magnetite and apatite, the former being very common and the latter rare. Glass inclusions, however, are very common and characteristic. They are almost always to be seen in the larger and sometimes also in the very smallest crystals, and vary in number from one to twenty or more in case the crystal is unusually large. They are usually roundish or oval, but may be irregular in shape, or they may have polygonal forms resembling that of the crystal. They are usually colorless or have a light-brown shade, but never the deep brown to be seen in many of the feldspars. The color of these glass inclusions does not seem to depend on the color of the glass base nor even upon the presence of such base. Nearly always each of these inclosures may be seen to

contain a gas bubble, the size of which does not bear any relationship to the size of the inclosing glass. However, one can often find glass inclosures without gas bubbles in the same crystal in which most of the glass inclusions contain bubbles. The size of such inclusions varies from about 0.01 millimeter to very minute microscopic dimensions. In fig. *C* of Pl. XV is presented a hypersthene crystal with such inclosures of glass and bubbles.

Hypersthene is almost invariably perfectly fresh. It may at times show a slight trace of serpentinization through the development of a yellowish, fibrous, polarizing substance.

As stated above, hypersthene is to be ranked as one of the oldest crystallizations, but although it occasionally occurs inclosed in the plagioclase phenocrysts it is not always older than this mineral, as the plagioclase sometimes impresses its form on the hypersthene.

In addition to phenocrysts, not a few of the Crater Lake andesites also contain very much smaller hypersthene crystals with a slender lath-like habit. It is not always clear whether these are to be considered as belonging to a later generation and as forming a part of the groundmass or not. In a few cases, at least, of decided glassy varieties (9, 13, 16), this conclusion seems to be justified. In such rocks the groundmass consists of a brown glass containing magnetite grains, a few feldspar microlites, and abundant slender, almost microlitic prisms of augite and hypersthene. The hypersthene is quite uniformly about 0.05 millimeter in length and about one-fifth to one-tenth of that amount in width. The augites are sometimes the same size, but usually not more than half as large. These hypersthenes of the groundmass are sharp, and they frequently show flat terminations. They contain magnetite and also glass inclusions with bubbles. They are mostly very distinct from the hypersthene of the first generation in size and habit and are very much more abundant.

AUGITE.

The phenocrystic augites are, like the hypersthenes, usually sharply crystallized, but they are not so persistently idiomorphic. They not infrequently occur in hypidiomorphic or in granular forms. This, of course, is naturally the case where they form nests either with or without hypersthene. In color they show in thin sections a nearly uniform pale green, the depth of color varying with the thickness of the slide. They rarely show any appreciable pleochroism, and this property, together with the stronger interference colors and the oblique extinction, nearly always suffices to distinguish them from the hypersthenes. Twinning parallel to the orthopinacoid is very common. This is true not only of simple twins, but also of crystals with repeated or polysynthetic twinning.

The inclosures in augite are exactly the same—even to the glass inclusions with bubbles—as are to be found in hypersthene. The crystal form is also very closely analogous to that of the orthorhombic pyroxene. These are the prism with brachypinacoids and macropinacoids and a flat terminal form, presumably a pyramid. Usually, however, the prism and the pinacoids are about equally developed.

Parallel growths of augite and hypersthene are occasionally to be seen (11,171), in which the augite forms more or less irregular shells around the older hypersthene (see fig. *E* of Pl. XIV, p. 76); but this phenomenon is by no means as common as with the basalts of this region. A more detailed description will be found under the basalts.

As a groundmass constituent augite is very characteristic and is universally present. In proportion to the development of hypocrySTALLINE groundmass, this mineral is to be seen in more and more granular form. In the great majority of specimens, however, this mineral assumes well-defined slender prismatic form. In the hyalopilitic varieties the form is very sharp indeed. The crystals measure two or three or even five times as long as wide. In exceptional cases the length may be proportionately greater still. Usually in sharply

developed crystallites the width varies between 0.001 and 0.004 millimeter and the length between 0.01 and 0.03 millimeter. In the holocrystalline varieties the augites are not only granular in shape, but usually much larger. Both microlitic and granular individuals customarily inclose minute magnetite in octahedral and granular forms.

ACCESSORY MINERALS.

Quartz does not appear to form an essential ingredient in these andesites, except as it may form part of the allotriomorphic colorless material to be seen in most of the holocrystalline varieties. With this exception this mineral has been certainly identified in only two cases (46, 79), and in these two cases it does not occur at all evenly distributed, but only in a few irregular grains that may easily be accounted for by secondary or accidental causes.

Tridymite was recognized in only one case, an andesite of a decidedly dacitic type (79), about 1-1/2 miles south of the camp ground.

Hornblende.—A very few yellowish-brown and strongly pleochroic crystals of this mineral, mostly in fragments, are to be seen in specimen No. 44, from near the camp ground, and specimen No. 45, from Cathedral Rock. The larger grains have the black resorption rims of magnetite so common in andesites. In the smaller individuals the resorption is complete and only a black mass of granular magnetite remains (see Pl. XVI, B). Also one small crystal is seen in No. 48, a rock transitional between andesite and dacite. This mineral, which is very common in the dacites of Crater Lake, is otherwise entirely wanting in the andesites.

Olivine occurs very sparingly as an occasional rounded grain or fragment, more particularly among the nests of older crystallized minerals. In nearly all the andesites it is entirely wanting. It is most abundant in No. 49, where it is seen in well-rounded grains that have marked resorption rims of magnetite and, apparently, of augite. In No. 43 there are one or two forms which resemble olivine crystals and which are filled with a yellowish polarizing substance, presumably serpentine.

Magnetite forms an always present but rather sparingly developed ingredient among the minerals of the first generation and occurs frequently inclosed in plagioclase, hypersthene, and augite. In the groundmass it is perhaps more abundant, and then occurs as small octahedral crystals or as grains; also in the andesites with a brown, glassy base, as a very fine powder. It is likewise very abundant as inclosures in the augite microlites of the groundmass.

Hematite appears to occur occasionally either as a reddish stain or as minute brownish-red hexagonal scales (65).

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Geological Survey Professional Paper 3

The Geology and Petrography of Crater Lake
National Park

THE PETROGRAPHY OF CRATER LAKE NATIONAL PARK

By HORACE BUSHNELL PATTON.

HYPERSTHENE-DACITES.

In all the descriptions of the rocks of Crater Lake heretofore published the rocks which are here designated as dacites have been called rhyolites. This is not to be wondered at, as these rocks present all the outward characteristics of rhyolites, and even a microscopic examination does not at first give strong ground for the change of name. Previous descriptions have been based largely upon field observations. But, in spite of the fact that comparison may frequently be made and is made in this paper between these dacites and rhyolites of well-known occurrence, a careful study of the mineralogical characteristics, supported by the chemical analyses, has led the writer to the conviction that the change of name is justified. As will appear later, the determination of these rocks as dacites is further strengthened by resemblance to other dacites in the adjacent regions of northern California.

As will be seen to be the case with the basalts the dacites of Crater Lake are somewhat local in their distribution. As they are chiefly confined to distinctive lava flows that, with one exception, represent the latest eruptions to be seen on the rim, and whose outlines can be definitely traced, it is possible and desirable to treat each of the dacite flows separately. Beginning with the most conspicuous flow, that of Llao Rock, and passing around the lake toward the east, the dacite flows will be described under the following heads: Llao Rock, Grouse Hill, Cleetwood Cove, Wineglass, Cloud Cap, Sun Creek. Outside of these six areas, as well as within the same, there occurs abundant dacitic material, in the form of bombs and tuffaceous matter, that will also receive separate consideration.

As is usually the case with dacites, the groundmass of these rocks presents a most remarkable variety of structures, and upon the variations in the groundmass most of the distinctions are to be based. To a certain extent this is true of the phenocrysts, at least as far as their relative abundance is concerned. Upon the whole, however, the Crater Lake dacites, irrespective of the extreme variations in the groundmass, are characterized by the presence of well-defined phenocrysts. These minerals are labradorite, hypersthene, and brown hornblende, all of which are usually present, also augite and olivine, which may occasionally be seen.

MINERAL COMPONENTS.

FELDSPAR.

While phenocrysts of feldspar are fairly abundant in all these dacites, and in some specimens very numerous indeed, in no case could orthoclase be detected. Not only is it true that the feldspars turn out to be plagioclase, but plagioclase of a decided basic variety, usually

labradorite. In form they do not appear to differ materially from the similar phenocrysts in the andesites. There are to be seen comparatively large, stout crystals with the basal pinacoid and brachypinacoid, the two half prisms, and an additional dome or pyramid; also crystals that are more nearly rectangular in cross section and usually smaller in size. The stout crystals with more elaborate forms are probably older than the others, at least they appear to have greater extinction angles and to belong to a more basic plagioclase. These crystals are usually not numerous enough in any one thin section to allow the accurate determination of the maximum extinction angles; the extinction angles given below, therefore, although they are the maximum observed, probably do not indicate feldspars as basic as those actually present. Sections cut perpendicular to the twinning plane, and therefore showing symmetrical extinctions, gave the following maximum extinction angles, viz: 30°. 101, 31°. 104, 30°. 197, and 33° in No. 103. All four of these specimens came from the dacite of Llao Rock. No. 101 is a vitrophyric dacite from the southern edge of the flow, and is almost identical with No. 102, of which a chemical analysis will be found on page 140. No. 104 is a spherulitic variety of a vitrophyric type, and Nos. 197 and 103 are approximately holocrystalline types. These measurements indicate a plagioclase at least as basic as labradorite, and probably more so. The above extinctions represent, however, not the whole crystal, but the inner part. The outer shell often gives much smaller angles. For instance, in No. 101 the margin gives an extinction angle of 24° is six degrees less than at the center, but even this is not too small an extinction for labradorite. The measurements given for the plagioclase phenocrysts of the Llao Rock flow do not differ materially from the observed extinction angles in the other dacite masses.

Zonal structure is very strongly developed in these larger plagioclase phenocrysts, and is particularly conspicuous in sections cut approximately parallel to the brachypinacoid. In such sections the zonal banding, as seen in polarized light, indicates that the crystals in the earlier stages of growth had simpler forms. For instance, in a section parallel to the brachypinacoid, showing externally traces of the basal pinacoid, prism, and two domes, the central core shows only the basal pinacoid and one of the domes almost at right angles to the first-named form. In such sections the zones of different extinctions usually shade gradually into each other, so that from the center outward the extinction angle becomes less and less oblique to the trace of the basal pinacoid. Almost always, however, there are to be seen one or more quite sharply defined shells with rather abrupt difference in extinction. Furthermore, this abruptness of change from one shell to the next is not infrequently accentuated by the fact that the extinctions do not change regularly from the center outward, but oscillate more or less. In other words, the plagioclase consists of concentric shells that alternate between less acid and more acid feldspars. As far as observed, the actual center is nearly always the most basic portion of the feldspar, but the shell immediately surrounding this center may be more acid than the next succeeding one. The alternation of more and less acid shells is not usually sharp enough to admit of positive measurement. In the two following cases the measurements were sharp enough to justify recording.

In No. 102 occurs a section of plagioclase that is cut approximately parallel to the brachypinacoid and that shows the alternation of zonal shells very clearly. This may be seen illustrated in fig. *F* of Pl. XIV (p. 76). The three most conspicuous zones are marked 1, 2, and 3, from the center outward. The crystal forms that could be identified by means of the cleavage cracks are the basal pinacoid (001) and the prism (110). Two other plagioclase crystals are grown into this one—one almost at right angles, to be seen on the left side of the figure; the other, in the upper left corner of the figure, appears almost to continue the outlines of the main crystal. These two crystals do not appear to be in twinning relationship to the other. The extinction angles, as measured to the trace of basal pinacoid, as well as the corresponding percentage of the anorthite molecule, are given below for the three zones:

- 1 = -12° per cent An = basic andesine.
- 2 = -21° per cent An = labradorite.

3 = -5° per cent An = basic oligoclase

The percentages of An are given as corresponding to extinction angles measured on a section exactly parallel to the brachypinacoid. That this is not quite true of this section is proved by the fact that the angle of equal illumination for the three zones is +29° the required angle of +34°. As these extinction angles do not indicate quite as basic a plagioclase as do the extinction angles on symmetrical sections, it is probable that a section cut exactly parallel to the brachypinacoid would give still larger extinction angles than are here indicated. But, at least, these measurements suffice to prove that in this case the inner portion of the crystal is not as basic as is the intermediate zone.

In No. 101 was seen another section of plagioclase, cut similarly to this one, and also showing similar extinctions. Like the example given above, 1 is the center and 4 the margin.

- 1 = -22° labradorite.
- 2 = -14° basic andesine.
- 3 = -16° basic andesine.
- 4 = -5° basic oligoclase.

A comparison of the refractive powers of the plagioclase phenocrysts in the rocks containing these two crystals shows that they have higher refractive power than has the adjacent Canada balsam, i. e., higher than 1.540. This would indicate that they are more basic than oligoclase, even at the edge of the crystal.

The plagioclase phenocrysts are frequently broken and the fragments scattered through the glassy groundmass. They also show frequent corrosion, but, unlike the andesitic plagioclases, they do not often contain abundant glass inclusions; at least, the crowding with glass inclusions and their distribution in an intermediate zone is not characteristic. An exception must be taken to this statement, however, in favor of the dark-colored secretions that receive special treatment further on in these pages. Inclusions of slender apatite needles are common; also zircon crystals in short colorless or slightly brownish prisms may be seen, but very sparingly.

The plagioclase that belongs more particularly to the groundmass seems to be oligoclase, on account of the very small extinction angles. A more detailed description of the groundmass feldspars will be found in connection with the description of the different dacite flows.

Orthoclase and *quartz* are also entirely confined to the groundmass and will be discussed later. *Tridymite* is not common. It occurs in the customary clusters, apparently filling small cavities (121) also to some extent in the fluidally arranged lithoidal dacites.

HORNBLLENDE.

This is a very characteristic ingredient of the Crater Lake dacites. While it is almost entirely wanting in the andesites, it is conspicuously present, although in only occasional crystals, in the dacites, or, at least, in most of them. Out of twenty-eight thin sections prepared from different rock specimens, hornblende could be found in all but five. True, it is to be seen in a few of the thin sections in very small crystals, and in none of the rocks does it assume a prominent role as far as quantity is concerned, but it is always very easily recognized by its peculiar color and characteristic pleochroism. It occurs always in long slender prisms, several to many times as long as thick. The prism invariably, and sometimes also to a slight extent the clinopinacoid, is strongly and sharply developed. Terminal faces are often wanting, and when present appear to be the usual flat basal or pyramidal faces. They are frequently minute and are rarely over 1.5 millimeters in length. These hornblendes may all be classified as belonging to the brown variety, although there is really a great range in color. They may be

further divided into, first, brownish-green; and second, brownish-red varieties.

The first, or brownish-green hornblende, is much more common than is the second variety. It may be studied in Nos. 102, 117, and 118. Pleochroism is very strong. c = dark olive green with usually a trace of brown, b = dark greenish brown, a = lemon yellow to greenish yellow. At times the rays vibrating parallel to c are almost a pure deep olive green. In any event brown is most conspicuous in the rays vibrating parallel to b . This hornblende has a very unusual absorption. in that the absorption parallel to b is greater than that parallel to c , thus, $b > c > a$. In some cases there appears to be very little difference in color and absorption between b and c , but wherever there is a marked difference the absorption is as given above. Professor Rosenbusch^a refers to an observation by A. Osann of a hornblende phenocryst in an andesite from Hoyazo, Cabo de Gata, which has not only the same absorption but also nearly the same colors as have these hornblende phenocrysts from Crater Lake. The pleochroism as given is as follows: a , light greenish yellow; b , greenish brown; c , dark greenish yellow; and $b > c > a$.

^aMikroskopische Physiographie, 3d edition, Vol. I, 1892, p. 558.

The extinction angles for these hornblende crystals are very small, 6° or 7° being the maximum observed. Further optical properties, as far as could be observed, appear to correspond with those of the similar hornblende that forms a large part of some of the so-called secretions to be described later in this paper. Twinning parallel to the orthopinacoid is very common.

The dark brownish-red variety of hornblende is to be seen in Nos. 104, 110, 112, and 114; it also occurs less abundantly elsewhere. In form it does not differ from the above-described variety. The pleochroism is fully as marked, but the colors are very different, c = dark brownish red, b = reddish brown, a = yellow, with $c > b > a$. The absorption is normal. The deep brownish-red color of the rays vibrating parallel to c are very striking and characteristic. This color is sometimes almost blood red and reminds one strongly of the color of hematite in very thin scales. The extinction angle does not differ materially from that of the first variety.

In one or two cases both of these varieties of hornblende may be seen in the same thin section (104). They are both of them usually perfectly sharply crystallized and unaltered. Only in rare cases can a partial resorption with development of black rims be noted (124), and, from the very few sections observed, it is not possible to state whether both of the varieties may have such resorption rims, but it appears as though this were the case. As far as can be seen, there appears to be no difference in the relative ages of these two varieties. They are the youngest of all the phenocrysts. The greenish-brown variety, at least, contains inclosures of plagioclase, hypersthene, and augite. The hornblende occasionally appears with other minerals in the form of nests and then is not as apt to occur in slender prisms as in more irregular grains.

HYPERSTHENE.

This mineral is not as abundant as it is in the andesites, but it is never entirely lacking. It occurs in the same forms—namely, prism, two pinacoids, and flat terminal faces, in the same habits and with the same color, pleochroism, and inclosures of glass, etc., as it does in the andesites. The reader, therefore, is referred to the description of this mineral as given under the andesites on pp. 78 to 82. It could not be noticed that the pleochroism is less pronounced or the colors less deep than they are in the andesitic hypersthene, so that there is no reason for considering these orthorhombic pyroxenes as enstatite rather than hypersthene. The

crystals are mostly very sharp, although they may at times show some rounding of the corners. In only one case was a resorption noted, accompanied by the development of a dark, blackish-red, opaque rim (112).

AUGITE.

This mineral is to be seen in about one-third of the thin sections studied. It is much less abundant than hypersthene and is inclined to occur in more or less irregular grains rather than in sharp crystals, although the latter are by no means lacking. In color it is a pale green without noticeable pleochroism. It has been noticed to inclose magnetite and apatite. It is younger than hypersthene and also, as a general thing, younger than plagioclase, but is older than hornblende.

OTHER MINERALS.

Olivine was observed only in the older secretions that accompany these dacites and will be referred to under that head. *Apatite* and *zircon* occur as occasional inclosures in the different phenocrysts, as does also magnetite. The first of these, however, is not easily found. Its color is sometimes a distinct brown, and the form roundish prismatic.

The order of crystallization for the above minerals, leaving out these last-named accessory minerals is as follows: Hypersthene, plagioclase, augite, and hornblende, with some variability as to the plagioclase, as this mineral is at times older than hypersthene.

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Geological Survey Professional Paper 3

The Geology and Petrography of Crater Lake National Park

THE PETROGRAPHY OF CRATER LAKE NATIONAL PARK

By HORACE BUSHNELL PATTON.

BASALTS.

As will be seen by consulting the map the basalts of Crater Lake comprise only the later volcanic eruptive masses that form the various cones, mounds, and flatter lava sheets to the north, west, and south of the lake. No basalts whatever are found in the walls of the crater or in the dikes cutting them. Nor are they to be seen on the immediate outer slope of the crater.

In the great majority of cases the basalts bear a very close resemblance to many of the andesites, and sometimes can not surely be distinguished as basalts. In not a few cases, however, typically developed basaltic structures are to be noted. This type will be considered first.

INTERSTITIAL BASALTS.

This type of basalt is represented by four specimens (152, 153, 154, 155) taken from the hill that rises 500 to 600 feet above the level of the plain of Diamond Lake, in the extreme northwest corner of the Crater Lake area; also by two specimens from the lava flow at the east base of Red Cone, about 1-1/2 miles northwest of Llao Rock on the crater rim (156, 157); also by four specimens taken from different places in the basaltic area west of Anna Creek in the extreme southwestern corner of the region mapped (158, 159, 160, 161).

These rocks are all rather light colored, of a grayish to brownish tint, and contain occasionally a few cavities, but are never really scoriaceous. The grains are remarkably uniform and are rather dense, but not extremely so. Under the lens they appear holocrystalline and disclose occasionally greenish to reddish olivine grains and likewise greenish grains of hypersthene. Both olivine and hypersthene have a distinctly resinous luster.

An absolutely holocrystalline structure can only occasionally be made out under the microscope (156, 152), but in all cases a glass base plays a very subordinate role. The structure is dominated by the feldspars, which occur in mostly very distinct lath-shaped forms, while the augite is largely confined to the more or less angular spaces between the feldspar laths, after the manner of a mesostasis. This structure may be termed interstitial (Rosenbusch's "intersertale struktur"). The rocks in question, however, are too decidedly feldspathic to give typically interstitial structures. In one or two cases they assume a nearly hypidiomorphic (156) and in others a porphyritic structure. The porphyritic development, however, is caused by the occurrence of phenocrysts of olivine and hypersthene, and rarely of augite or plagioclase.

MINERAL COMPONENTS.

FELDSPAR.

The feldspar is entirely plagioclase, which, on account of its great abundance, dominates the structure of the rock. It has the rather long lath form common to basalts of this class. In most cases the laths are rather irregular in outline, but where a glass base is more in evidence, as is usually the case, the edge of these lath forms may be quite sharp. In such cases the ends are cut off squarely, as though by a pinacoidal face. Wherever the absence of a glass base prevents the free development of the terminal faces the long sides of the laths are more perfectly formed than are the ends. Their length is usually several times their width. The general shape of these plagioclase crystals is tabular, as the square cross sections so characteristic of plagioclase in microlitic form are conspicuously absent. The different thin sections of these basalts present not a little variety in the size and uniformity of the feldspars in the same specimen. No. 161 will serve to illustrate one in which the feldspars are unusually uniform in size. Their average length is 0.2 millimeter. Nos. 152 and 157 show much greater variation in the size of the feldspars, those of No. 157 having an average length of 0.3 millimeter, with a maximum of 0.7 millimeter and a minimum of 0.1 millimeter: the feldspars of No. 158 have an average of 0.15 millimeter with a maximum of 0.3 millimeter and a minimum of 0.04 millimeter. Most of the plagioclase laths disclose sharply defined polysynthetic twinning, the smaller and more slender laths having two or three and the larger ones half a dozen or more stripes. In each thin section, however, there are not a few individuals that do not appear to be twinned. There is no good reason to infer that any of these represent a monoclinic feldspar. Usually such untwinned individuals have much broader forms, such as one would expect to see in a tabular plagioclase cut parallel to the largest face. The supposition that this is the case is strengthened by the frequent appearance of well-defined cleavage cracks that correspond in direction to the basal cleavage of plagioclase. These larger apparently untwinned sections not infrequently also show a well-defined zonal structure, which structure may also be seen at times on the larger crystal grains that are cut so as to show the twinning. As is generally the case in zonal plagioclases the zonal banding is best seen on the brachypinacoid. The extinction angles observed indicate a very basic plagioclase, namely, anorthite. Measurements made on sections at right angles to the brachypinacoid—that is, on sections that give equal extinction angles to the right and to the left of the trace of the twinning plane—gave maximum angles varying between 30° and 36° (the last-named angle was observed in No. 152). These measurements were made on crystals of different sizes, not only on the largest ones. In cases where the individuals were too small to allow one to determine the direction of cutting the very large extinction angles commonly obtained also point to a very basic feldspar.

With the exception of an occasional apatite needle and a little black dust, these feldspars are free from inclosures. An exception to this statement may, perhaps, be taken in that where the dust is conspicuous there is not unlikely also a small amount of glass inclosing it. Part of this black dust appears to be opaque and may be considered to be magnetite, but other particles, when highly magnified, lose their apparent opacity as well as their blackness. These last are undoubtedly globulitic matter. Such dust-laden glass is quite similar to the small amount of glass base that at times may unmistakably be detected between the plagioclase laths of these and of other basalts of this region. In a few cases (155) a small number of somewhat larger and thicker plagioclase crystals are to be seen that may possibly be considered as phenocrysts and as belonging to an older generation, but they bear little resemblance to the more characteristic phenocrysts of the andesitic basalts described further on in these pages.

AUGITE.

Augite is abundant, but is invariably much less so than plagioclase. It appears in thin section

in pale-greenish or yellowish-green colors, and nearly always in small angular grains filling the spaces between the feldspar laths. Occasional exceptions to this rule may be mentioned (153) where the augite assumes in part roughly prismatic form, resembling that of the hypersthene. It is invariably younger than the plagioclase and also younger than the hypersthene. In a few cases (156-157) contiguous or adjacent grains have simultaneous extinction, and develop into an ophitic structure through partially inclosed plagioclase laths. Augite is usually much more abundant than hypersthene, although it may become less so (152). As a general thing the augite is perfectly fresh, but brownish to deep-red iron oxide stains are common.

HYERSTHENE.

Hypersthene is a characteristic but not always abundant constituent of these basalts. It is very fluctuating in amount. Although it may be more abundant than augite, as above noted (152), it is generally not so abundantly represented, and in one case appears to be entirely absent (161). It occurs almost invariably in small, fairly well-defined prisms that are two or three times as long as wide. In the more distinctly holocrystalline varieties this mineral is almost granular, the prismatic habit being very roughly developed. On the other hand, where the structure is less crystalline and the glass base distinctly recognizable, the characteristic habit of hypersthene can readily be made out. In such cases the forms are brachypinacoid and macropinacoid with subordinate prism, terminated by a flat pyramid. In color and pleochroism they exactly resemble the hypersthene of the andesites. In the very thin sections, however, necessary for the study of these rather fine-grained rocks, it is not easy always to distinguish between augite and hypersthene. In such cases the general form, parallel extinction, and lower double refraction are usually sufficient. In the finer grained specimens the hypersthene does not differ greatly from the plagioclase laths in size, being perhaps, on the average, somewhat smaller; in the coarser rocks they are apt to be decidedly smaller than the feldspar laths. They are nearly free from inclosures, magnetite octahedrons and an occasional apatite prism being the only observed exceptions. As stated above, they are older than the augite grains, and seem also in most cases to be older than the plagioclase.

Parallelism of growth between augite and hypersthene is a common occurrence. This is more noticeable in the basalts that are poor in augite. In such parallel growths the augite invariably appears as a slender strip on each side of a prismatic hypersthene prism, the two strips on the opposite sides of the crystal extinguishing together. Very rarely may augite be seen on the end of a hypersthene crystal. It is worthy of note that this parallelism of growth between these two pyroxenes is not universal, that is, not all of the hypersthene in any one thin section are thus bordered by augite.

OLIVINE.

Olivine is a constant but very fluctuating ingredient. It appears to be particularly abundant in those rocks where hypersthene is either missing or at least not abundant. No. 157 well illustrates this fact. It is a nearly holocrystalline basalt, with abundant augite and olivine, but with only two or three hypersthene individuals visible in a thin section. The olivine appears either colorless or slightly yellow, but it is frequently stained blood red along the irregular cleavage cracks. In a few cases a slight serpentinization has started in. The olivine occurs usually in granular form or in clusters of grains and only exceptionally in roughly defined crystals. It is the largest constituent of these basalts and is the only one that may be classed as a phenocryst. In No. 152 the olivine appears to have suffered to some extent from magmatic resorption. This is indicated by a border of opaque ore grains. This black border does not occur on all individuals. It is best seen on the smaller ones. It may occur on one end of a crystal and be missing on the other end. A few of the smaller crystals show only a core of unaltered olivine while the greater part of the crystal has been thus altered. In this specimen

the small individuals of olivine are unusually well defined and show quite distinctly the crystal shape. In such cases the granular mass of ore has retained the original crystal form of the olivine. The olivines show occasional inclosures of magnetite and also once in a while of brown glass.

MAGNETITE.

Magnetite is not present in very great abundance. It occurs in the customary grains and small octahedral crystals scattered throughout the rock and inclosed in all the other ingredients. It varies considerably both in amount and in the size of the individual crystals, but it never assumes the importance that is ordinarily expected in basalts. It also occurs, as described below, in the form of fine dust impregnating the interstitial glass.

As already mentioned, the glass base of these basalts varies somewhat in amount. It is never very conspicuous, and it vanishes almost entirely at times. In a number of cases the glass can not actually be seen, but its presence is probably indicated by the occurrence of black dust, which is probably magnetite and globulitic matter, and which occurs either in separate but very minute grains that are too small to measure or in very minute rod-like or trichitic-like growths. Apparently these opaque particles, are inclosed in the feldspars, but as they are to be seen mostly at the junction of the plagioclase laths it is more likely that they are really embedded in a very thin film of glass. None of the specimens above described is entirely free from this black powder.

This interstitial structure is brought out in fig. C of Pl. XIX (p. 138).

The chemical analysis of No. 158 will be found with the analyses of other basalts from Crater Lake on page 161. Although this is as typical an example of basalt as may be found around Crater Lake, the analysis indicates a rock closely allied to the andesites. It is distinctly more acid than is the olivine-bearing basalt (173), a description of which may be found on page 155.

A partial analysis of another interstitial basalt (162) was carried out in the chemical laboratory of the Colorado State School of Mines by Prof. R. N. Hartman. This analysis gave $\text{SiO}_2=55.18$ per cent. It would seem, therefore, from these two analyses that the interstitial basalts of Crater Lake have unusually high percentages of silica.

HYPERSTHENE, APATITE, AND PSEUDOBROOKITE CRYSTALS IN BASALT.

In a specimen of basalt of this type collected on the east base of Red Cone (156) occur numerous flattish cavities that measure from one-quarter to one-half inch in greatest diameter. These cavities are lined with minute crystals of four different kinds; first, hypersthene; second, pseudobrookite; third, apatite; fourth, unknown white mineral.

The crystals of hypersthene occur in very brilliant though minute tablets, transparent, and of a fine deep-brown color. When examined under the microscope these crystals give the properties of hypersthene as seen in section parallel to the brachypinacoid. Pleochroism is marked with greenish color in the direction of the vertical axis and a decided brown at right angles to this direction. The extinction is parallel and the vertical axis the direction of least elasticity. No optical image can be obtained on the large crystal face.

Owing to the extreme brilliancy of these hypersthene crystals and to the fact that they appeared to present interesting crystal forms, pieces of the rock containing these cavities were sent to Dr. C. Palache, of Harvard University for further identification and measurement. The writer is extremely indebted to Dr. Palache for working out the forms of these crystals as well as for the identification and measurement of the pseudobrookite crystals. The result of this

painstaking work is given below. As will be seen by comparing his measurements the supposition that these brown, pleochroic tablets are hypersthene is abundantly proved.

The cavities also contain a very few black and not well-defined crystals which, under the microscope, appear to have a deep reddish-brown color and to show no pleochroism. Although the writer is not certain that these black crystals are the same as those identified by Dr. Palache as pseudobrookite, the probability is in favor of that supposition.

APATITE CRYSTALS.

Apatite occurs in very delicate, minute, slender needles. The identification as apatite rests upon the needle form and the fact that they possess very low double refraction and have parallel extinction with negative extension.

The unknown white crystals occur in abundant, roundish forms which, when broken, are seen to be aggregates. It is possible that they are tridymite, with which they have some resemblance, but this could not be proved.

Below is submitted the report on hypersthene and pseudobrookite crystals by Dr. C. Palache.

HYPERSTHENE CRYSTALS.^a

The hypersthene is in the form of minute tabular crystals, 0.5 to 0.75 millimeter in length, 0.3 to 0.5 millimeter in breadth, and about 0.1 millimeter in thickness. They are always attached to the walls of the cavity by an edge in such manner that double terminations never occur. The faces are bright and sparkling except *a*, 100, which is sometimes striated parallel to the vertical direction; but on account of their minute size the reflections are dim, and the readings, therefore, subject to considerable variations.

^aThe description here given is the work of Dr. C. Palache.

The observed forms (position of Groth, *a*: *b*: *c*=1.0308: 1: 0.5885) were as follows:

<i>a</i> , 100	<i>n</i> , 210	<i>i</i> , 121
<i>b</i> , 010	<i>w</i> , 310	<i>u</i> , 322
<i>m</i> , 110	<i>k</i> , 102	----

The most frequent combination of these forms is shown in fig. *I* of Pl. XIV (p. 76), which is an exact reproduction of the figure given by Schmidt^a for the hypersthene from Málnás, Hungary.^b

^aZeit. für Kryst., vol. X, 1885, p. 210.

^bThis figure is given by Dana, p. 349, fig. 2, but with incorrect lettering. With the axes there adopted, the letters *a* and *b* on the two pinacoids should be interchanged.

k, 102, also found on the Málnás crystals, was found only on a single crystal shown in fig. *J* of Pl. XIV, and the same was true of *n*, 210, a single narrow face not shown in the drawing. *w*, 310 was observed on several crystals and measured on two. This form was first observed by Fouqué on hypersthene from Santorin,^c but he did not indicate it as new and gave no

measurements. It has therefore been rejected in most of the recent lists of hypersthene forms, but appears to have been confirmed by the present measurements.

^cBull. Soc. min. France, Vol. I, 1878, p. 47.

	Measured.				Calculated.				Number of readings
	θ		p		θ		p		
	o	'	o	'	o	'	o	'	
m , 110	44	12	90	00	44	07	90	00	5
n , 210	62	46	90	00	62	44	90	00	1
w , 310	71	24	90	00	71	02	90	00	5
k , 102	90	00	15	55	90	00	15	56	2
i , 121	25	55	52	34	25	52	52	36	3
u , 322	55	27	46	06	55	30	46	06	2

PSEUDOBROOKITE CRYSTALS.^d

Accompanying the hypersthene in a single cavity were several slender, needle-like crystals, having a brilliant metallic luster. Their appearance and the association in which they occurred recalled the description of pseudobrookite as found in the hypersthene-andesite of Aranyer Berg, Hungary;^e and, notwithstanding the minute size of the crystals, it was found possible to obtain approximate measurements from two of them, which seem to confirm this determination.

^dThe description here given is the work of Dr. C. Palache.

^eAmong others, Traube, Zeit. für Kryst., Vol. XX, 1892, p. 327.

The forms found are shown in fig. *K* of Pl. XIV (p. 76) and in the following table, together with the measurements:

	Measured.				Calculated.				Number of readings
	θ		p		θ		p		
	o	'	o	'	o	'	o	'	
a , 100	90	00	90	00	90	00	90	00	4
b , 010	00	00	90	00	00	00	90	00	4
m , 210	63	42	90	00	63	45	90	00	6
l , 110	46	00	90	00	45	23	90	00	3
e , 103	90	00	20	57	90	00	20	53	2

The faces of the pinacoids, *a* and *b*, were bright, but the prisms were deeply striated and gave very poor reflections.

The position here adopted is that originally proposed by Koch* and retained by Schmidt,

Traube, and Groth. With Dana and Goldschmidt the axes *b* and *c* are interchanged. The former seems the more natural choice, in view of the pronounced prismatic habit of the crystals and since the chemical relations of pseudobrookite to brookite do not seem to bear out the apparent form relations between the two minerals which it was the purpose of the altered position to express.

* A. Koch, Min. Mitth., vol. I, 1878, pp. 77 and 344.

FLUIDAL-INTERSTITIAL BASALTS.

In at least two instances (152 and 155) the above-described interstitial basalts disclose a decided tendency toward a fluidal arrangement of the plagioclase laths, and thus present a transition stage between the more typically developed interstitial basalts and what may be termed basalts with a fluidal-interstitial structure. This last-named type is well illustrated by four specimens, three of which (162, 163, and 164) were collected in different parts of the basaltic area to the southwest of Crater Lake, from which most of the interstitial basalts came, and the fourth (165) from a widely separated section, namely, from the southwest slope of Timber Crater, situated about 4 miles to the northeast of the lake.

These rocks consist of plagioclase, augite, hypersthene, and magnetite with almost no olivine. Glass is also undoubtedly present, but certainly not in large amount. The fluidal structure is due mainly to the fact that the plagioclase appears in very long and slender lath form, and to the further fact that these feldspar laths have a very marked parallelism of arrangement. The structure is indeed quite suggestive of the fluidally arranged sanidine laths in trachytes and many rhyolites. These plagioclase laths are quite sharp in outline, or, at least, this may be said to be true of the sides of the crystals. They are many times as long as wide, and have an average size of about 0.1 to 0.2 millimeter. The fluidal structure is further accentuated by the fact that the hypersthene and to a considerable extent also the augite occur in rather slender prisms, which are likewise arranged parallel to the feldspars. Hypersthene is distinctly the dominating pyroxene, being usually much more abundant than augite. It occurs only in prismatic form in crystals that measure usually about 0.02 to 0.05 millimeter in length, and about one-third that amount in width. Occasionally somewhat larger individuals may be seen, but, as a general thing, their size is very uniform. They inclose small grains and octahedral crystals of magnetite. The augite is to be seen both in grains and in minute prisms, almost identical in size and appearance with the hypersthene prisms. In fact, in white light it is almost impossible to distinguish between the two, as in color, size, shape, and inclosures they resemble each other. Even the pleochroism can hardly be used as a means for distinguishing these two pyroxenes, because of the necessarily thin sections required for the proper study of such fine-grained basalts. In polarized light, however, the distinction is not difficult. Parallelism of growth between hypersthene and augite may be observed exactly as in the above-described rocks, the augite appearing in the thin section as slender parallel strips on each side of the hypersthene.

The fluidal-interstitial structure is shown in fig. *D* of Pl. XIX (p. 138).

The almost complete absence of olivine in the basalts in which hypersthene is unusually abundant is a further corroboration of the frequently noticed fact that the development of olivine in a basalt is not so much dependent on the chemical composition as upon the conditions of solidification. Irrespective of the fact that the amount of olivine in these and in the more typically developed interstitial basalts appears to vary inversely with the development of hypersthene, it may be remarked that the small amount of olivine present in all these basalts falls in line with the remark of Professor Rosenbusch,^a to the effect that olivine occurs most sparingly in the basalts of a hypidiomorphic or of a doleritic type. The

basalts under discussion, although hardly to be called typically doleritic, are at least more allied to that type than to any other.

^a Mikroskopische Physiographie, 3d edition, vol. II, 1896, p. 993.

In No. 163 are to be seen minute, rod-like microlites of a deep reddish-brown color and almost opaque. In size they measure on the average 0.01 millimeter long and 0.001 millimeter wide. They resemble rutile, but do not give the brilliant polarization colors characteristic of such minute crystals of that mineral. In fact, it could not be shown that they affected polarized light at all. They have not been noticed in the other basalts.

These fluidal-interstitial basalts, when compared to those already described in these pages as interstitial, are closely allied to those occurring in the northwest corner of the Crater Lake area, and more especially to Nos. 152 and 155. No. 164 shows the fluidal structure much less perfectly developed than do the other three and may be considered as intermediate between the two types. No. 166 was collected at the same place as No. 164 and is probably a locally differentiated variety. It could hardly be classed here if taken by itself. The plagioclase is much less abundant and occurs in somewhat larger slender laths, that lie in all directions but are not abundant enough to interfere with each other to any great extent. The bulk of the rock consists of a feldspathic paste thickly crowded with extremely minute pyroxene prisms and with octahedral crystals of magnetite. Both augite and hypersthene are represented, but it is impossible to determine in what proportion.

These two types of basalt are, then, very closely linked together, and the transitions between the different specimens collected are much closer than are the transitions between these and the porphyritic basalts whose description follows, and still more plainly is this true as compared with the basaltic-looking andesites of this same region. The force of this statement will better be appreciated in connection with the comparison made below with the so-called hypersthene-andesite from Franklin Hill, Plumas County, Cal. We have seen that many of the basalts and andesites of Crater Lake can with difficulty be distinguished from each other, but this can not be said of the above-described interstitial and fluidal-interstitial basalts. The more marked characteristics of these rocks for purposes of comparison with the andesites is the almost complete absence of porphyritic development. This is seen both in the scanty development of phenocrysts and in the lack of a younger generation of the mineral ingredients.

These fluidal-interstitial basalts (especially No. 162) bear a close resemblance to a rock from Franklin Hill, Plumas County, Cal., which is briefly mentioned by Mr. H. W. Turner in the Bidwell Bar folio.^a In his article on The Age and Succession of the Igneous Rocks of the Sierra Nevada^b he calls it a hypersthene andesite, and describes it as follows:

"In the area of the Downieville and Bidwell Bar atlas sheets are numerous bodies of a dense fine-grained gray lava, which usually weathers with a slaty fracture, the apparent cleavage being often vertical. The rock is composed of plagioclase, augite, a slightly pleochroic rhombic pyroxene, and grains of magnetite. The feldspar, augite, and rhombic pyroxene are in the form of minute elongated prisms or laths, and this is true of the rock at widely separated localities, and the laths of all are nearly of the same size. About half a gram of No. 661, powdered and treated with HCl by George Steiger, yielded no gelatinous silica, but nevertheless there appears to be some glass present."

^aGeologic Atlas U. S., folio 43.

^bJour. Geol., vol. III, 1895., p. 409.

Through the kindness of Mr. Diller the writer was enabled to make a study of a thin section of No. 661, referred to above. The resemblance between the rock which Turner calls a hypersthene-andesite and those just described from Crater Lake is even closer than might be inferred from the above-quoted description. The differences are rather in the size of the grain than in more important matters. One sees the same delicate, uniform prisms of rhombic pyroxene and of augite, the same slender feldspar laths, and, locally developed, in the thin section the same parallelism of structure. In the California rock the pyroxenes are somewhat larger and therefore more plainly developed. Mr. Turner also gives in the same paper a partial chemical analysis, as follows:

Partial chemical analysis of hypersthene-andesite from Franklin Hill, Plumas County, Cal.

	661. S.N.
SiO ₂	56.90
CaO	7.83
K ₂ O	1.37
Na ₂ O	3.24

This analysis alone certainly seems to justify Mr. Turner in calling the rock he describes an andesite, but upon close inspection it will be seen that the analysis is really that of a rock intermediate between a basalt and an andesite. As far, as the silica alone is concerned the amount is more suggestive of a hypersthene-andesite than of a basalt. But the percentage is only a little over 1 higher than that given for a basalt glass (tachylite) from Säsebühl, near Dransfeld, Hanover.^a Furthermore, Mr. Diller has published a list of chemical analyses of quartz-basalts from Cinder Cone, northeast of Lassen Peak, California,^b in which silica runs as high or higher—in one case three-quarters of 1 per cent higher—than that given for the Franklin Hill andesite. Inasmuch as Mr. Iddings has fairly demonstrated^c that the presence of primary quartz in basalts is not due to the excessive amount of silica present in the magma, it may well be claimed that the rock from Franklin Hill is not necessarily too acid for a basalt.

^aRosenbusch, Elemente der Gesteinslehre, Stuttgart, 1898, p. 309.

^bA late volcanic eruption in northern California and its peculiar lava: Bull. U. S. Geol. Survey No. 79, 1891, p. 29.

^cOrigin of primary quartz in basalt: Am. Jour. Sci., 3d series, Vol. XXXVI, 1888, p. 220.

When the lime, potash, and soda in this rock are taken into account it would be impossible to distinguish as to whether the rock were a basalt or an andesite, for it would be easy to cite analyses of both rocks in which these substances are present in almost the exact relationships that are given in the case under discussion. As to whether the Franklin Hill rock should really be called a hypersthene-basalt instead of an hypersthene-andesite the writer will not assume to say, as this might well depend on surrounding associations with which he is not sufficiently familiar. In the absence of a chemical analysis of the fluidal-interstitial basalts of Crater Lake it may perhaps be assumed that the composition does not vary greatly from that of the California rock. Even so, on account of the close resemblance to well-defined basaltic

types of the same region, and on account of the sharp contrast it presents to the andesites of this same region, one may, in the opinion of the writer, be justified in calling these rocks basalts. In any case, on account of the great variability in the chemical analyses of rocks we are accustomed to class under the same family name, the structural relationships would serve better as a means for determining the rock name than would the chemical analysis alone, especially in cases where that analysis is not typical.

PORPHYRITIC-INTERSTITIAL BASALTS.

This type of basalts may be said to contain well-defined and usually abundant phenocrysts, always of olivine and generally also of plagioclase, hypersthene; and augite, in a groundmass that bears a more or less close resemblance to the interstitial basalts. As a rule, however, the groundmass is inclined to contain more glass and the minerals of the second generation have more sharply developed forms than is the case with the corresponding minerals that compose the interstitial basalts.

The lava of Desert Cone, immediately north of Red Cone, may be taken as the best example of this type of structure. Red Cone also is composed of basaltic lavas that belong to this type, but not entire so, as will appear later.

The lava of Desert Cone is represented by three specimens—No. 167 from the north side, near the summit, and Nos. 168 and 169 collected close together about 1 mile farther south on the southern slope. All three are very much alike. In the specimen from the north side olivine is the only phenocryst; in the two from the southern slope, in addition to olivine, plagioclase, in a rather subordinate role, occurs as a phenocryst.

The olivine in these specimens is to be seen in very sharp idiomorphic crystals and also in crystal fragments. They are particularly well adapted to a study of the crystallographic forms and optical properties. At first glance some of the olivine crystals, especially the fragments, resemble augite somewhat, the color being a light yellowish green. Irrespective of the crystal form, however, one can usually distinguish both the crystals and the fragments by their unusually rough appearing surface and by their high interference colors, also by the absence of well-defined cleavages. They usually appear in rectangular or hexagonal shapes. The dominant forms are the brachydome (021) and a prism. In sections cut parallel to the macropinacoid this combination gives hexagonal outlines, the angle formed by the trace of the brachydome being not far from 80° . Such a section also gives a positive bisectrix, with large optical angle (168).

In No. 169 the olivine phenocrysts have very sharply developed forms and show an extensive alteration to iron oxides. This alteration product occurs both as a broad rim and as finely granulated masses scattered throughout the crystal. In the very smallest crystals the olivine has been almost completely replaced; in the larger ones the unaltered olivine rarely composes more than one-half of the entire bulk and generally much less than one-half. This iron oxide alteration product consists sometimes of perfectly black, opaque material, which is presumably magnetite; in other cases the grains are slightly transparent and are of a deep red color, suggestive of hematite. Still more commonly both magnetite and hematite abound. In spite of the sharpness of the crystal forms the olivine phenocrysts are frequently penetrated by plagioclase laths, thus indicating a very basic feldspar. (See fig. *L* of Pl. XIV, p. 76.) These penetrating feldspar laths do not occur in the center, but only at the margin of the crystals; occasionally, also, one may see an olivine crystal impressing its form on a plagioclase phenocryst. This, however, is by no means as common as the other case. It would seem from this that the feldspars had commenced to crystalize out before the olivines had ceased to grow. Possibly they may have begun simultaneously with the olivines.

The only other phenocryst in this basalt is plagioclase, and even this is absent from one of the three specimens (167). It is by no means conspicuous nor very markedly different from the smaller feldspathic laths that make up the greater part of the groundmass. The shape is rectangular or long rectangular. The largest extinction angles noticed on sections cut perpendicular to the albitic twinning plane was 30° in No. 168 and 29° in No. 169. This does not indicate so extremely basic a feldspar as its relationships to olivine would suggest. Probably if the plagioclase phenocrysts were more numerous sections could be found showing larger extinction angles.

The groundmass appears to be nearly holocrystalline. It is composed of well-developed plagioclase laths of hardly more than microlitic proportions, augite in minute grains, or in both prisms and grains, and abundant magnetite in mostly very minute octahedrons and grains. Hematite powder is also abundantly developed in the groundmass of No. 169 as well as in the olivine phenocrysts. In addition to the above-named minerals hypersthene has been recognized in No. 168. It is entirely confined to the groundmass and occurs in but one generation. It forms very small prisms that measure 0.06 millimeter long by 0.01 millimeter wide and that very closely resemble similar prisms of augite. They are too small to show any pleochroism and are to be recognized only by their parallel extinctions and lower interference colors. In fact, it requires some little familiarity with these rocks before the distinction between the pyroxenes can be made.

In the southwest corner of the area covered by the Crater Lake map, and about half a mile south of the road, was collected a specimen of basalt, No. 170, that is closely connected with the interstitial basalts. In a groundmass composed of plagioclase laths, augite, hypersthene, and a little dust-laden glass occur perfectly developed comparatively large plagioclase phenocrysts that exactly resemble the andesitic plagioclases; also an occasional hypersthene, augite, and blood-red olivine crystal. The plagioclase is in broad crystals that show rectangular and six-sided outlines and, as in the andesites, zonal structure. The interior is crowded with glass inclosures, while the margin is free from the same, or else both the interior and the margin are clear, while the inclosures are confined to a narrow intermediate zone. One of these phenocrysts, cut perpendicular to the brachypinacoid, gave an extinction angle of 34°.

The groundmass of this rock, were it free from plagioclase phenocrysts, would be identical with the interstitial basalts. The plagioclase laths are the dominant mineral, and appear to inclose the angular augite grains as well as the little glass present in the interstices formed by their intersection. Hypersthene, which occurs only very sparingly as a phenocryst, is more abundant in the groundmass, but as it is found here only in prismatic crystals and not in grains like the augite, it is properly not to be considered as belonging strictly to the groundmass, but rather to the older generation of crystals.

Although this rock presents an entirely different appearance from the basalt from Desert Cone, it must still be assigned to the type which has been designated as porphyritic-interstitial. It is in a way intermediate between the holocrystalline interstitial and the andesitic types.

Quite similar to this rock is No. 171, collected between Crater Peak and Sun Creek.

Still another development of the porphyritic-interstitial type of basalt is to be seen in part of the lava rocks of Red Cone. These are dark-gray, in one case red, dense, scoriaceous lavas. The phenocrysts are very inconspicuous, but may be made out under the pocket lens. They consist of yellowish to red olivine, yellow to black augite, and white plagioclase.

Under the microscope these appear to be decidedly porphyritic rocks with abundant and well-

defined, though small, phenocrysts of olivine, augite, and plagioclase. The plagioclase is the most variable of the phenocrysts, as one specimen (172, collected about 1 mile southwest of the cone) contains almost no phenocrysts of this mineral. It occurs in rectangular, broad to narrow, lath-shaped crystals, the smaller of which graduate into the plagioclase of the groundmass. The ends of the laths are cut squarely off, as by a pinacoid, where the groundmass is distinctly glassy, but, in case the latter is more decidedly crystalline, the ends are somewhat frayed. They inclose at times a small amount of dusty-looking glass similar to that of the groundmass, but neither in shape nor in the appearance or arrangement of the inclosures do these plagioclase phenocrysts resemble those of the andesites or of the last-described basalt. Extinction angles in symmetrically cut sections, i. e., in sections perpendicular to the brachypinacoid, were measured as follows: 27°, 30°, 31°, and 34°. They are younger than both olivine and augite.

Of the pyroxenes augite is the only one of consequence. Of the four specimens studied three (174, 175, 172) contained no hypersthene and one (173) contained but one individual, which consisted of a roundish grain having a small core of hypersthene and the outer and larger part augite in parallel position. This growth of augite appears to be secondary and distinct from the more customary occurrence of augite growing around hypersthene crystals. Aside from this one case augite occurs in granular form, but even so impresses its form upon the plagioclase wherever it comes in contact. It is to be found both isolated and in nests with olivine. The color is usually greenish, but in No. 174 many of the grains have a brownish cast, or else they have greenish centers and shade into brown on the outside. It may be added that the hand specimen also discloses a few black augite phenocrysts, 2 to 3 millimeters long, that do not appear in the thin section.

Olivine is a very abundant constituent. It occurs in well-defined, sometimes in very sharply defined crystals, as well as in grains, the latter form being common where the olivine forms nests with augite and occasionally with plagioclase. In No. 174 this mineral occurs exactly as described for No. 169, one of the specimens collected on Desert Cone. It has the same clear-cut forms and has undergone the same alteration to hematite. In this case, however, the alteration has progressed still further. Not only have we the outer rim of almost opaque hematite, but the center of even the largest crystals is so thickly crowded with hematite as to leave very little clear olivine visible. (See Fig. *M* of Pl. XIV (p. 76.)

The groundmass of these rocks is abundant and mostly very distinct from the phenocrysts. It consists essentially of a colorless but dusty glass base that is crowded with augite microlites in the form of minute prisms and grains, also microlitic plagioclase laths and sharp magnetite octahedrons. The interstitial structure is not clearly brought out, but is produced in part by the plagioclase of the phenocrysts and in part by the plagioclase of the groundmass, there being no well-defined distinction between the two. The porphyritic structure, therefore, is much more in evidence than is the interstitial, and this rock may be considered in a sense as intermediate between the porphyritic interstitial and the more distinctly porphyritic basalts. It does not, however, bear much resemblance to that type of porphyritic basalts that are described as andesitic in these pages.

The chemical analysis of No. 173 will be found on page 161.

Two specimens, Nos. 176 and 177, collected about 3 and 4 miles, respectively, west of Red Cone, have been placed in this group of porphyritic interstitial basalts, although they are decidedly transitional between this group and the interstitial basalts proper. The greater part of the rock, as seen in thin section, constitutes a sort of holocrystalline groundmass similar to that of the more coarsely grained interstitial basalts. In this groundmass of plagioclase, augite, and magnetite occur some rather sharply defined phenocrysts of olivine, augite, and plagioclase. The two last-named phenocrysts occur also in granular form or in nests of grains,

and grade off into the same minerals of the groundmass, so that no sharp line can be drawn in either case between the components of the groundmass and the phenocrysts. In the case of olivine, granular forms also occur, but these are always distinct from the groundmass in which no olivine occurs.

The olivine is slightly serpentinized, and is stained in places a deep red. It contains inclosures of magnetite. The better formed crystals of augite disclose the customary forms, namely, prism, two pinacoids, and flat terminal pyramids or dome faces. It is frequently twinned in double, triple, and multiple twins. The twinning plane is the orthopinacoid. It incloses olivine and magnetite, and, to a very slight extent, also plagioclase. The plagioclase crystals show more or less rectangular, but not very sharply cut, outlines. The period of development almost exactly coincides with that of the augite, as these two minerals often impress their form on each other. A few crystals contain minute glass inclosures, but usually they are free from inclosures, and do not bear any resemblance to the plagioclase phenocrysts of the andesites.

Hypersthene appears to be entirely wanting.

A very similar basalt, No. 178, from near the road south of Castle Creek, at the very edge of the district covered by the map, is also placed in this division.

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Geological Survey Professional Paper 3

The Geology and Petrography of Crater Lake
National Park

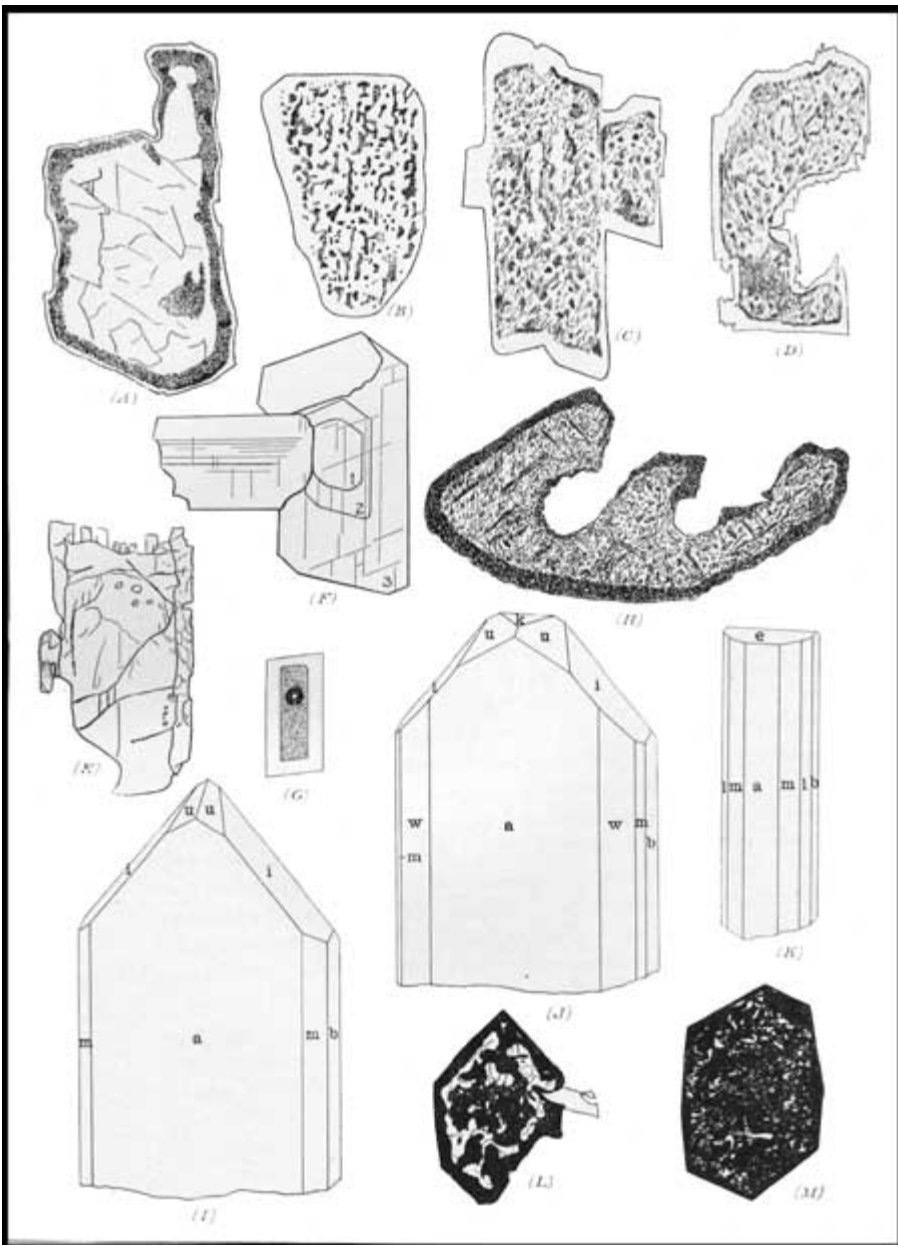
THE PETROGRAPHY OF CRATER LAKE NATIONAL PARK

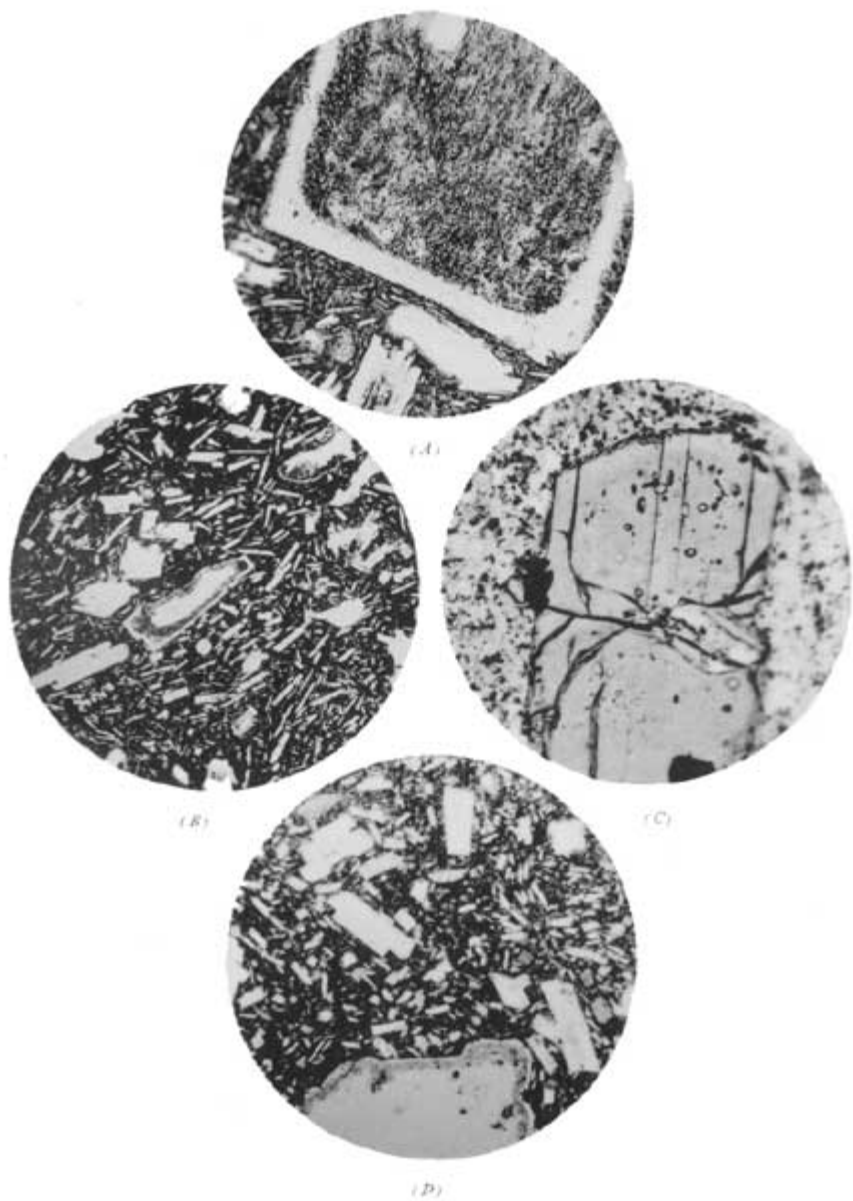
By HORACE BUSHNELL PATTON.

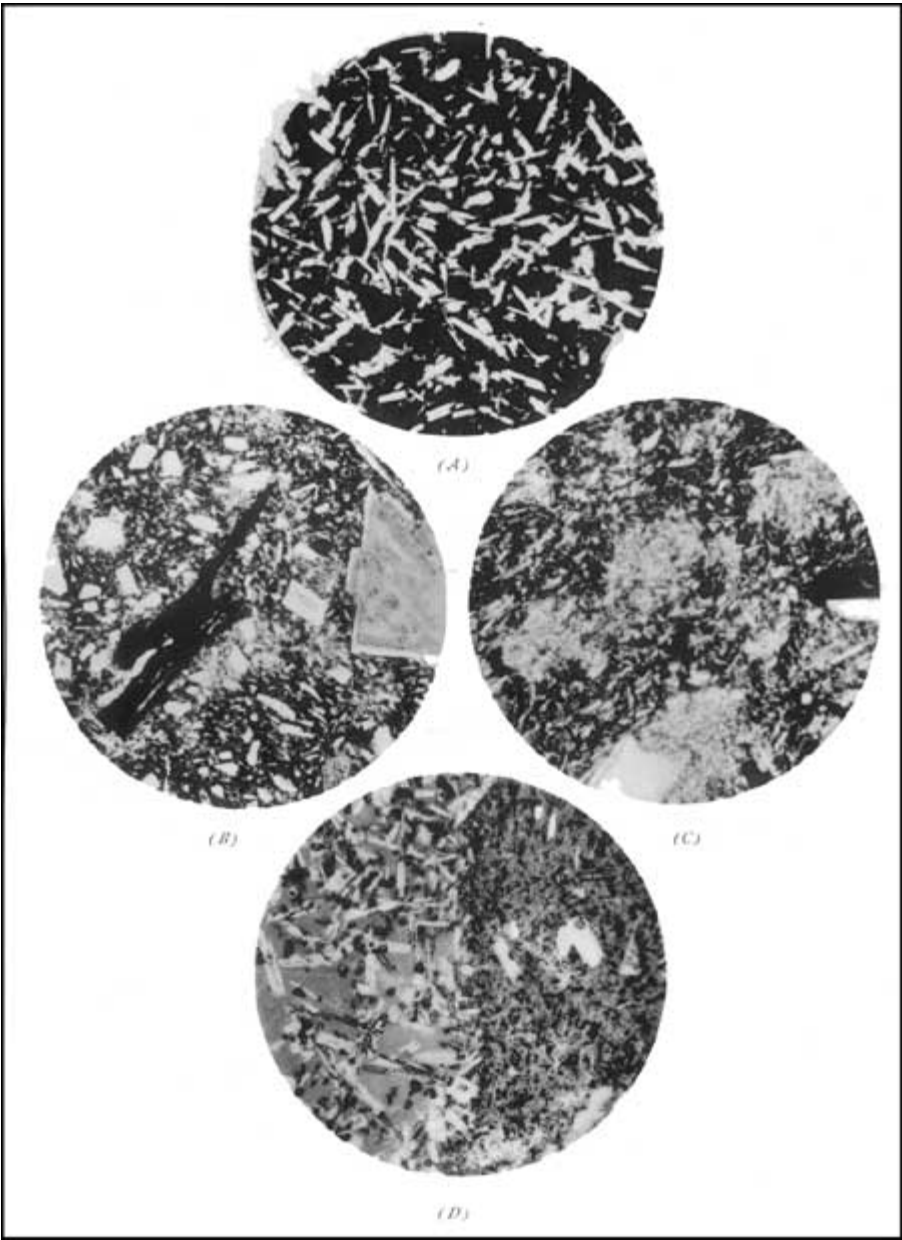
List of Crater Lake rocks in the order in which they are described in this paper, giving in each case the corresponding original number.

1	127 51	4,466 101	133 151	151
2	128 52	4,467 102	4,420 152	4,521
3	132 53	4,472 103	4,421 153	4,522
4	142 54	4,475 104	134 154	4,523
5	144 55	4,484 105	4,504 155	4,524
6	4,402 56	4,540 106	4,505 156	4,401
7	4,409 57	4,549 107	4,506 157	4,508
8	4,411 58	4,556 108	4,507 158	4,426
9	4,412 59	4,396, b 109	4,501 159	4,428
10	4,425 60	4,403 110	4,502 160	4,438
11	4,435 61	4,434 111	4,560 161	4,442
12	4,444 62	4,443 112	4,561 162	4,430
13	4,474 63	4,455 113	4,562 163	4,445
14	4,476 64	4,473 114	4,494 164	4,448
15	4,477 65	4,483 115	4,481 165	4,509
16	4,480 66	4,490 116	4,482 166	4,449
17	4,497 67	4,492 117	4,486 167	4,515
18	4,529 68	4,496 118	4,487 168	4,516
19	4,537 69	4,535 119	4,488 169	4,517
20	4,538 70	4,545 120	4,489 170	4,446
21	4,558 71	4,559 121	4,457 171	4,456
22	130 72	4,563 122	4,458 172	4,527
23	145 73	4,564 123	4,460 173	138
24	4,408 74	4,566 124	4,461 174	139
25	4,433 75	4,429 125	4,468 175	4,440
26	4,450 76	4,462 126	4,469 176	4,532
27	4,464 77	4,479 127	4,471 177	4,533
28	4,495 78	4,396, a 128	4,470 178	4,447
29	4,503 79	4,424 129	4,427 179	4,452

30	4,539 80	4,478 130 4,547 180 4,453
31	4,546 81	152 131 4,548 181 4,454
32	4,555 82	153 132 4,552 182 4,439
33	4,557 83	154 133 4,553 183 4,525
34	126 84	155 134 4,399 184 4,531
35	131 85	156 135 4,544 185 4,534
36	143 86	157 136 4,422 186 4,440
37	146 87	158 137 137 187 4,441
38	4,396 88	159 138 4,397 188 4,511
39	4,396, c 89	160 139 4,499 189 4,512
40	4,404 90	161 140 4,528 190 4,513
41	4,407 91	4,551 141 4,398 191 4,514
42	4,410 92	4,536 142 4,417 192 4,518
43	4,413 93	4,536, a 143 4,423 193 4,519
44	4,414 94	4,419 144 4,459 194 4,520
45	4,415 95	4,550 145 4,500 195 4,526
46	4,416 96	4,554 146 4,498 196 4,530
47	4,418 97	129 147 147 197 136
48	4,436 98	4,463 148 148 198 140
49	4,451 99	4,405 149 149
50	4,465 100	4,406 150 150









(A)



(B)



(C)



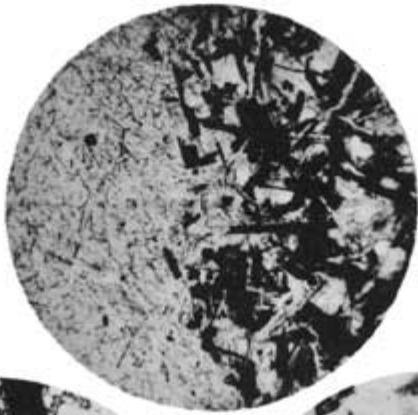
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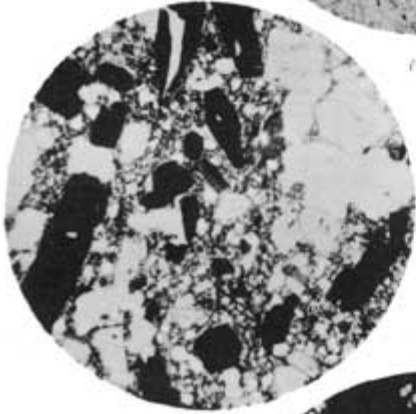
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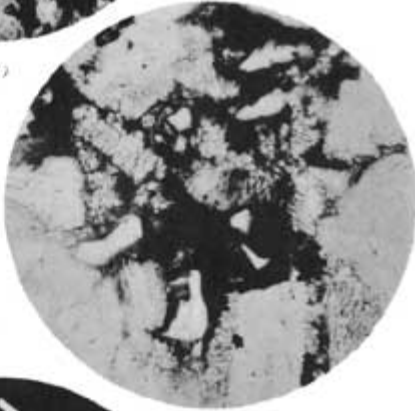
(F)



(A)



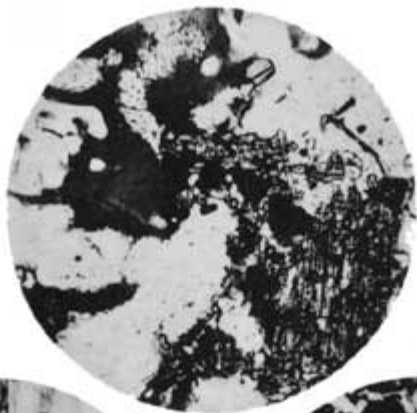
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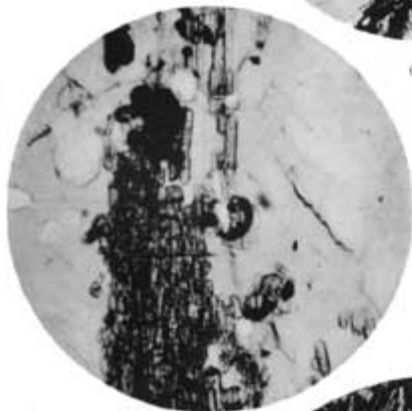
(C)



(D)



(A)



(B)



(C)



(D)



Geological Survey Professional Paper 3

The Geology and Petrography of Crater Lake National Park

THE GEOLOGY OF CRATER LAKE NATIONAL PARK

By JOSEPH SILAS DILLER.

CRATER LAKE.

(continued)

INFLOW OF CRATER LAKE.

The drainage area within Mount Mazama is very small as compared with the size of the lake. It is circumscribed by the crest of the rim and limited to its inner slope, with an area, according to Mr. E. C. Barnard, of 27.48 square miles. As the area of the lake, including Wizard Island, is 21.30 square miles, the drainage area encircling the lake is 7.06 square miles—that is, less than one-third of the size of the lake itself. The prevailing southerly and southwesterly winds of winter, when the precipitation is largest and is in the form of snow, greatly increases the catchment over the normal precipitation by drifting snow over the southern rim. It hangs upon the inner slope and furnishes many avalanches to the lake during winter as well as many small streams in summer. Sixty-three small streams were closely estimated or measured by running them over a weir at the end of a trough, and it was found that during the time we were there they added to the lake 10.754 cubic feet per second, or 929,145.6 cubic feet per day. The area of the water surface of the lake is approximately 20.42 square miles, and the water added to the lake in a day, although it seems large in the streams, would raise its surface only 0.00002 foot, an amount which is not appreciable.

OUTLET OF CRATER LAKE.

Crater Lake has no visible outlet, nor any other reaching the surface directly within a few miles, for if such were the case the water would issue with great force on account of the pressure. If there are outlets at lower levels the route to the opening must be long and tortuous, so that the friction completely overcomes the pressure and allows the water to issue as from an ordinary spring.

The annual precipitation in the region, roughly approximated years ago by Mr. Gannett and republished by Mr. Russell, was given as from 60 to 70 inches, while the annual evaporation, by the same authority, is 40 to 50 inches.

We may get a suggestion as to the precipitation in the region from the snow line marked by moss on the trees. On the southwest portion of the rim the snow line ranges from 5 to 20 feet above the ground. The variation is due to drifting. On Wizard Island among the trees the wind has much less effect, and the snow line is sharply marked 12 feet from the ground. This probably represents a fair approximation to the average depth of snow. Most of the precipitation is snow, although there is some rain. There is considerable snow properly

included in the precipitation estimate, but not represented in the snow line.

Measurements were made in a 12-foot snow bank near camp to determine the water equivalent for such a bank of snow. The average of a number of trials at different levels, which differed but little among themselves, was that 37 inches of snow yielded 22 inches of water. The snow was probably more compact than that of the island, but it was not saturated with water, for we failed entirely to get water from snow holes, as we had done in previous years. The snow was dry. Twelve feet of such snow would equal about 85 inches of water, and it is believed that the average annual precipitation for that region is nearer 80 than 70 inches.

The peculiar position of the caldera on the summit of the broad range greatly increases the catchment of the basin, for the winter storms from the south and southwest drift vast quantities of snow from the gentle outer slopes of the rim across the crest, to lodge in great banks on the inside. It seems evident, there ore, that much water must escape from this closely landlocked lake by percolation besides that which leaves by evaporation.

It was for the purpose of getting, if possible, an approximate measurement of the amount thus lost by percolation that observations were made last summer of the evaporation and inflow at the same time that the sinking of the lake surface was measured. From these observations it appears that while the lake sank at the rate of 0.0155 foot per day, notwithstanding a small influx, the loss by evaporation was only 0.0125 foot per day. In other words, an amount equal to about one-fourth of that lost by evaporation escapes by percolation through the porous base of Mount Mazama.

The walls of the caldera inclosing the lake are made up of alternating sheets of lava dipping away from the lake practically in all directions, and are so porous as to afford easy passage for much water. Springs are abundant and remarkable in size, especially on the southeast side, along a fault which forms a bluff extending from Modoc Point by Fort Klamath far up directly toward Crater Lake. It is very probable that this fault, cutting the old lavas of Mount Mazama, affords an outlet for much of the water that percolates through that portion of the rim. Much of this spring water appears to be appreciably warmer than that of the main body of Crater Lake.

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