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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE GEOLOGY AND PETROGRAPHY OF CRATER LAKE NATIONAL PARK

BY

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WASHINGTON

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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. I) 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 prin-

[a] An 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.

cipal 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.

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.

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

[a] This celebrated health resort has a good hotel, fine scenery, hunting, and fishing.

road and within 2½ 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 traveling 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 striæ 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.

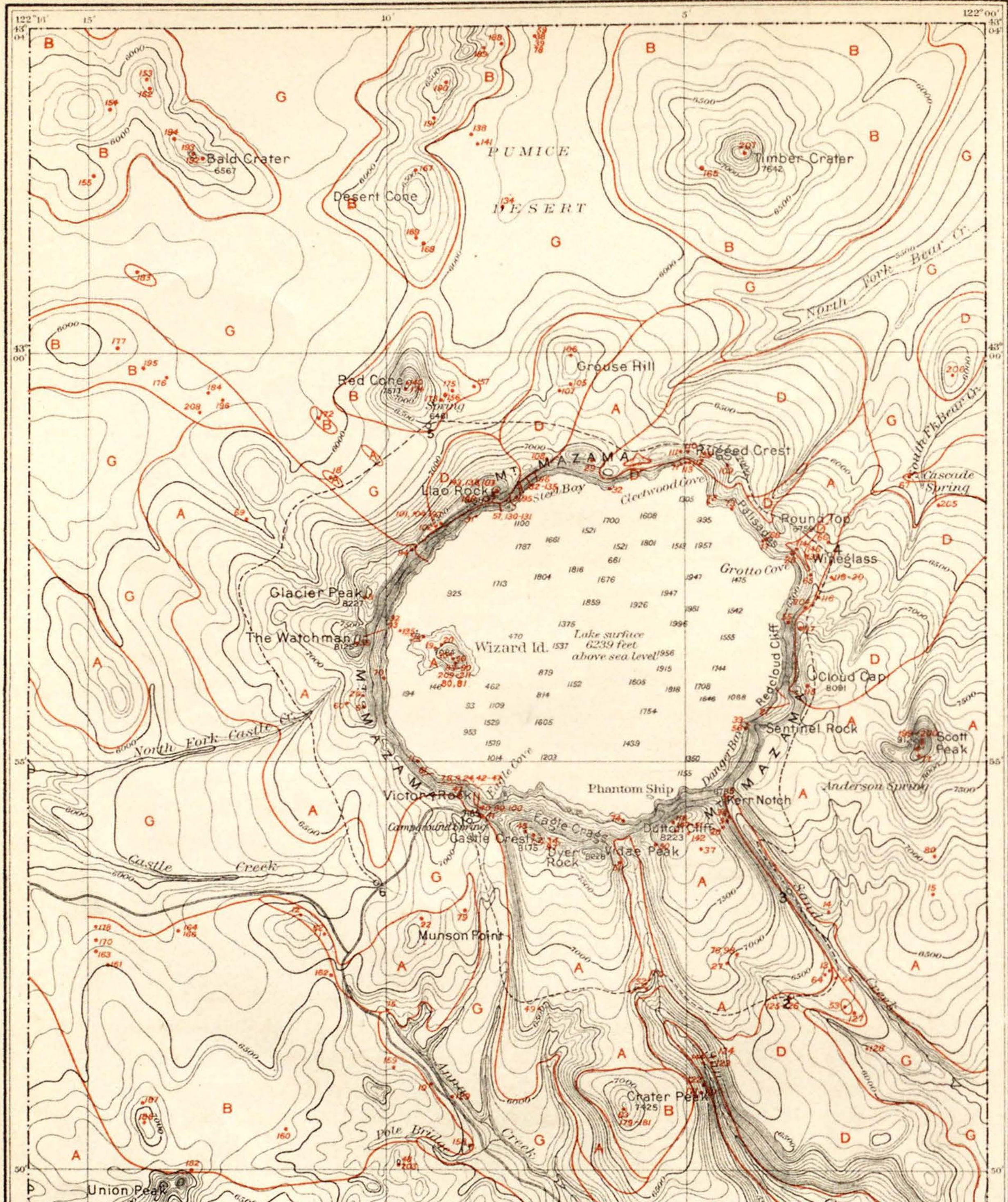
PART I

THE GEOLOGY OF CRATER LAKE NATIONAL PARK

By JOSEPH SILAS DILLER

CONTENTS OF PART I.

ILLUSTRATIONS IN PART I.



JULIUS BIEN & CO. LITH. N.Y.

MT MAZAMA AND CRATER LAKE NATIONAL PARK, OREGON.

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

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.

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.

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

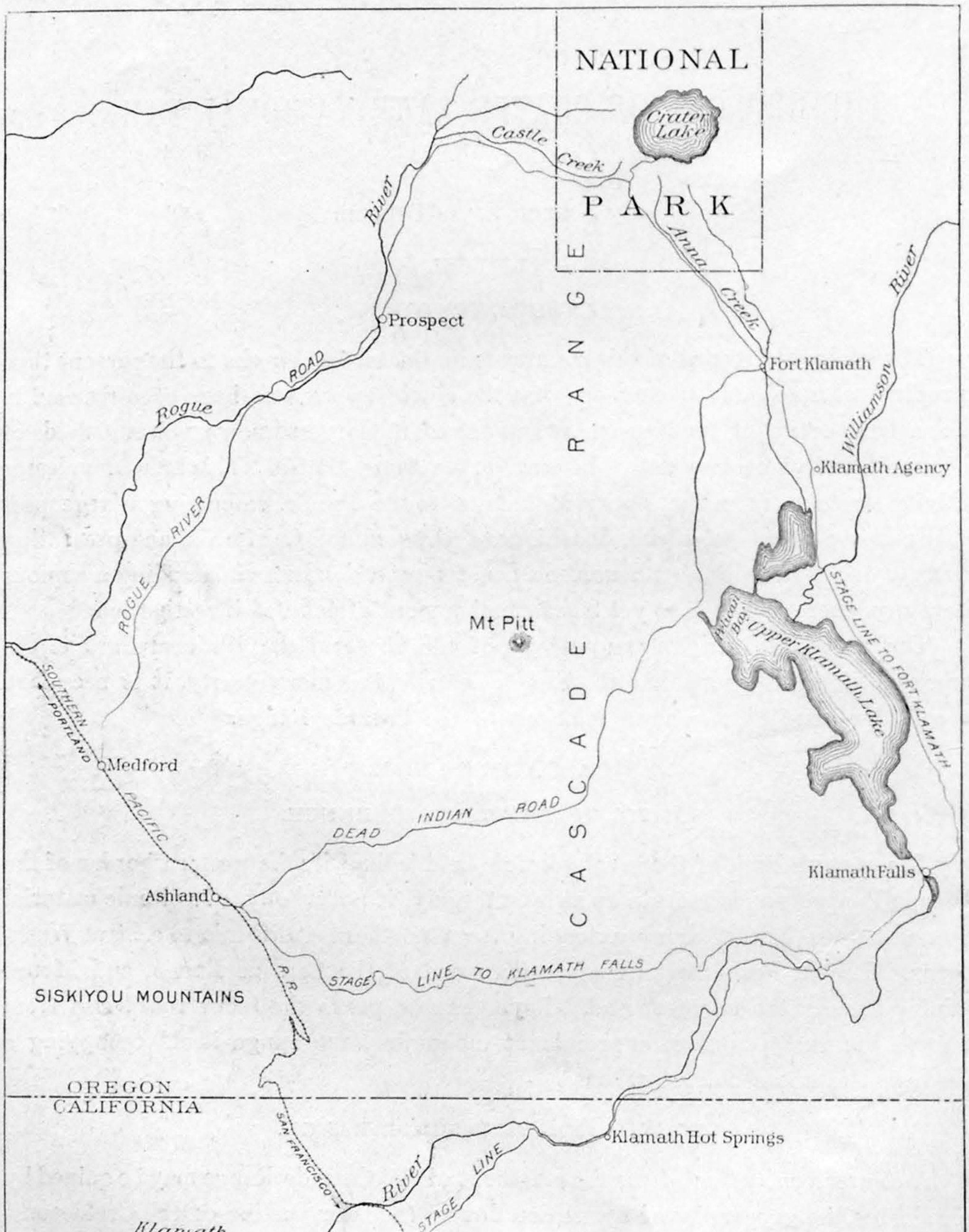


FIG. 1.—Map showing routes to Crater Lake.

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.

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 the 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.

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

[a] Seventeenth Ann. Rept. U. S. Geol. Survey, Part I, 1896, p. 456.

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.[a]

MIOCENE HISTORY OF CASCADE RANGE.

There can be no doubt, however, that during the Miocene[b] 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.

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.

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.

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

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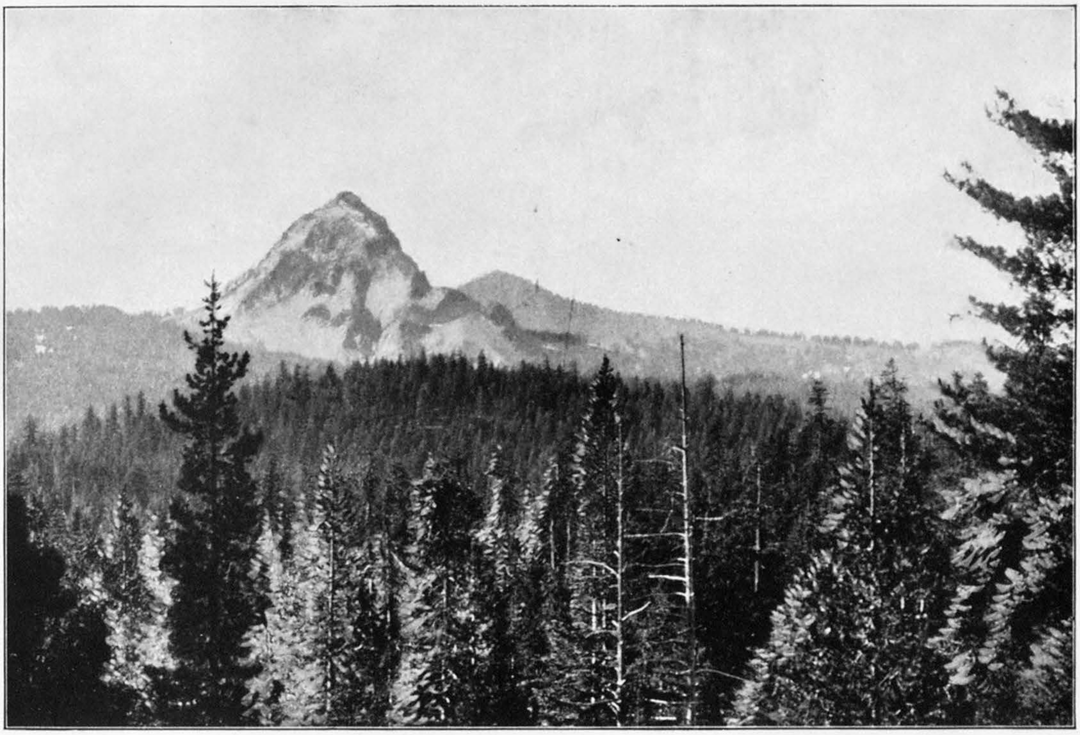
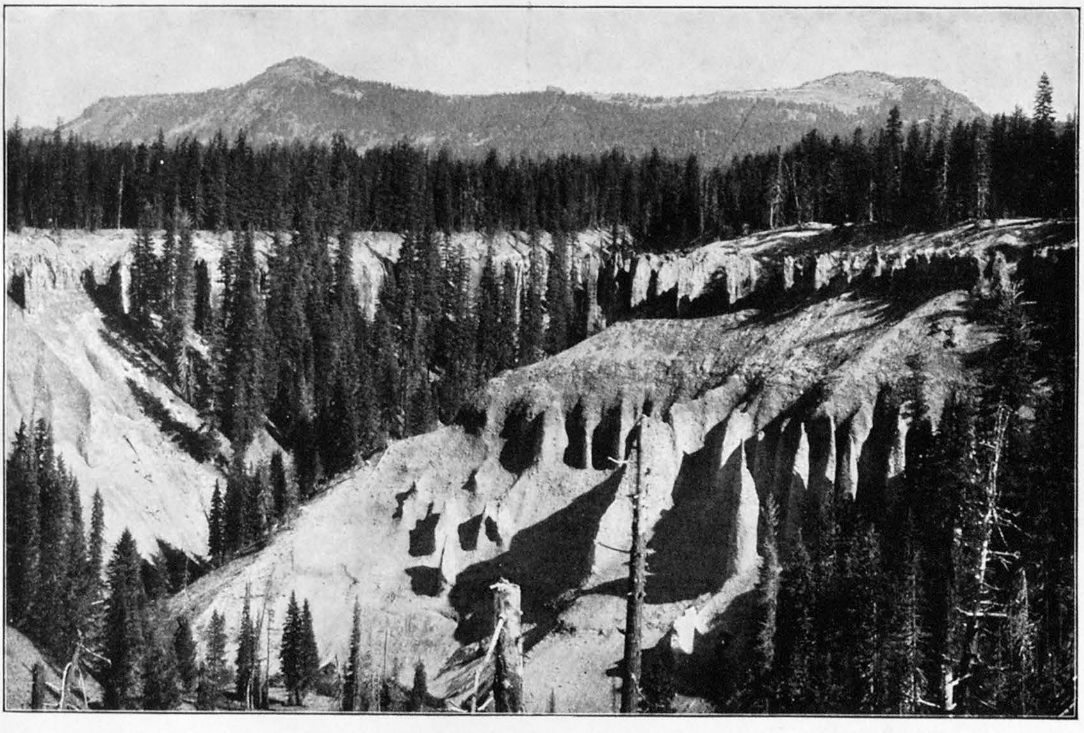
[a] Bull. Dept. Geol. Univ. California, Vol. II, No. 9, p. 285.
[b] Twentieth Ann. Rept. U. S. Geol. Survey, Part III, 1900, p. 32.



A. UNION PEAK.



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.

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.

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.

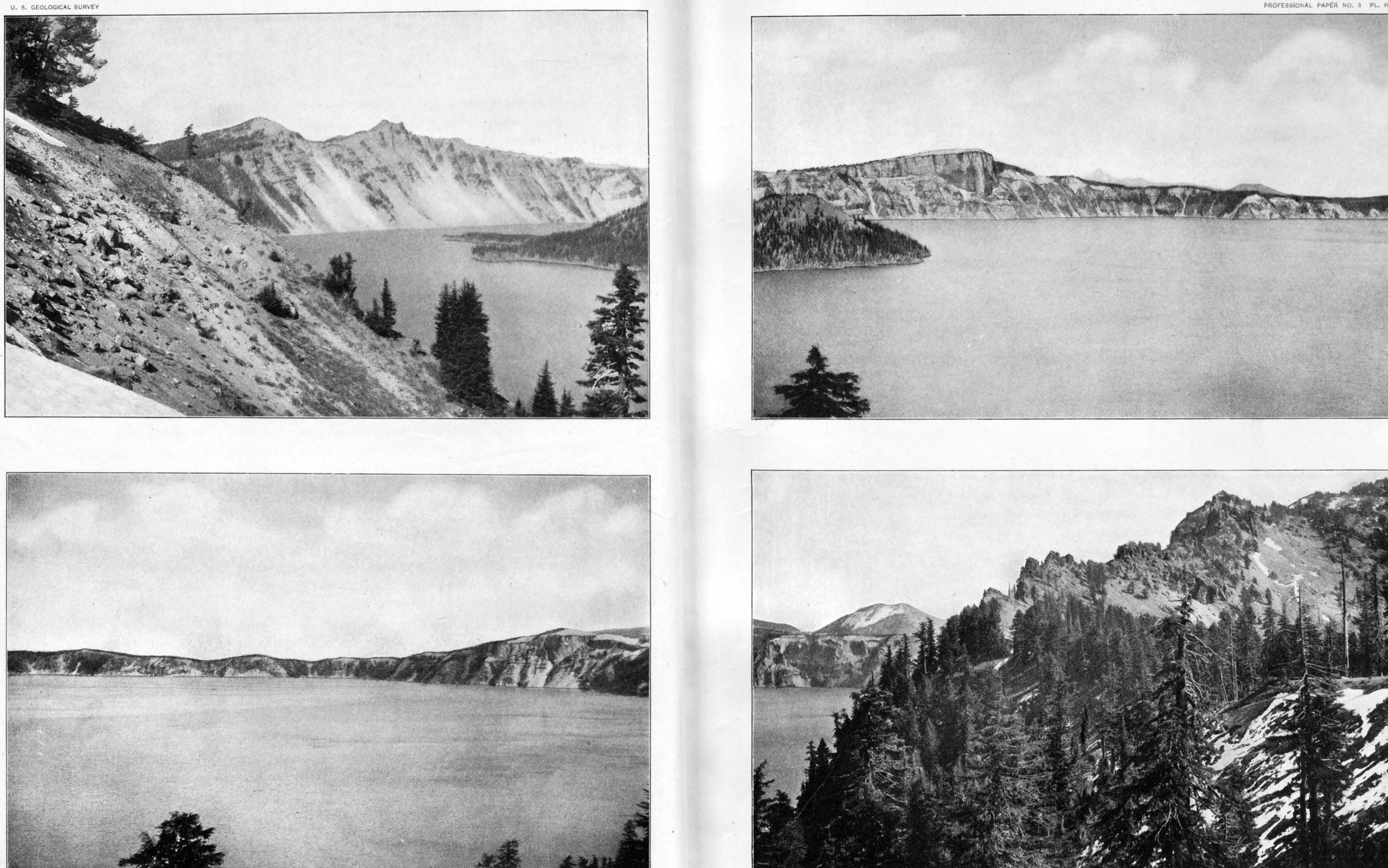
The rim encircling Crater Lake, when seen from a distance from any side, appears as a broad cluster of gently sloping peaks rising about 1,000 feet above the general crest of the range on which they stand. A good view is obtained from the road along Anna Creek, where the southern portion of the rim appears 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.

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 4¼ miles wide and 6¼ miles long, with an area of nearly 20½ square miles.

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.

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.



PANORAMI[illegible]F CRATER LAKE.

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.

LAVAS OF MOUNT MAZAMA.[a]

There are three types of lavas in Mount Mazama—andesites, dacites, and basalts—and their areal distribution is represented on the accompanying map (Pl. VI). The immediate rim of the lake is made up wholly of andesites and dacites, chiefly the former; the basalts are limited to the outer slope. They came from the smaller vents around the base of the larger cone.

The theory of magmatic differentiation, so ably advocated by Professor Iddings and others in this country to explain differences in lavas erupted from the same volcanic center, accords well with the course of events in Mount Mazama. Its eruptions began with and long continued to be composed of lava having intermediate composition. This lava was followed first by less siliceous lava, the basalt from a number of small vents on the flanks of the great volcano, and finally by the dacites, which closed the petrographic cycle. It is possible that the basalts and dacites may have been in part contemporaneous, but the last eruption from the great mountain was of dacite. Then came the great engulfment, and a new petrographic cycle began with the andesite of Wizard Island.

ANDESITES.

Andesites constitute by far the greater portion of the lavas of Mount Mazama. A rough estimate makes their volume at least ten times the combined volume of the dacites and basalts. They form almost the whole of the inner slope of the rim, where the overlapping sheets of successive flows appear in section in their order of eruption, from the earliest to the latest. Flows lying at a depth of nearly 2,000 feet beneath the mountain slope are seen, but a much larger amount of flows still deeper is unexposed. Were it possible to remove the water of the lake, the thickness of the exposed lava would be nearly doubled, and there is no evidence to show that its character is very different from that which now outcrops by the water's edge around the lake. However, at still greater depths there probably occur Tertiary and Cretaceous sediments resting on older rocks similar to those of the Klamath Mountains. Hornblende- and mica-andesites, which are commonly associated with the hypersthene-andesites of the great volcanic centers of the Cascade Range—as, for example, Lassen Peak, Mount Shasta, and Mount Hood—have not been found

[a] The rock specimens collected in the vicinity of Crater Lake have been studied by Prof. H. B. Patton, and are described in detail in the second part of this paper. The numbers used in both papers refer to the same collection.

in Mount Mazama. Traces of hornblende were observed in only two of the hypersthene-andesites collected; one of these is a massive sheet nearly 100 feet thick along the trail near the point where it begins the descent to the lake (44),[a] and the other is a gray lava (45) on the slope of Castle Crest.

The oldest flows exposed on the southwest side of the lake are represented by specimens Nos. 24, 61, 11, and 163. They are overlain by many streams which successively issued and spread from the summit or upper slopes of Mount Mazama. The flows vary greatly in size and number in different portions of the rim. In places as many as 30 superimposed layers, mixed with many beds of fragmental material, make up the wall of the rim. The largest number of flows exposed in one section occurs about Sun Creek Notch. Many flows are 30 to 40 feet in thickness. Under Castle Crest nearly a score appear in this steep slope, and they range from 30 to 80 feet in thickness. Between many of them are layers of volcanic conglomerate, which are usually thin, and, being softer, less prominent. In the western rim flows are not so numerous, and conglomerate was estimated to form about one-fourth as large a mass as the solid lava. More fragmental material appears to have accompanied the earlier than the later flows, and on the whole there is a larger proportion in the rim at the head of Anna Creek than elsewhere. In the East Palisade (Pl. VII, *B*) the thickest flow of andesite is well exposed. It is cut by many joints, reaches more than halfway from the water to the crest of the rim, and has a thickness of nearly 500 feet.

The thickness of any flow upon the mountain slope depended chiefly upon the amount of lava, its liquidity, and the inclination of the surface over which it flowed. Many of the sheets are uniformly thin. They follow the outer slope for considerable distance, and indicate a moderate supply of lava that flowed easily. Other flows, as that of the Palisades, filled valleys in the outer slope of Mount Mazama and varied greatly and abruptly in thickness, becoming very thin on their edges. The thickest of all the flows, however, is the great dacite flow of Llao Rock, which is over 1,200 feet thick over the middle of an old valley. The material was evidently very much less fluent than the andesites, for the flow, although thick, is short and narrow.

In distribution the andesites on the outer slope of the rim are divided into ten areas, and each may be designated by some contained feature, as The Watchman, Castle Creek, Munson Point, Union Peak, Eagle Crags, Dutton Cliff, Sentinel Rock, Round Top, Bear Creek, and Steel Bay. All these areas are practically joined by a complete ring of andesite exposed upon the inner slope of the rim of the lake. In addition to these areas around the rim is Wizard Island, which is also composed of andesite.

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[a] The rock collection to which the numbers refer is in the National Museum, Washington, D. C.

WESTERN BORDER OF CRATER LAKE, FROM VICTOR ROCK TO LLAO ROCK.

WATCHMAN ANDESITE AREA.

The area of which The Watchman is part contains a number of separate flows, but upon the map they are not distinguished. They are particularly well exposed by numerous cliffs, but in much of the area they are covered by glacial material. Although the flows are much alike when compared with one another, there is considerable variation within each flow. The holocrystalline gray forms, like No. 60, pass into the type like No. 6—dark, porous, soft, and crumbly, but rich in amorphous matter—and No. 26, which is decidedly vitreous. The composite character of the flows may be best seen upon the inner slope, where their sections are exposed. The andesites are generally gray, and may be reddish. They are seldom as vitreous as No. 26. No. 60 has a decidedly platy structure, which is locally well marked, although absent at other points. The plates are usually about one-half inch to an inch in thickness, and strike N. 70° E. nearly parallel to the spur, with a dip of 25° NW. The thickness of the plates at each outcrop is rather uniform, but it varies between the outcrops.

At The Watchman and Glacier Peak the layers of lava have a decided upward curve when viewed from the lake, and suggest that the volcanic vent from which the lavas of that portion of the rim issued was not central over the lake, but much closer to the western border. This view is fully borne out by the character of the igneous material in Glacier Peak. It is composed in small part of darker slaggy andesites and much red, yellow, or whitish fragmental material which is highly colored, as if by the escape of hot volcanic gases near the vent. From the lake these colored patches are brilliant in the morning light. On the inner slope of Glacier Peak (Pl. VII, *A*) are numerous columns, one of which is over 100 feet high. To call this Glacier Peak is a misnomer, for the glaciation here is much less distinct than on the hills farther south along the rim.

CASTLE CREEK ANDESITE AREA.

On the western border of the rim north of Castle Creek is a hill of andesite much like that a short distance to the east, from which it is separated by a belt of glacial drift.

MUNSON POINT ANDESITE AREA.

For 2 miles from the crest of the rim the divide between Castle and Anna creeks is covered largely by morainal material, but andesites finally crop out in occasional cliffs and give evidence of the character of the rock beneath the surface deposits in the Munson Point area. A somewhat dacitic specimen (79) from one of the rounded ledges of this area was found by Dr. Patton to contain tridymite. To the south and southwest, beyond the main road, this andesite is covered by a large mass of basalt.

UNION PEAK ANDESITE AREA.

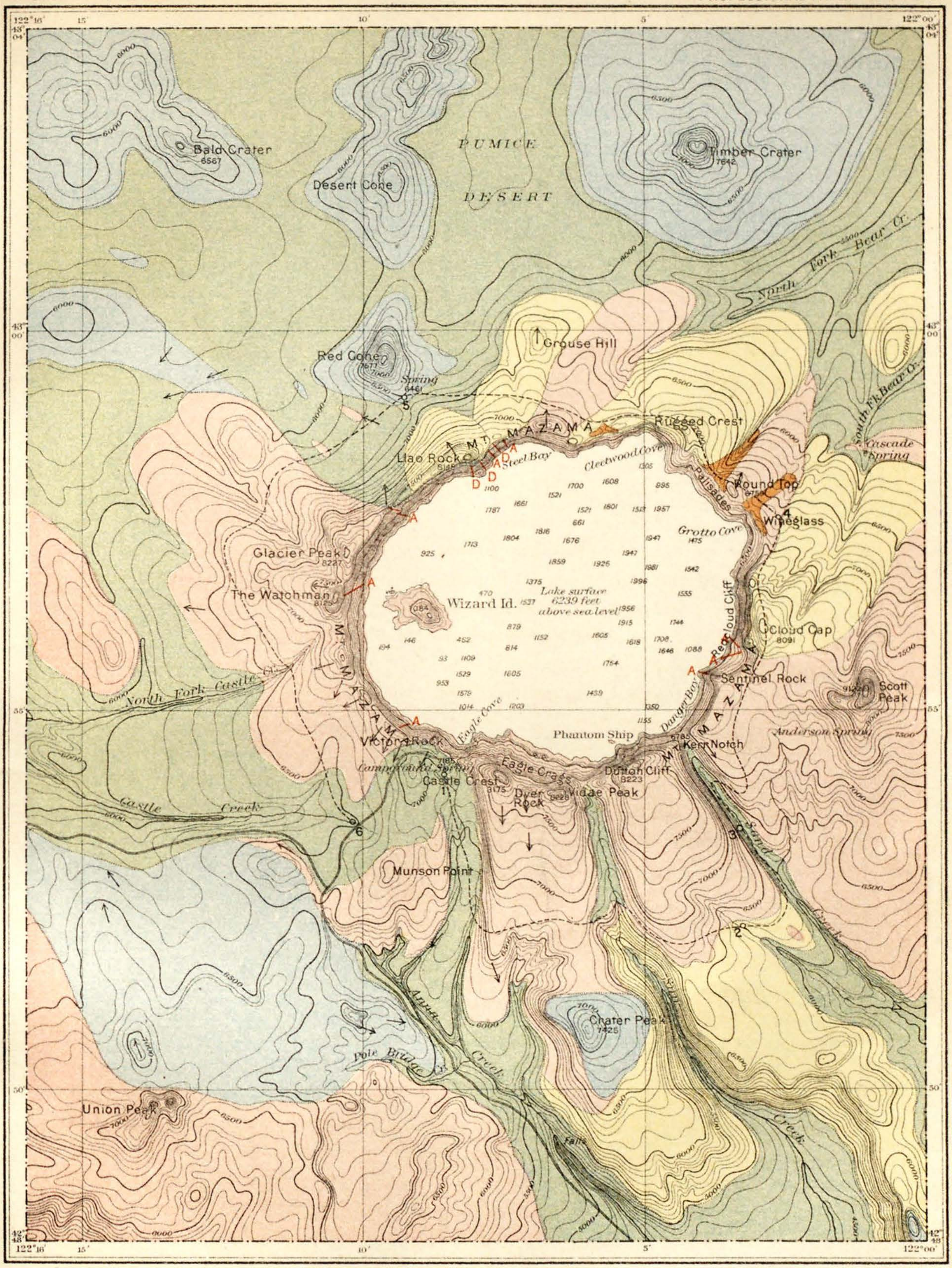
Toward the southern border of the area mapped, near Pole Bridge Creek, is a mass of andesite, forming a bold, rocky point, which has been strongly glaciated on the side toward Crater Lake. The two types of andesite (41 and 100) found here do not look entirely alike, yet the rocks appear to be the same. The first is andesitic in appearance and the second somewhat dacitic. This is part of the large area which is outlined as including Union Peak, but is recognized as containing much basalt. Although the summit of Union Peak is hypersthene-andesite, the middle and lower slopes upon the eastern side are composed of basalt occasionally rich in olivine. There was no opportunity to map the southern and western borders of the park in as great detail as the other portions.

EAGLE CRAGS ANDESITE AREA.

The large area of andesite forming the broad divide between Anna and Sun creeks is made up of many prominent sheets. This is best seen from Dutton Cliff, where the edge of the platform appears under Vidae Peak, the highest point in the rim of the lake. Although the structure is partially obscured by steep talus slopes, enough is visible to show that the rim is made up of successive sheets of lava, which dip away from the lake approximately parallel to the present surface. On the upper surface of this platform exposures are few, excepting where the surface layer of sand and pumice is removed.

In strong contrast to the eastern edge is the opposite border of this platform in Castle Crest, which is rugged, and so sharp as to be impassable. At the foot of a precipitous wall a thousand feet high, on the north side of this serrated crest, lies Crater Lake. This is the only portion of the crest that is practically impassable. In the summit of Castle Crest the gray andesite is like that which is most common about the rim, but was found by Dr. Patton to contain a small amount of hornblende, thereby affording an approach toward hornblende-andesite, which has not yet been found about Crater Lake. On the ragged edge of Castle Crest, toward Eagle Crags, are great masses of volcanic conglomerate, such as are rarely exposed on the outer slope of the rim, but are common on the inner slope. They frequently alternate with solid sheets of andesite, and sometimes attain large dimensions, especially in the southwestern portion of the rim. They are generally composed of fragments of andesite, rich in amorphous matter and often dark or red in color. On the divide south of Dyer Rock there is much morainal matter and pumice, so that the solid lavas rarely outcrop, but where they do they are well glaciated.

Near the southern margin of the area mapped is Crater Peak, a hill of basalt resting on a platform partly of andesite and partly of dacite. The relative age of these rocks is clearly shown, and is further demonstrated by the fact that fragments



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

BY J. S. DILLER

Triangulation and Topography by Mark B. Kerr
Surveyed in 1886

Scale
1 0 1 2 3 4 5 miles

LEGEND

Glacial moraines and dacite tuff
Tuffaceous dacite
Dacite
Basalt
Hypersthene-andesite
Glacial striæ
A Hypersthene-andesite dikes
D Dacite dikes

JULIUS BIEN & CO. LITH. N.Y.

of the underlying andesite were thrown out during the activity of the basaltic crater.

Great cliffs of andesite border Sun Creek Canyon in places, and the rock is well exposed also at the falls where Sun Creek, at an altitude of about 6,500 feet, leaves the broad U-shaped valley and plunges 400 feet over a series of cascades into a sharper canyon cut in dacite. This line of cliffs across the course of Sun Creek connects the andesites of the two divides east and west of that stream.

DUTTON CLIFF ANDESITE AREA.

In the broad divide between Sand and Sun creeks andesite plays a smaller part and shows but little variation. Near the middle of the divide, at an altitude of about 7,000 feet, there is an andesite (76) full of secretions (98). The andesite is quite normal, but the inclusions are basaltic. The same material with secretions occurs in the form of large bowlders near by, and a short distance to the west, in one of the head gulches of the West Fork of Sand Creek, it is overlain by a decidedly platy andesite (27). Similar andesite (50) full of secretions was seen near the edge of the water under Sun Creek Notch. The andesitic lavas of the south rim are much alike everywhere, with the exceptions noted above, and are represented by Nos. 50 and 46, the latter from Dutton Cliff, where it is capped by 10 feet of pumice.

Sand Creek, like its neighbor, is bordered by great cliffs, especially on the west. Ascending this creek one-half mile south of the lake rim, I collected a platy andesite (36) at the bottom. One hundred feet up No. 5 was taken, and 600 feet from the bottom of the canyon No. 23 was collected, while No. 37 came from the top of the hill. On this divide were collected the interesting ejected fragments (147–151) of dacitic material. About 2 miles from the notch the andesite has a marked platy structure, which is curved, showing broad surfaces and folds.

Farther southeast, at an altitude of about 6,200 feet, the cliffs of andesite (64) overlie dacite. Near the contact from which a great spring issues the andesite is black, as if from the presence of much amorphous matter, due to the sudden cooling of the under surface. Near by is a mass of very platy andesite closely associated with the underlying dacite. A short distance to the southeast, upon the same divide, the andesite (53) bears the same relation to underlying dacite (127). The approximate contact between the two rocks may be traced across to the canyon of Sun Creek.

SENTINEL ROCK ANDESITE AREA.

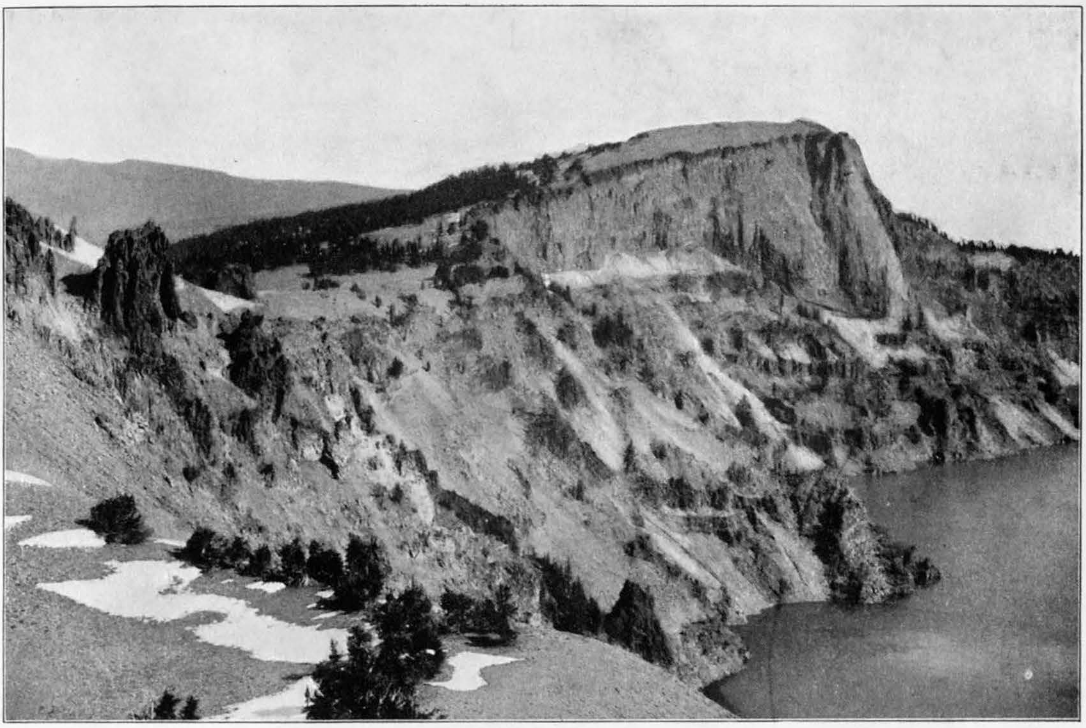
On the lake slope of Kerr Notch is a vitreous andesite, well jointed (16), with columns 46.6 inches thick. This sheet of columnar lava dips away from the lake and is exposed near the bottom upon both sides of Sand Creek Canyon near the notch.

From Sentinel Rock eastward to the vicinity of Scott Peak is one of the largest areas of andesite, but by far the greater part of it is covered with pumice, and outcrops are few. Occasional cliffs and large fragments of andesite occur on the steep slopes east of Sand Creek Canyon, but beyond these the surface is generally covered with a layer of small pumice fragments. Scott Peak is about 1,000 feet higher than any other point in the vicinity of Crater Lake. It was once an active volcano, and among its neighbors next in size and importance to Mount Mazama. In fact, it marks the only distinct andesitic vent of this center outside of the principal one represented by Mount Mazama. Its lavas spread to the east, away from the lake, for in the Sentinel Rock section of the rim the lavas appear to have flowed westward from the Mazama center.

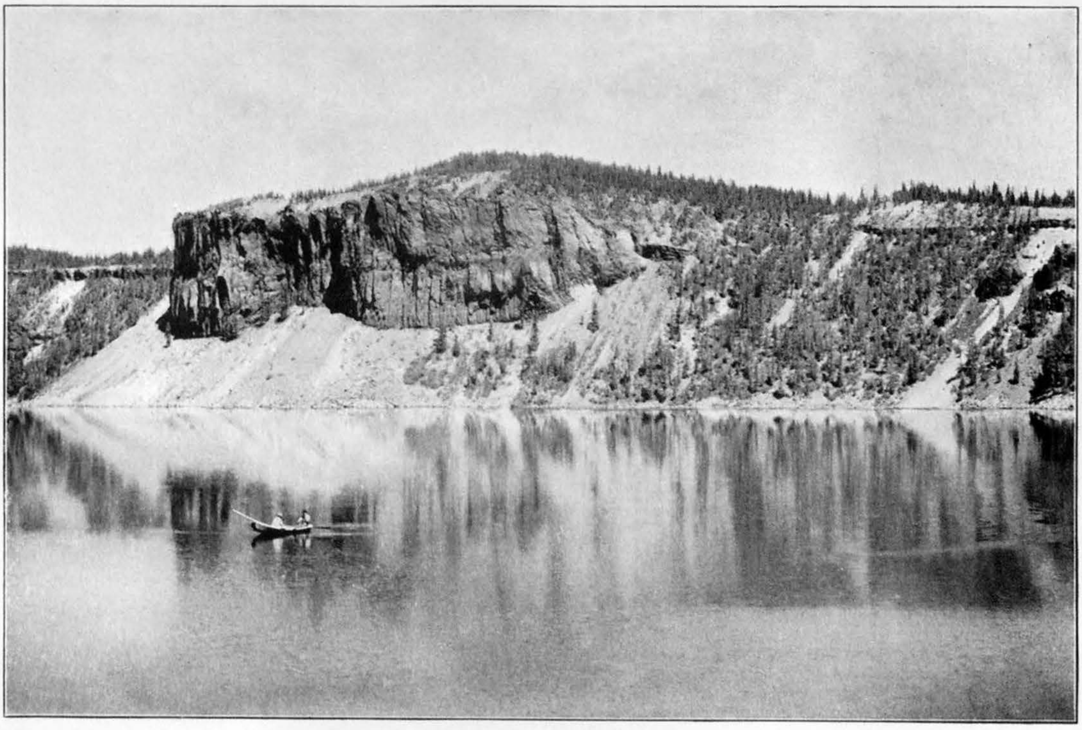
Scott Peak was once a well-defined crater, but it has been broken away upon the northwest, and drains into the South Fork of Bear Creek by a broadly rounded valley, which looks as if it had been cut by glacial action. The slopes of the mountain are generally covered with pumice, but here and there are fragments of andesite (80), and near the summit actual ledges (77) occur. The lava is generally reddish or gray (200), but sometimes greenish (198), as if considerably altered. Occasionally (4) it is somewhat glassy. Both Nos. 200 and 4 were loose pieces on the southwest side of the crater, but No. 198 was in place. The quaquaversal dip of the sheets of volcanic material shows that Scott Peak was a crater, and the 2 miles of country intervening between it and the rim shows its individuality. The whole aspect of the mountain is one of considerable age, and it is evident that it became extinct before the last eruption of Mount Mazama, which spread pumice everywhere. On the outside the slopes are gentle, but within the curve of the ancient crater they are very steep, and the snow lodged there is but a remnant of the glacier that once started at that point.

ROUND TOP ANDESITE AREA.

The Round Top area is simply a part left uncovered by two dacite flows, one on each side, and the glacial material to the northeastward. It embraces upon the surface of the rim two flows, forming prominent cliffs, the easternmost of which is shown in Pl. VII, *B*. The western palisade flow fills an old valley to the water's edge, and, like its neighbor, has a thickness of over 300 feet. The lower 10 feet of this flow, especially that of the eastern palisade, where it comes in contact (17) with its bed, is glassy. It is much broken below, and lies in places upon conglomerate. Parts of it are very platy, excepting in the glassy portion below, and an imperfect jointed structure extends through the mass. It thins out rapidly on both sides to an edge, and is overlain by a thin layer of tuffaceous dacite, a later flow of which appears at the left in Pl. VII, *B*.



A. INNER SLOPE OF GLACIER PEAK.



B. EAST PALISADE.

STEEL BAY ANDESITE AREA.

The area of andesite on the outer slope of the rim represents a large flow from the rim at Steel Bay northeast toward Bear Creek. Like the Round Top area, it lies between two later flows of dacite, and to the north passes out of sight beneath the pumice plain. It is a typical andesite (29) and much glaciated.

ANDESITE OF WIZARD ISLAND.

Wizard Island is a perfectly preserved volcano consisting of a cinder cone (Pl. VIII, *B*), with crater[a] above and lava field about its base. Amid such impressive surroundings it is one of the most attractive and inviting spots of the region. The lava is andesite and belongs not only to the last andesite flow, but to the final eruption connected with this great volcanic center. The bulk of the older lavas is andesite; then come the basalts from the cones around the base of the rim, and the dacites on the mountain slope succeeded. Finally, after the great catastrophe which engulfed the upper part of Mount Mazama, an andesitic eruption on the floor of the caldera followed, which built up Wizard Island and apparently covered almost the whole bottom of Crater Lake.

Wizard Island has an area of nearly nine-tenths of a square mile. The eastern half is a prominent cinder cone, and the western is an extremely rough lava field. The cinder cone rising from the lava field has very steep slopes, made up chiefly of fragmental material blown out of the crater, and rises to a height of 845 feet. The crater in its summit is about 250 feet in diameter and 80 feet deep. Its bottom is solid lava. Inside its rim upon the southwest slope is a great snow bank, where the snow accumulates during the winter and lasts almost throughout the year. The lapilli are rather coarse and usually dark or black, but many are red. There are numerous fragments of lava and comparatively little sand. The solid lava is brilliant red only upon the surface; within it is dark. When the material is porous, the color may permeate the whole mass. One hundred feet below the summit on the northwest slope a little stream of lava (30) 6 to 15 feet in thickness broke out and coursed down the slope for 150 feet. Its surface is very rough and somewhat ropy, and along the under surface it picked and inclosed numerous fragments from the slope over which it passed. Near the summit is a mass of brilliantly red lava (56). The cone is therefore not wholly composed of cinders, but contains, besides lapilli and chunks

[a] The saucer-shaped depression in the summit of the cinder cone of Wizard Island is properly called a *crater*. It marks an orifice from which lava reached the surface to build up the cinder cone and lava field. From the fact that the lake is called Crater Lake the term crater has been applied to the great depression which the lake occupies. The large depression does not in its present size mark the orifice from which the lavas of Mount Mazama issued upon the surface to build up the mountain, but rather, as will be shown in the sequel, the hole through which the summit of the mountain sank into the earth. Great depressions like that containing Crater Lake, originating by subsidence in connection with volcanic activity, are often called pit craters, but better still *calderas*, which is distinctive. Prof. W. M. Davis very appropriately remarks (Physical Geography, p. 215) that the depression containing Crater Lake is "one of the most superb calderas in the world."

of lava, a number of small flows, not of sufficient size, however, to interrupt the regularity of the cone. Near the base of the cone, where it merges into the lava field, several "volcanic bullets" were observed. They are round, and range in diameter from 1 to 2 feet, with irregular fractures. They appear to have solidified before ejection, like those so well developed about the base of the cinder cone 10 miles northeast of Lassen Peak, California.[a]

The lava flow which extends westward is extremely rough and made up of large angular blocks of the broken flow. It is a dark, somewhat basaltic-looking andesite (19), which is occasionally streaked with lighter colored material (20) among the dark bands. The lava escaped chiefly from the west base of the cinder cone and spread westward beyond the present limit of the island, for beneath the clear water it may be seen to extend far west toward the shore of the lake. Some escaped eastward, and it is probable that lava from the Wizard Island center spread over much of the floor of the lake.

The eastward flows are less broken upon the surface, and are probably older than those to the west, for they are well covered with trees. The flow is well exposed in section along one of the small streams on the east shore of the island, and exhibits to a marked degree an arched platy structure parallel to the surface of the flow. Such structure is rare on the island, but has been observed curving around the narrow and thick flows of the rim, especially in the neighborhood of Llao Rock.

ANDESITIC DIKES.

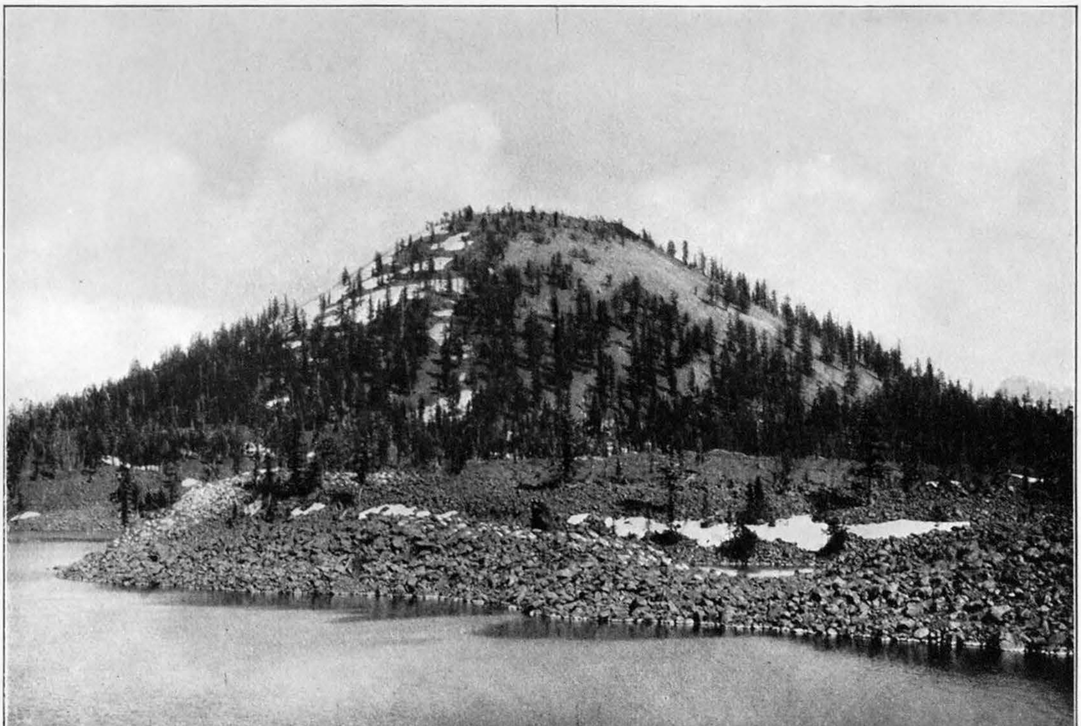
A cruise on the lake reveals a number of dikes which cut the rim radially. Eleven were observed in all—seven near Llao Rock, three opposite Scott Peak, and the remaining one a short distance west of Eagle Cove. Nine of these are of andesite and two of dacite.

The only prominent dike (Pl. VIII, *A*) is of andesite. It cuts through the entire rim from lake to crest and stands out conspicuously between Glacier Peak and Llao Rock. It has been named the Devils Backbone. This prominent dike is nearly vertical and strikes N. 50° W. It varies from 5 to 20 feet in thickness, and offsets near the middle of the slope. The sample of this rock (94) was taken on the crest, and in the mass, to the unaided eye, it resembles gray basalt more than the normal andesitic rock of the rim. On microscopical evidence Dr. Patton refers it to the andesites. It has a columnar structure across the dike and a less conspicuous parting near the sides parallel to the contact with the adjacent rock.

Under the east end of Llao Rock are two dikes, of which the southern one is remarkable. It first appears with a width of 15 feet at the top of a talus slope 100 feet above the lake, and has a vitrophyric border. Upward it thickens slightly as it

[a] Bull. U. S. Geol. Survey No. 79, 1891, Pl. IV.

A. DEVILS BACKBONE.



B. WIZARD ISLAND.

rises for several hundred feet, then expands into a sheet of lava which was a surface flow on the slope of the growing volcano at the time the dike was formed. At the lower end of the dike No. 95 was collected, and No. 91 represents the adjacent andesite.

A short distance farther northeast is another 15-foot dike, which spreads into a sheet about 500 feet above the lake. The material, although andesite, is rather dacitic (132). It is full of secretions (133) which are somewhat basaltic in their character.

On the west arm of Steel Bay is a 12-foot dike which has a dacitic aspect, but proved under the microscope to be an andesite. About halfway up the rim it expands, connecting with the great flow, 200 feet thick, extending from Llao Rock to the northeast corner of Steel Bay. It fills a fissure in the mountain side from which a large part of the flow escaped. This dike, as well as most of the others, is much older than the one on the Devils Backbone.

No dikes were seen around the northern and southern shore of the lake, but at the southern end of Redcloud Cliff, under the great rhyolite flow of Cloud Cap, three more dikes appear. The one at Sentinel Rock (33) is irregular, 10 to 25 feet in width, with a number of secretions, and for a short distance is cut up into a large mass of conglomerate. Farther north is a 4-foot dike (21) which strikes a little north of east. The transverse jointing in it is especially well developed. It intersects sheets of lava and conglomerate, but does not reach quite to the great flow of dacite above. Almost directly under Cloud Cap is another interrupted dike, trending southeast. Although the dikes noticed thus far are of andesite, and earlier than the great dacite flows, their association with the portions of the rim over which these dacite flows emanated is of interest.

A short distance west of Eagle Cove, about halfway between the crest and the lake, is a 10-foot dike with horizontal jointing. It runs down the slope to the water, and at one point stands out as a prominent ledge 50 feet in height.

Under The Watchman is a dike which reaches neither to the crest nor to the water's edge. It is about 40 feet in width and its border is black and glassy, like the vitrophyric dacite of Llao Rock, but near the middle it appears holocrystalline, with a light-gray color peppered with small dark crystals of pyroxene.

BASALTS.

Unlike the andesites, the basalts are limited to the outer slope of Mount Mazama, and do not approach nearer than about a mile of the crest. None of the basalt flows came from the central vent of Mount Mazama. They all issued from adnate cones upon the lower slopes of that great volcano. The northern part of the area mapped contains the principal basalt masses, which issued from four vents—Timber Crater, Desert Cone, Bald Crater, and Red Cone.

TIMBER CRATER BASALT FLOW.

Timber Crater, 5 miles northeast of Crater Lake, is the peak next in size to Scott Peak. It rises 1,500 feet above the surrounding plain and has a somewhat eccentric conical form with gentle slopes covered largely, to an elevation of 6,700 feet, by pumice from the final eruption of Mount Mazama. At 6,900 feet a reddish vesicular flow of basalt (165) issued from the southwest slope. Another basalt stream forms a prominent spur to the northwest. The lava is fresh, with all the peculiarities of a recent flow. Above this point the slope is made of lapilli, with a light covering of pumice. That the upper portion of the mountain is a cinder cone is not seen by the traveler until he reaches the summit, where there is a well-defined crater 50 feet deep and 250 yards in diameter. The crater is double, or rather there are two craters of equal size side by side. One is nearly north of the other, and the two were most likely active at different times. With the progress of the eruption the vent shifted slightly parallel with the range. This is a common feature in many volcanic fields, but is rather unusual in the Cascade Rangē. The coating of pumice from Mount Mazama is spread upon the slopes of the cinder cone of Timber Crater, showing that its activity had closed before that of Mount Mazama.

The view of Crater Lake and its rim from Timber Crater is especially fine, and to the northward Mount Thielsen, the "lightning rod" of the Cascade Range, sometimes also called the "Matterhorn" of the range, stands out conspicuously.

DESERT CONE AND RED CONE BASALT FLOWS.

Desert Cone and Red Cone are volcanoes in line with a number of others which form a decided ridge, practically the crest of the range. They are evidently due to a number of vents on one fissure, and the material erupted is essentially the same throughout, although the volcanoes were not active at the same time. The oldest is to the northward, and the youngest is Red Cone. At the eastern base of the ridge, near the northern limit of the portion that appears upon the map, the basalt is vesicular (188), but farther up on the slope is compact and holocrystalline (189). This spur is plainly a flow to the east. The lava is often rough upon the surface and has lost little by weathering, presenting an aspect of newness not found on the associated lavas. The summits of the two most northern hills of the ridge were once craters, but the loose material has been swept away by subsequent erosion, exposing in the cliffs of the crest the solid lava (190, 191) of which the central portion of the cones is composed.

Desert Cone, near the southern end of the ridge, next to Red Cone, is a cinder cone with rough, chiefly reddish, basalt (167). The summit has an imperfect crater broken away toward the northwest. Its slopes are very steep.

Of all the small volcanoes which have furnished basalt in the northwestern part of the area mapped, Red Cone is the best example. It is well preserved, its lavas have the freshest look, and, all things considered, it appears to have been active later than any of the craters about the great central vent of Mount Mazama.

Red Cone is composite. The basal portion or pedestal is made up very largely of basalt flows, and the upper 500 feet is a cinder cone composed almost wholly of lapilli, sand, and slaggy chunks of red and gray basalt. Much of the reddish lava is vesicular, but the gray is not vesicular. The rim on the south side is 50 feet above the bottom of the crater, which drains to the northeast. The crater contains numerous fragments of dacitic pumice, like that of the final eruption of Mount Mazama. The fragments of dacite are so abundant in the crater and upon its slopes as to leave no doubt that Red Cone had closed its career before the final eruption of Mount Mazama. The radiating flows which form the base of the cone spread far beyond the limits of the cinder cone. To the east they are well exposed, and some of the flows are vesicular. The elongated cavities are flattened and lined with hyalite. The gray basalt (156) is often rich in olivine. From the base of Red Cone a great sheet of basalt spreads westward in the flat, forested country, where underlying rocks are concealed by a layer of pumice. Here and there, however, domes of the basalt rise through the pumice. The fresh vesicular basalt is like that of the base of Red Cone, from which it was derived. Its surface is well glaciated, and near the western border of the area mapped becomes irregular and rugged on a small scale, with many striated ledges and occasional meadows due to lava dams formed in a narrow part of the valley. Rarely (184) the basalt is platy. How far down Rogue River these flows extend is unknown. Basalt occurs along the Rogue River road for many miles, but it is a darker lava and much more vesicular than that of Red Cone.

BALD CRATER BASALT FLOW.

Bald Crater has a well-defined pit on the summit of its cinder cone. Some solid flows of dark basalt (192, 193) are exposed, but red and black lapilli are most abundant. Its crater, being bare and prominent, affords a fine view, and when seen from neighboring points stands out conspicuously above the deep-green forests.

CRATER PEAK BASALT FLOW.

Crater Peak is the center of a small area of basalt on the divide extending south from Castle Crest and Vidae Peak between Anna and Sun creeks. The hill rises over 700 feet above the general level of the platform of andesite on which it rests. At the northern base of the hill is a mass of reddish-brown basaltic tuff. The general layer of pumice extends far up the slope, showing that, as in other cases, Crater Peak was not active after the final outburst from Mount Mazama. The pumice layer is decidedly darker than the material of which the peak

(179–181) is composed. The cone is largely if not wholly fragmental, and there is no definite flow from it unless it extends to the northwest. Among the prevailing dark fragments of basalt there are occasional andesitic fragments hurled out from the underlying andesites. The summit of Crater Peak is a well-defined crater 100 yards in diameter and 25 feet deep, draining to the southwest. Some good-sized firs grow on it, and it contains a bank of snow as late as August.

OTHER FLOWS.

Toward the southwestern corner of the park there is a large area of basalt, in which there is considerable variation, and the mass may have been built up from a number of vents. It forms a bluff near the road southwest of Anna Creek from Pole Bridge Creek toward the summit. It ranges in color from gray and reddish to almost black and some is vesicular. North of Union Peak it rises to over 7,000 feet and is associated with basaltic tuff. The divide at this point is a ridge of basaltic lapilli, indicating the proximity of a volcanic vent, although no well-defined crater was seen. The rocks are well glaciated and the original form of the cinder cone may have been greatly modified thereby. The ridge of lapilli affords a fine view of Union Peak a few miles farther south on the crest of the range. Union Peak is rugged and composed largely of andesite, which came from a vent which was more ancient than that from which the basalts issued. Upon the northern border, as elsewhere, gray (164) and reddish (166) colors are common, but on the whole the darker colors (182, 187, 163) are most abundant, and in places, especially near the Rogue River road, the rock is decidedly platy.

In the southeastern corner of the park is a hill of scoriaceous basalt with lapilli overlying dacite, and west of this, in the flatter country near the border of the park, there are bowlders and bluffs caused by streams of basalt which may have descended from Crater Lake, although the connection was not observed. The falls of Anna Creek below the forks are over basalt, but the exposure is very small. Small areas of basalt occur along the road between the falls and Pole Bridge Creek, and basalt may cover much of the country marked andesite in the southwestern portion of the park.

DACITES.

Dacites are much less abundant than andesites in the rim of Crater Lake, but unlike the basalts, they come from the same general vent. They are very unequally distributed. One flow is on the southern slope some distance from the summit; the others are along the northern crest of the rim and are later than the andesites, excepting only the andesite of Wizard Island. The separate flows to be considered are those of Sun Creek, Cloud Cap, Grouse Hill, Llao Rock, Wineglass, and Cleetwood Cove. Among them there is wide variation, from obsidian through spherulitic to well-banded and largely crystalline material, while some are mud flows streaked with black glass.

SUN CREEK DACITE FLOW.

The canyon of Sun Creek below the falls has upon the west a number of cliffs and terraces, due to successive flows of dacite, exposing a total thickness of about 600 feet. At 6,300 feet east of Crater Peak the cliffs begin. The first is 200 feet, made by a solid flow of dacite with conspicuous structural features. The next terrace, at 5,900 feet, exposes a decidedly perlitic and spherulitic rhyolite banded with small lithophysæ, and forms a bluff 75 feet in height. There are bands of perlitic and spherulitic grains alternating with others which show neither structure. At 5,700 feet is a plain of fine material, filling the valley to a width of three-fourths of a mile. In the soft material Sun Creek has cut a canyon 200 feet deep. Upon the eastern side in the canyon wall dacitic rocks (123, 124) appear, containing cavities lined with minute crystals of tridymite. The layer of pumice covers nearly everything beyond the canyon, so that the nature of the underlying rock is to a considerable extent a matter of doubt. On the West Fork of Sun Creek, just above where it begins to cut a canyon in the material filling the valley, masses of dacite (125, 126) appear, and if not in place have not been moved far, for the rocks immediately to the north are andesite. On the spur between the West Fork and the main stream of Sand Creek a well-marked dacite (127) occurs, with conspicuous fluidal banding and aligned cavities sparkling with tridymite; it appears to form the whole ridge excepting the small capping of andesite. A short distance farther north a strong spring issues from the contact between the dacite and the overlying andesite.

The Sun Creek dacite is the oldest about Crater Lake It is evidently older than the andesite which lies upon it at an altitude of 6,600 feet. This is considerably above the level of the lake, and if the rhyolite came from Mount Mazama it should appear on the inner slope of the rim under Dutton Cliff. From a boat by the shore the cliff was examined to see if the dacite flow could be recognized, but it was not found.

CLOUD CAP DACITE FLOW.

Cloud Cap is on the eastern crest of the rim and marks the point of departure of a stream of dacite which spreads to the northeast. It forms a large part of Redcloud Cliff, which takes its name from the reddish-yellow tuff or tuffaceous dacite that underlies the principal flow. This flow, or, rather, group of flows—for it appears to be made up of at least three streams—forms a prominent cliff for over half a mile along the rim and has a thickness of over 300 feet. It appears to form one-third of the inner slope of the crest. This flow presents a series of great cliffs about its borders, especially on the northwest. The finest is upon the west side nearly half a mile from the lake. It is 250 feet high and of great length, smooth and polished as if by glaciers, but distinct striæ could not be found. The rock (118) is especially glassy, often banded with brown, and may be finely spherulitic or lithophysal. The canyon heading between Cloud Cap and Scott Peak presents cliffs which are less imposing. Upon the east side of this canyon at the northern end of the flow the rock, although dacite, is more massive and lacks the vitreous features of the main body of the flow near its source. To the west this series of dacite flows, along the southern arm of Grotto Cove, may be seen to overlie the adjacent streams of andesite. The base of the dacite flow near the contact is glassy, with numerous spherulites and lithophysæ.

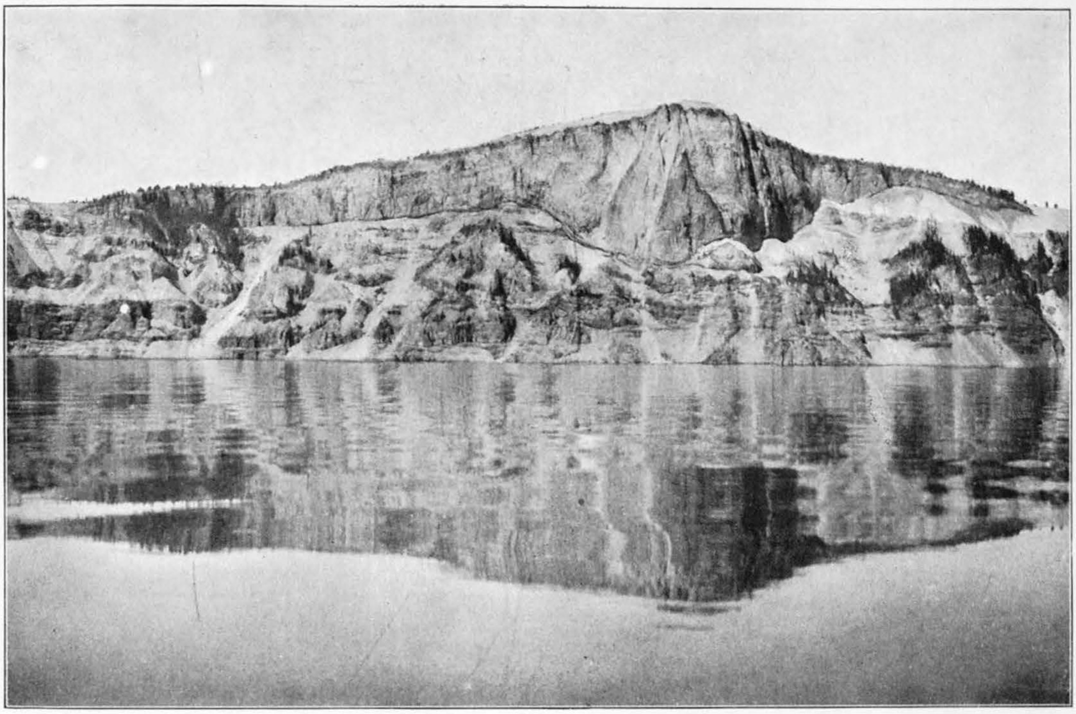
Farther northeast, between the forks of Bear Creek, is a small area of dacite, which was regarded as an andesite in the field, but Dr. Patton finally relegated it to the dacites. The regularity of the hill gave rise to the expectation that it would be found to be a cinder cone, but this is not the case, as it is composed of solid dacitic lava. Its sides are covered with lapilli of pumice, like that found elsewhere, and upon the south bear a fine growth of yellow pine. There are a number of other hills farther north which appear to be composed of the same material.

GROUSE HILL DACITE FLOW.

Possibly of about the same relative age is the Grouse Hill flow, which crosses the crest a short distance northeast of Llao Rock. On the inner slope the layer of pumice beneath the great flow of Llao Rock overlaps the Grouse Hill flow, showing that the Grouse Hill flow is older than the Llao Rock eruption. For this reason the two flows are separated on the map. At the south base of Grouse Hill the dacite (107) is regularly banded, and on the hill next northeast of Llao Rock it (108) is spherulitic. This flow has been much eroded, and has a more ancient look than other flows of this portion of the rim.

LLAO ROCK DACITE FLOW.

The Llao Rock flow is one of the most interesting of the region and is the most conspicuous. Its general outline in cross section filling a valley of the rim may be clearly seen (Pl. IX, *A*) across the lake. The flow is more than a mile wide along the crest and over 1,200 feet thick in the middle, tapering to edges on both sides. Considering its great thickness the flow is remarkably short, for it can be traced with certainty only about a mile from the rim, although it may extend for some distance farther beneath the pumice-covered plain. On the northeast it tapers rapidly to an edge, and ends in a mass of pumice nearly 100 feet thick. The lower portion of this pumice is clearly stratified, but in the upper part the lines are less distinct. The valley filled by the flow is small and has an irregular surface. On the northeast side there is a prominent mass of pumice (Pl. IX, *A*), under the Llao Rock flow, but on the opposite side there is little or no pumice. On the



A. LLAO ROCK.

B. FLOW OF TUFFACEOUS DACITE EAST OF PUMICE POINT.

summit of Llao Rock there is much pumice. On the western slope it has been largely swept away, exposing the underlying rock. The edge of the flow, and, in fact, the entire periphery, is practically obsidian; the interior portion is more crystalline. Where glassy it is rich in small feldspars (102). On the summit, which has suffered much from erosion, a portion of the flow (103), originally some distance beneath the surface, is exposed, and on this account the rock is on the whole less glassy than near the border.

An imperfect columnar structure is given to the dacite of Llao Rock by two sets of joints. One set is radial from the lake and perpendicular to the rim; the other set crosses the first nearly at right angles. They are best developed in the lower portion of the flow. Near the surface a curved structure due to flowing is marked. Below, the flow structure is straight and nearly horizontal.

WINEGLASS DACITE FLOW.

The Wineglass flow is of small size and peculiar. It lies in the next gap of the rim southeast of Round Top (Pl. VII, *B*), has a width of scarcely 500 feet, a length of probably a mile, and a thickness of about 20 feet. It is decidedly like a tuff (114) and might well be so considered were it not for the stringers of black glass intermingled with a reddish groundmass containing fragments of other material and imparting a decided fluidal structure to the mass.

A short distance farther east there is another small sheet of this tuffaceous dacite 10 feet thick. It has the characteristic streaks of black glass which fix its identity. It occurs locally along the western edge of the Cloud Cap flow, and closely resembles much of the tuffaceous material of Redcloud Cliff. At the Wineglass slide it is immediately associated with pumiceous tuff. The hard rock of the rim is andesite, overlain by 15 feet of pumiceous tuff with 10 feet of red tuffaceous dacite. This is overlain by 30 feet of conglomerate and capped by a fine layer of pumice 25 feet thick. It is evident from this section that the fragmental dacite does not represent the final eruption, for that finds expression in the top layer of pumice.

The gap west of Round Top contains a small sheet of tuffaceous dacite like that on the other side, but is thicker. It appears in Pl. VII, *B*, at the left of the Palisade crowned by Round Top. It is 50 feet thick in the middle and tapers to a thin edge on the west. On the east of Round Top it extends up the slope a short distance, for it is clearly seen above glacial striæ and is undoubtedly a post-Glacial flow. In this gap, as upon the east, it overlies a sheet of pumice and underlies conglomerate into which it appears to pass by becoming more fragmental. Near the western edge of the gap it appears to be overlain by large bowlders, and where the exposure of the dacite ceases the sheet of large bowlders becomes more marked. On the geological map this area of dacite adjoins the edge of the great flow of Rugged Crest. In reality, however, it overlaps the Rugged Crest flow and is of later date.

The same tuffaceous dacite occurs farther west along the crest beyond Cleetwood Cove, where, as upon the east, it overlaps the flow of Rugged Crest. It extends nearly to Pumice Point (Pl. IX, *B*), where it appears between two thick masses of pumice. This peculiar tuffaceous dacite occurring along much of the northern crest of the rim all belongs to one flow, which spread as a uniformly thin sheet over that portion of the base of Mount Mazama. It is altogether unlike the other flows of dacite and appears to be intermediate between them and tuff.

CLEETWOOD COVE DACITE FLOW.

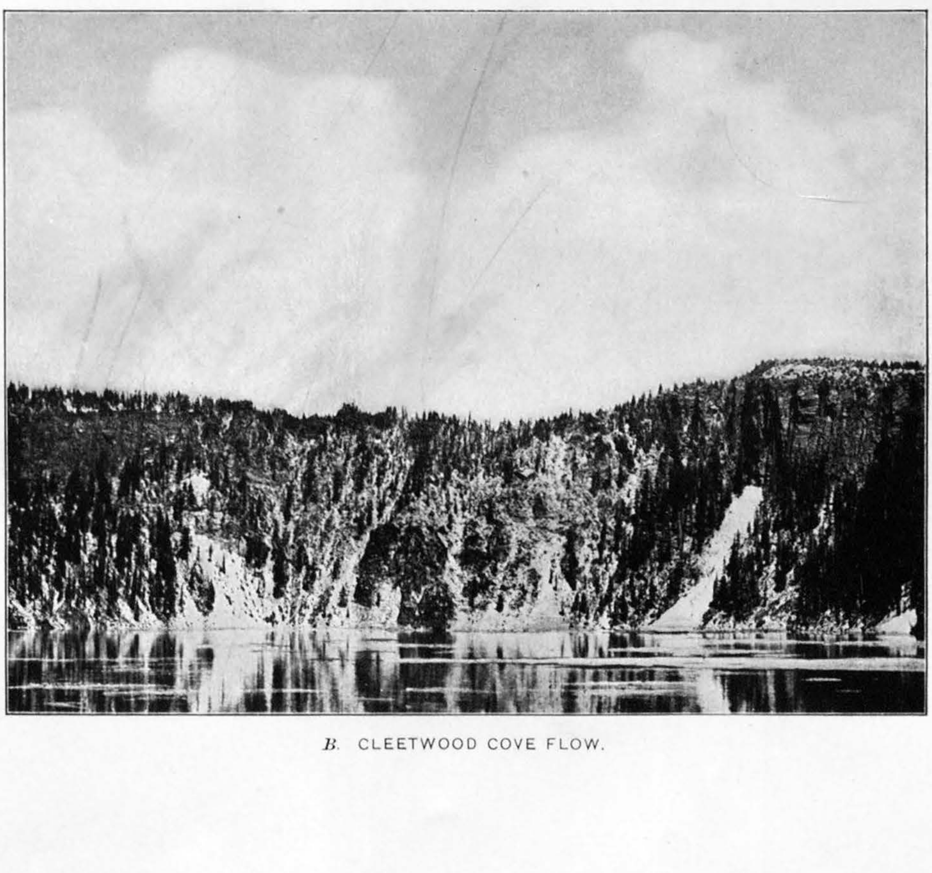
Among the final flows of the great volcano is the one of Cleetwood Cove. The rim at this point is remarkable. It is unlike any other portion of the rim in its rugged roughness without being sharp edged like Castle Crest. It is wooded with small pines and firs, but the bold crags stand out among them in pinnacled relief. The lava is a black, yellow, or brown glass, and is greatly broken and rough on the top. It forms the crest of the rim for nearly a mile, extending upon both sides of Cleetwood Cove, where it makes prominent cliffs. It fills an old valley at the head of the cove, and has a thickness of over 300 feet in the middle, tapering to a thin edge on both sides. Pl. X, *B*, illustrates its appearance from the lake. This broad flow extends from the rim northeastward for nearly 3 miles, where it disappears beneath the plain of pumice and glacial material. The bottom of andesite on which the dacite rests is irregular, and in places the two rocks are separated by a thick layer of pumice.

On tracing the rugged mass of dacite away from the lake there is found upon its surface a small valley (Pl. X, *A*) lined with cliffs and local columns. The valley is nearly as deep as wide. Huge blocks of dacite have tumbled about in the most irregular manner, producing small inclosed basins. The valley is not a waterway, and judging from its peculiarities it is altogether probable that it is a caved-in lava tunnel.

Upon both sides of the surface the dacite is flattish and looks glaciated, yet no certain glacial marks could be found, although large fragments regarded as bowlders were seen resting upon it. West of the chaotic channel and also on the east above the cliff there appears to be some morainic material. Close to the crest at the head of Cleetwood Cove the surface is most broken and rugged. A little farther west the flow thins rapidly, forming West Deer Cliff, and runs out near the next point.

The upper portion of the sides of Cleetwood Cove is a cliff of dacite, beneath which there is a layer of pumice, succeeded downward by 350 or more feet of exposed andesitic flows. These subdacite lavas are continuous around the head of the cove, but

A. VALLEY OF CAVED-IN TUNNEL.



B. CLEETWOOD COVE FLOW.

are not exposed. At the head of the cove they are covered by dacite which flowed down the inner slope of the rim from the caved-in tunnel of Rugged Crest to the lake.

The flow is wide above and narrow below, lapping down over the edges of the andesite into the lake. How far it extends beneath the surface of the lake is unknown, but apparently only a short distance.

Some distance above the lake, upon both sides, the flow and platy structure of the dacite overlying andesite dip toward the central stream, which in places dips toward the lake at an angle of 35° and lies parallel to the present surface. The structure inclined toward the lake is very clear, and its parallelism to the surface underneath well exposed upon both sides. Near the summit the glassy rock (111) is red and black, and may be mixed with gray. Nearly midway from summit to lake, where the slope is steepest, the lava (112) is somewhat less glassy than near the crest, and near the lake (113) the crystalline structure is still more marked.

DACITIC DIKES.

Only two of the eleven dikes of Mount Mazama are dacite. They cut the older andesites (57) and connect directly with the thickest part of the Llao Rock flow. One of the dikes has a thickness of 10 feet. In the middle (130) it is holocrystalline and contains crystals of hornblende, but upon the border it is black and glassy, a vitrophyre (131), like most of Llao Rock. The other dike is regular, varying from 2½ to 4 feet, and the material closely resembles the last in all respects. One of these, or possibly both, contributed to the escape of the great mass of Llao Rock.

DACITIC PUMICE.

The dacitic eruptions of Mount Mazama were generally accompanied by more or less pumice. Pl. IX, *A*, shows a large amount of pumice which underlies the Llao Rock dacite and which is, therefore, somewhat older than that flow. It is arranged in layers, probably due to the assorting influence of the atmosphere. Under the main body of the flow the sheet of pumice is sometimes wanting or thin and irregular. It is possible that this pumice belongs to the earlier part of the eruption which gave rise to Llao Rock.

The summit of Llao Rock is composed of fragmental material, approximately 120 feet in thickness, of which the lower 90 feet is pumice resting on the surface of the dacite. It is clear that this body of pumice is later than the Llao Rock flow, although it may belong to the final portion of the same eruption. The layer of white, pinkish, or yellowish pumice of the ordinary dacitic type (136) on the summit of Llao Rock is overlain by 20 feet of more or less pumiceous material, which is heavier and much darker in color. The fragments, like those of the layer below, are small, being rarely as large as 6 inches in diameter. Some of them (143) are black, rich in phenocrysts of hornblende and feldspar, and are doubtfully of a dacitic nature. There can be no question that the darker layer represents the concluding stage of the final explosive eruption of Mount Mazama. It is one of the largest masses of this sort of material found anywhere about the rim crest, and is of unusual importance on account of its peculiarities, for it is markedly unlike any of the dacitic lavas.

Along the crest above Danger Bay, near Sentinel Rock, there is a succession of pumice and glacial deposits. There are two deposits of what appear to be glacial gravels succeeded by layers of very pumiceous material, recording the fact of alternating glaciation and volcanic eruption. The lapilli of the two pumice layers appear to be the same. Farther to the northwest, beyond Cloud Cap, a thin sheet of tuffaceous dacite appears at the top of the lower pumice.

Tuff with much pumiceous fragmental material is widespread in the Crater Lake region, and is so abundant in places as to indicate a great explosive eruption among the final events in the history of Mount Mazama. Pumice Desert is a treeless tract north of the rim, in which pumice prevails. Fragments are usually from 1 to 4 inches through, although some nearly a foot in diameter are common in places, and occasionally larger ones appear. The largest mass of dacite seen (138) is 10 feet in diameter. It is very pumiceous and yet distinctly fragmental. Near by was a fragment 3 feet in diameter, rich in hornblende. Such fragments are not abundant, although black sand (134) composed chiefly of feldspar and hornblende is abundant everywhere. Here and there may be seen occasional chunks of andesite. From Mount Thielsen to Red Cone, a distance of over 10 miles, nothing but fragmental material was seen near the trail. As Red Cone is approached some of the red and black lapilli washed from the cone appear upon the surface to overlie the dacitic pumice and tend to give a wrong impression as to their order of eruption. The sheet of pumice, although not indicated upon the map, covers by far the larger part of the flows, but ledges are in general sufficiently numerous to determine approximately the distribution of the various kinds of lava. Along the southern border of the rim the greatest thickness of pumice, about 10 feet, is exposed at the top of Dutton Cliff. The largest fragments at that place are not more than a few inches in diameter and appear to be the farthest from the rim. The peculiar black lapilli rich in crystals of hornblende are numerous. Specimen 142 was collected from a piece 18 inches in diameter. Near the same place, in 1883, I found a bowlder-like bomb of the same size as that noted above. It had a blackened shell which was cracked to a little depth, and the cracks stood open like those of a bursted apple. The outside was very hard and glistened (148) as if melted and glazed. Within the rock was very porous and pumiceous (147). Near by another specimen had a thin, reddish, cracked rind with a more crystalline granitic center. Specimens 150 and 151 also were found along the northern rim of the lake and belong to this peculiar ejectamenta.

On the broad divide north of Crater Peak is a moraine composed largely of andesitic material. It is covered with dacitic pumice in such a way as to mark the relative age of the glaciation and eruption.

GLACIATION OF MOUNT MAZAMA.

The glaciers of Mount Mazama have left distinct records in the form of striæ and moraines, with their outwash plains lower down upon the mountain slopes. The radial arrangement of the striæ across the very crest of the rim overlooking the lake is clearly displayed, as shown on the map (Pl. VI). The rocks are well striated, especially upon the western and southern crest, and the glacial cutting has been sufficiently deep to remove all the surface features of the lava flows on the outer slope of the rim. On the adjacent slope toward the lake the same rocks present rough fracture surfaces showing no striæ. The glaciation of the rim is a feature of the outer slope only, but it reaches the very crest. The glaciers that striated the crown of the rim carried stones in their lower parts, and must have come down from above. The central peak from which the glaciers radiated has disappeared, as it is evident that the topographic conditions of to-day afford no such source of supply.

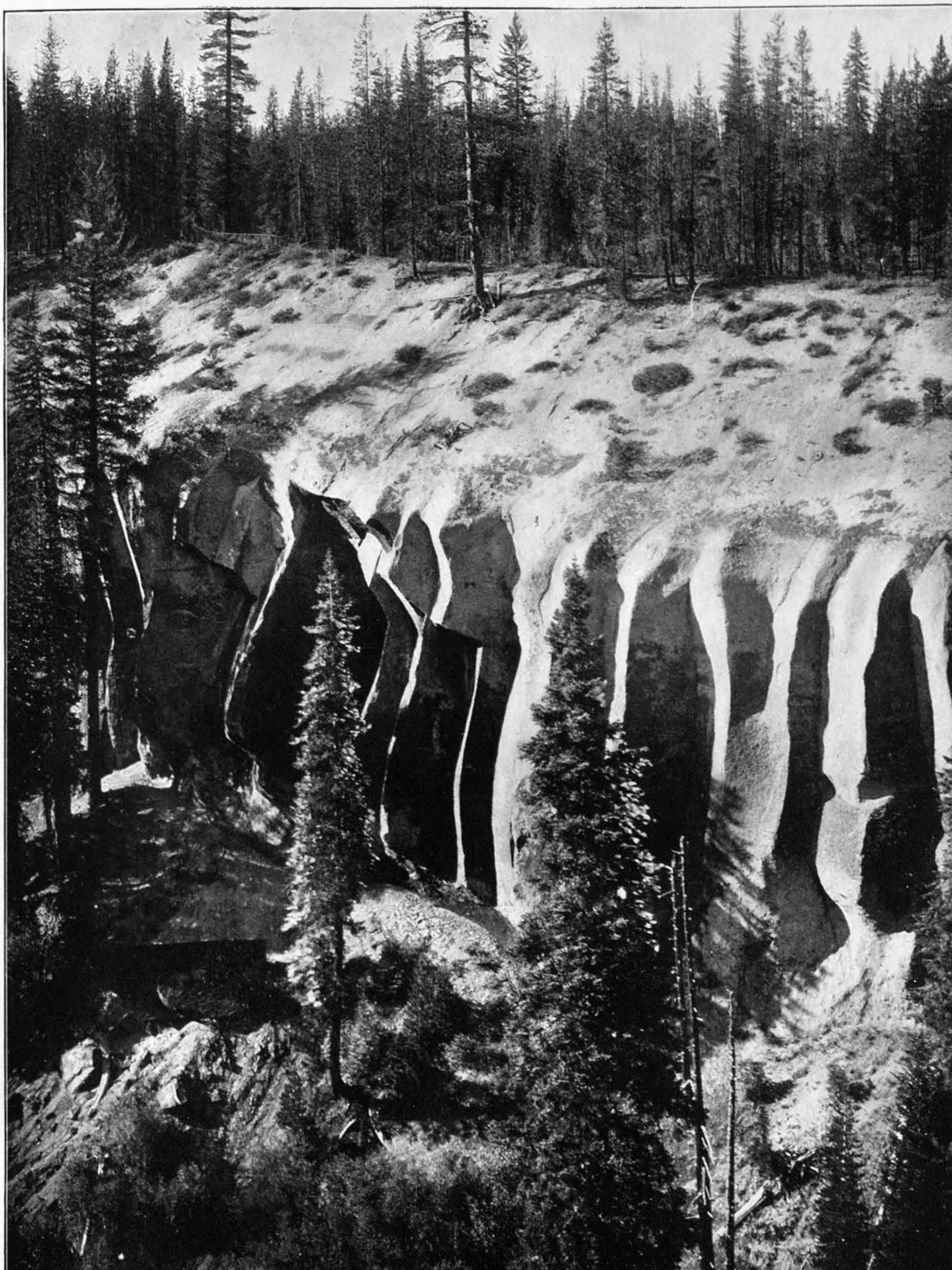
The only portion of the rim along which positive signs of glaciation were not observed is opposite Scott Peak, and yet it is altogether probable that glaciers existed here, for near Sentinel Rock there appear to be two layers of gravel of glacial origin, and there are evidences of glaciation in the valley heading between Cloud Cap and Scott Peak and draining this portion of the crest. Below the cascade on the South Fork of Bear Creek the valley is bordered by one of the finest lateral moraines of the region. It is practically certain, therefore, that the crest of the rim has been glaciated throughout its entire circuit, excepting possibly Glacier Peak and the two highest points in the southern rim, and yet along these portions of the rim there is the clearest evidence of deep glacial cutting.

On the lower slope of Mount Mazama, the glaciers were broken up into tongues of glacial ice which occupied the valleys only, following closely the lines of drainage. One of the largest of these masses occupied the valley of Anna Creek, in the bottom of which glacial striæ have been found at a distance of over 3 miles from the lake. Beyond this point all the lava flows in the middle portion of the valley are concealed by a thick coating of fine volcanic detritus washed down from the higher slopes of the volcano, filling the valleys to great depths and effectually obscuring the records made by the glacier at the time of its greatest extension.

The moraine of the Anna Creek glacier on the rim near Victor Rock has a thickness of over a hundred feet. It is composed of angular fragments up to 8 feet in diameter, commingled with sand and clay. Near by, on the outer slope, at the head of the main divide between Anna and Castle creeks, it is bowlder covered.

On descending from the crest to the springs at the head of Anna Creek, terraces may be seen bordering a sharp V-shaped canyon cut wholly in morainal material containing smoothed bowlders of andesite. Some of them are dark colored and inclose gray secretions. The U-shaped glacial valley of Anna Creek, a short distance below the crest, is 120 feet deep, with moraines on the sides and on an irregular bottom 50 yards in width. The canyon heads against cliffs over which several streams cascade, to disappear in the débris below. They are fed by the snow banks near the crest, in which the Anna Creek glacier has not made a decided notch, as have the glaciers of Sun and Sand creeks.

The moraine-filled valley of Anna Creek, 1½ miles from the lake, has a width of nearly half a mile where meadows begin. The meadows become swampy in places, with fine pasture on somewhat irregular bottom, and continue to a morainal ridge 20 or 30 feet in height crossing the valley diagonally to the southwest, where the principal stream breaks through. At this terminal moraine the swampy patches cease and the valley becomes broad and dry. The stream near the west side, after passing the moraine, soon begins to cut into the somewhat irregular surface, where it becomes a well-marked plain covered with pumice and studded with pines and firs of moderate size. The stream cuts deeper and deeper into the plain as it advances, revealing a mass of fragmental material without definite stratification, although in places there are lines parallel to the surface of the pumice-covered plain. Three miles from the crest, and at least a mile beyond the small terminal moraine noted above, the stream exposes the rocky floor of the valley, which is clearly glaciated. The main stream at its junction with the west fork, which flows from the large spring near the wagon road, is a canyon 300 feet deep in comparatively fine volcanic material, like that of the plain above. The wagon road down the right bank of Anna Creek follows the plain for miles and affords fine views of the canyon. At the mouth of Pole Bridge Creek the plain is hummocky. It has not been leveled off and appears to be morainal, perhaps a portion of an earlier terminal moraine of the Anna Creek glacier, or of a side glacier along Pole Bridge Creek from Union Peak. This small valley is full of morainal material from the Union Peak region, which was also a glacial center, as is shown by the striæ near the southwest corner of the park. The striæ evidently record an ice movement from the Union Peak region north and northwest to join the Rogue River glacier from Mount Mazama. The distribution of the morainal material suggests another branch down Pole Bridge Creek to the Anna Creek glacier. The canyon of Anna Creek above the mouth of Pole Bridge Creek is shown in Pl. III, *B*. Below that point it has a depth of 300 to 400 feet, with almost inaccessible walls frequently ornamented by columns and other carved forms composed wholly



JOINTED TUFF OF ANNA CREEK.

of volcanic material. There are but few places where the stream can be reached. It is completely boxed in by cliffs, in which the jointed structure (Pl. XI) of the material is prominent.

The ice at the mouth of Pole Bridge Creek may have been not less than a thousand feet thick, for it polished the rocks at an elevation of 6,500 feet on the summit immediately south of that stream. The terminal moraine of the Anna Creek glacier at the time of its greatest extension may have been buried by the deposits of the Wood River Valley or the Klamath lakes.

The glacial phenomena of Anna Creek illustrate quite fully those of all the other important streams heading in Mount Mazama and may be taken as a type. In general, the moraines of the upper slopes are succeeded by extensive plains of sand and pumice, which fill the valleys to great depths and give rise to the box canyons in which the streams leave the lower slopes of that great volcano.

Anna Creek carries a larger proportion of water from the rim of Crater Lake than any other stream, for the reason, most likely, that it receives much of its supply from the great snowdrifts caught within the southwest portion of the rim crest. East of it lie Sun and Sand creeks, both of which occupy well-marked glacial canyons. In strong contrast to these are the valleys of Castle Creek and other streams which drain the western slope of Mount Mazama into Rogue River without perceptibly notching that portion of the rim, unless we consider the gap between Glacial Peak and Llao Rock as such. The bowldery moraine surface on the Rogue River side of the rim is best displayed at the head of Castle Creek. Along the road to the lake and below it are great plains of sand and pumice stretching for many miles down Rogue River. Ground moraine is widespread, but no conspicuous terminal moraine was noted anywhere on the western slope. Possibly it has been covered up, or may have been inconspicuous and overlooked.

A large glacial stream filled the broad valley between Glacier Peak and Llao Rock and spread over the broad plain west of Red Cone to the western border of the park, where a remarkable series of meadows occurs, due, most likely, to glacial dams at their lower ends. The Rogue River glacier had a width, measured along the crest, of over 4 miles, and was probably by far the largest glacier of Mount Mazama.

The canyons of Sand and Sun creeks are among the most striking glacial phenomena of Mount Mazama. The notches they make in the rim are prominent features. The canyons are clearly of the glacial form. Their walls are glaciated and their floors strewn with morainal deposits, which on Sand Creek are succeeded below by the usual box canyon cut in the plain, underlain by thick deposits of volcanic material. The canyon is not so deep as that of Anna Creek, and the descent to the plain of Klamath Marsh, at the east foot of the mountain, is gradual. In the case of Sun Creek the conditions are somewhat different. For 2 miles from the crest the grade is gentle and the broad even floor is on glacial débris; then the creek descends abruptly, by falls hundreds of feet in height, to a relatively narrow canyon, which attains a depth of over a thousand feet, and continues to the plain of the Klamath lakes. The canyon walls are composed of dacite, terraced by successive flows much older than the gorge. The canyon, which is the great one opposite Crater Peak, has a floor of fine material three-fourths of a mile wide, in which the present stream has cut an inner canyon 200 feet in depth. This canyon may differ from that of Anna and Sand creeks in the amount of filling, but we have no full measure of their depth. On the other hand, it is possible that this deep rocky canyon records a condition not found elsewhere about Crater Lake.

The cutting of the canyons of Sun and Sand creeks was the final glacial work of Mount Mazama. They are the only ones coming down from the upper portion of the mountain and must represent its principal streams. They would, therefore, contain the glaciers which remained after the epoch of general glaciation, during which the broad divides between the canyons were ice covered.

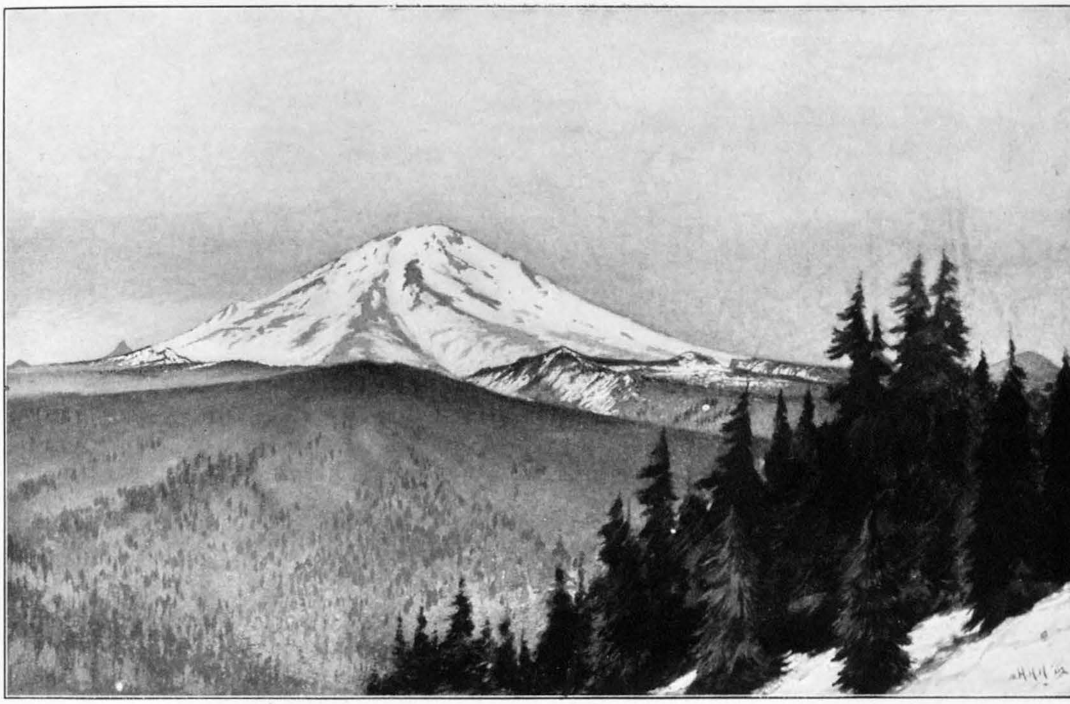
The northeast slope of the rim was well glaciated by masses descending into the forks of Bear Creek, especially the South Fork, where the moraine field is large and covered with but little timber. A short distance northeast of the cascade on the South Fork there is a well-marked lateral moraine, the finest seen anywhere in the region. It is a smooth, even ridge 200 feet in height, containing many rounded pebbles and bowlders, often striated, and having a final thin coating of pumice. It was bordered by two glacial lobes in the lee of a spur heading between Cloud Cap and Scott Peak.

ORIGINAL CONDITION OF MOUNT MAZAMA.

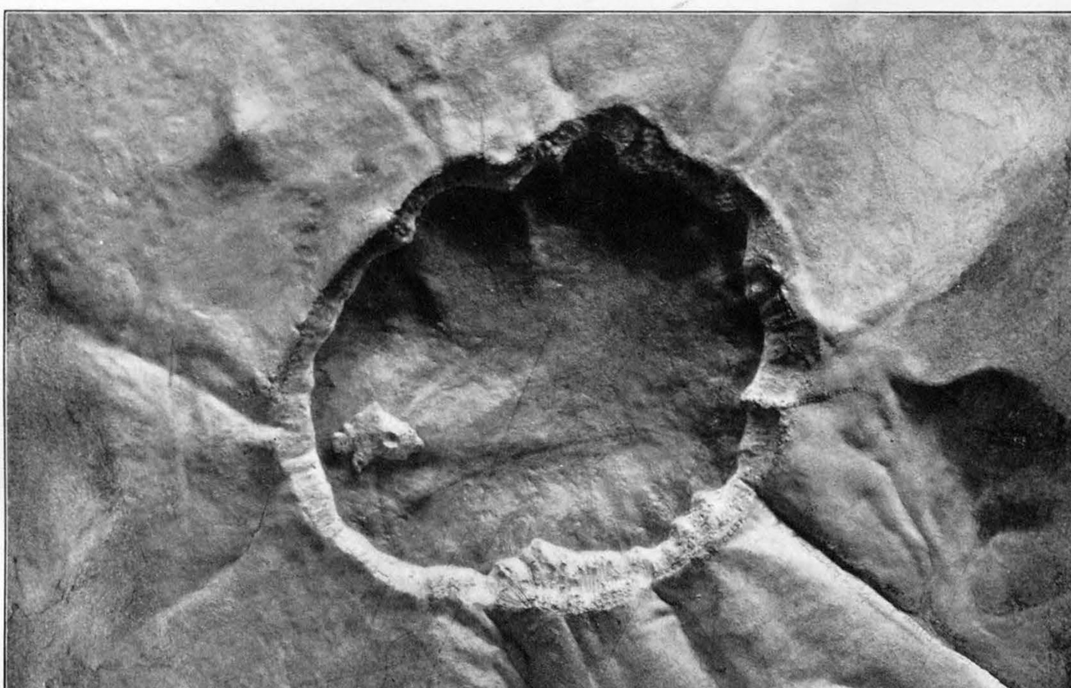
Thus far the existence of an original Mount Mazama has been assumed. The evidence on which this assumption is based may be briefly stated as follows: The inner slope of the rim presents sections of the broken lava flows, which radiate from the lake and were evidently effused from a source higher in each case than the respective flow in the rim. If the flows of the rim were restored to their original size by extending them inward from the rim, they would converge to a common source and make a volcano which would occupy the place of the caldera and make a prominent peak, Mount Mazama.

The peak must have had a crater similar in character to that of Wizard Island, for it was the source of much fragmental material spread in all directions on the mountain slope.

The former existence of Mount Mazama is indicated also by the radial dikes which cut the rim. They evidently originated from pressure in a column of molten material in the chimney of a volcanic peak rising some distance at least above the rim.



A. MOUNT MAZAMA RESTORED.



B. RIM OF CRATER LAKE.

The most convincing evidence of the existence of Mount Mazama on the site of Crater Lake is to be found in the glaciation and drainage of the rim. The radiating glaciers, which in their descent scored the crest of the rim, could have come only from a central peak. The records of the ice and water drainage from this peak in the topography of the rim are unmistakable.

There can be no reasonable doubt as to the former existence of Mount Mazama, but its shape and size are more difficult to determine. Mount Mazama is composed largely of lavas similar to those of Mount Shasta, and from the slopes of that famous peak we may draw an inference as to those of Mount Mazama. Mount Shasta, unlike Mount Mazama, does not stand on an elevated platform. It rises with a majestic sweep of 11,000 feet from gentle slopes about its base, gradually growing steeper upward to the bold peak. At the height of 8,000 feet it has about the same diameter as Mount Mazama at an equal elevation in the rim of Crater Lake. Above this Mount Shasta rises over 6,300 feet. The prominence of Mount Mazama as a drainage center is quite equal to that of Mount Shasta, but its slopes on the rim of Crater Lake, ranging from 10° to 15°, are scarcely as great as those of Mount Shasta at a corresponding elevation. On the other hand, the canyons of Sun and Sand creeks on Mount Mazama are more profound and have been much more deeply glaciated than any of those on Mount Shasta. It therefore appears reasonable to suppose that Mount Mazama had an altitude at least as great, and possibly greater, than Mount Shasta (14,380 feet).

From a large amount of data at hand concerning the base of Mount Mazama, an attempt has been made to restore its summit, and Pl. XII, *A*, illustrates the result. It is pictured as it would now appear, with a small but distinct glacier representing the Anna Creek glacier, which once overflowed the divide westward into the Rogue River drainage.

From the same general position, but at a somewhat greater elevation, a view of the rim as it appears to-day has been prepared by the same artist, and is shown in Pl. XII, *B*.

DEVELOPMENT OF MOUNT MAZAMA.

Scott Peak is only a large cone adnate to Mount Mazama. It belongs to the same center and holds essentially the same relation to it as Shastina does to Shasta. The slopes of Mount Mazama reach to the plains at its eastern base, and it is one of the largest mountains of the Cascade Range.

The beginnings of Mount Mazama are now deeply buried beneath the lavas of the range, including those displayed on the lower slopes of the great caldera beneath the water of Crater Lake. The earliest lavas now visible are those of the southern and western lake border, and when they were erupted the volcano was normally active, sending out with its streams of lava large contributions of fragmental material to make the heavy conglomerates of the older portion of the rim. The many succeeding flows of andesite and layers of conglomerate built up the mountain slope to the crest of the rim upon the southern and western side, and Scott Peak, too, had attained its full development when the peripheral vents of basalt opened and by a series of eruptions built up the surrounding country with adnate cones upon the outer slope of the rim of the lake. Then followed the large eruptions of dacite, forming Llao Rock and the northern crest of the rim to Cloud Cap. These flows occurred during the period of glaciation of Mount Mazama, and streams of lava alternated with streams of ice, a combination which doubtless gave rise to extensive floods upon the slopes, and filled the valleys below with volcanic débris from the mountain. In connection with the eruption of these viscous lavas (dacites) there were great explosive eruptions of pumice, which was spread for 20 miles or more across the adjacent country. The explosive activity of Mount Mazama culminated in the eruption of the peculiar dark pumice, rich in hornblende, which followed the outflow of the tuffaceous dacite.

DESTRUCTION OF MOUNT MAZAMA AND FORMATION OF THE CALDERA.

After the eruption of the pumice came the revolution which removed the large core and the upper 6,000 feet of Mount Mazama and gave rise to the caldera. There are only two ways in which this change could have been effected—either by an explosion which blew away the top of the mountain or by a subsidence which engulfed it.

The occurrence of vast quantities of pumice for a distance of 20 miles in all directions about the base of Mount Mazama is evidence of a most tremendous explosive eruption at that point, an eruption the equal of which has not yet been found anywhere else in the Cascade Range. Fine material was blown out in vast quantities at the same time and by drainage gathered into the surrounding valleys which it fills to an extent unknown, as far as I have observed, on the slopes of any of the other great valcanoes of the range.[a] This impressive evidence shows conclusively that a late, if not the final, eruption of Mount Mazama was explosive, and of such magnitude as to suggest that the removal of the mountain and the origin of the caldera may be counted among its effects. This suggestion, however, is not supported by the evidence resulting from a study of the ejected material and its relation to the lava flows of the rim. The fine material filling the valleys, and the pumice throughout its great area, are hornblendic in character

[a] As far as my own observation goes the above remarks apply to Lassen Peak, Mount Shasta, Mount Pitt, Mount Thielsen, Diamond Peak, and Mount Hood.

and were erupted in connection with the dacites of the rim. Their eruption, therefore, was of the usual type, and not of the kind which removes mountains. As far as may be judged from the size of the pumice deposits now exposed in the rim, the greatest eruption of that sort of material from Mount Mazama occurred before the extrusion of the dacite of Llao Rock, and is evidence that the greatest explosion occurred long before the destruction of Mount Mazama.

There is another matter of importance bearing directly on the explosive theory of the caldera which renders that theory wholly untenable and fully corroborates the conclusion derived from a study of the character and distribution of the pumice. The lava exposed on the inner slope of the rim is chiefly andesite, and its relation is such as to indicate that solid sheets of andesitic lava formed by far the larger part of Mount Mazama. If the caldera resulted from an explosion this mass of andesitic flows would have been broken to fragments and blown out, so as to fall around the caldera and form a rim of fragmental material. From the size of the lake and the remaining portion of Mount Mazama it is possible to compute approximately what the size of the rim formed in this way would be. But before we can do this it is necessary to consider the size and shape of the caldera, especially of that part which lies beneath the lake.

To determine the configuration of the bottom of Crater Lake a large number (168) of soundings were made under the direction of Major Dutton, who summarizes the results as follows:[a]

"The inferred configuration of the bottom may be conceived of as a nearly plane surface for the most part, upon which stand three abruptly rising prominences. The largest of these rises above the surface of the water and discloses itself as a large cinder cone. This one [Wizard Island] stands near the western margin of the lake. * * * The other two prominences are disclosed only by the plummet, for their tops are submerged, one at a depth of about 450 feet, the other at a depth of about 825 feet. The depth of the floor upon which these prominences stand varies from 1,600 to 2,000 feet. At the deepest cast the wire gave a reading of 1,996. To this should be added a small but unknown correction for the stretching of the wire, which will make the true depth of this cast fully 2,000 feet. So far as known to me this is the deepest fresh water in the United States."

On the map (Pl. VI) the principal soundings are noted. From this data, together with information from Mr. W. G. Steel, who was present when the soundings were made, the presence of two sublacustrine cones is inferred, and it is clear that a large mass of lava spread from the Wizard Island vent over the lake floor. The great depression toward the eastern margin of the lake may not have been filled up any after the caldera was formed, but it is evident that the depth of the western portion has been greatly reduced by the material erupted from the three small

[a] Eighth Ann. Rept. U. S. Geol. Survey, Part I, 1889, p. 157.

vents upon its floor. It appears well within the bounds of reason to assume that 1,500 feet is not greater than the average depth of the original caldera below the present level of the lake.

The area of the caldera, as marked out by the crest of the rim, is over 27 square miles, and its original volume, making some allowance for the subsequent refilling from the craters on its floor, is about 12 cubic miles. If to this we add 5 cubic miles for the part of the mountain above the caldera—and this is a conservative estimate—we get 17 cubic miles of material, for whose disappearance we have to account. If this material were blown out by a great explosion and fell equally distributed upon the outer slope of the rim within 3 miles of the crest it would make a layer over 1,000 feet in thickness. This mass would be so conspicuous and composed of such fragmental material that its presence could not be a matter of doubt. There can be no question concerning its complete absence, for the surface of the outer slope of the rim exposes everywhere either glaciated rock, glacial moraine, or pumice, all of which are features which belonged to Mount Mazama before its destruction, and no trace of a fragmental rim, such as is referred to above, was found anywhere.

The phenomena on the outer slope of the rim lend no support to the view that Mount Mazama was blown away and the caldera produced by a great volcanic explosion. In fact, they completely negative such a view, and we are practically driven to the opinion that Mount Mazama has been engulfed. Major Dutton, who studied the rim of Crater Lake with a training gained among the active volcanoes of the Hawaiian Islands, recognized the wide distribution of the pumice, but the absence of a well-defined fragmental rim kept him from attributing the origin of the caldera to an explosion. On the other hand, he fully appreciated the difficulty of proving that it originated in a subsidence.[a] He says:

"In the Hawaiian calderas the evidences of sinkage are conspicuous. They are not confined to the deeper floors of the pits, but are also seen in the partial subsidence of great blocks or slices of the walls immediately enclosing them, and in irregular sunken spots in their vicinity, also in the marks of powerful shearing or faulting action in the walls themselves. They appear to be correlated to the remarkably quiet habits of the Hawaiian volcanoes, to their habitual modes of eruption, and to the special structure of the volcanic piles, which do not rise in steep conical peaks, but are very broad and flat. At Crater Lake, neither in the walls themselves, nor in the immediate neighborhood back of the crest line, have any traces of sinkage been observed as yet. Nothing can at present be pointed out which suggests the Hawaiian mode of origin, beyond the fact that a vast crater is before us. The general structure and habits of the Cascade volcanoes are indicative of a more vigorous style of volcanic action than the Hawaiian."

[a] Science, Vol. VII, 1886, p. 181.

Let us examine briefly some of the possible conditions of engulfment. The width of the caldera across the crest of the rim is about half a mile greater than at the level of the lake, and Mount Mazama could not have subsided on the present inner slope of the rim as one solid mass without profoundly splitting the rim at one or more points. No such cross fractures of the rim have been observed.[a] The mountain, therefore, appears to have collapsed, one part after another in succession, probably from the center outward as the support was removed. The present inner slope of the rim may not in all cases or even generally be the one formed at the time of the collapse. In some cases, however, the inner slope was formed at that time. Of this we have evidence in the behavior of the flow at Rugged Crest. It was one of the final flows from the slope of Mount Mazama. Before the central portion of the flow, where thickest, had congealed within the solid crust, Mount Mazama sank away and the yet viscous lava of the middle portion of the stream flowed down over the inner slope of the andesitic rim into the caldera. The liquid interior of the flow having withdrawn, the crust caved in and formed Rugged Crest, with its peculiar chaotic valley of tumbled fragments, columns, and bluffs. Other explanations of the peculiar reversed flow of Rugged Crest have been sought but without avail. The facts are so simple and so direct that they appear to preclude any other hypothesis.

It would be apparent from the facts also that the collapse of the mountain was at least moderately sudden, for it is not at all probable that the Rugged Crest flow was long exposed before reaching the present level of the lake and the caldera beyond.

We may be aided in understanding the origin of the caldera by picturing the conditions that must have existed during the eruption of the Rugged Crest dacite from the upper slope of Mount Mazama. At that time a column of molten material rose in the interior of the mountain until it overflowed at the summit, or burst open the sides and escaped through the fissure. The rent of the mountain side was caused in such cases by the pressure of the column of molten material it inclosed. The molten lavas being heavy the pressure of the column within the mountain was very great, and increased rapidly with the height of the volcano. During the final activity of Mount Mazama there must have been within it a column of lava rising to a height of over 8,000 feet above the base of the Cascade Range. It is possible that this great pressure, aided perhaps by some other forces, made an opening formed low down upon the mountain slope, allowing the lava to escape. The subsidence of the lava within the mountain left it unsupported and caused its collapse. Phenomena of

[a] The dikes are in fractures across the rim, but they were all formed before the great catastrophe occurred.

this sort are well known in connection with the Hawaiian volcanoes. In 1840, according to Prof. J. D. Dana, there was an eruption from the slopes of Kilauea, 27 miles from and over 3,000 feet below the level of its summit. At Kilauea the summit of the lava column is well exposed in a lava lake. In connection with the eruption of 1840 the lava of the lake subsided to a depth of 385 feet, and the irregular walls surrounding it were left without support and broke off and fell into the molten material below. During the intervals between the eruptions of Kilauea the molten column rises toward the surface only to be lowered by subsequent eruptions. The subsidences, however, are not always accompanied by an outflow of lava upon the surface. At other times it may gush forth as a great fountain hundreds of feet or more in height as if due directly to hydrostatic pressure.

That Mount Mazama disappeared and the caldera originated through subsidence seems evident, but the corresponding effusion upon the surface, if such ever occurred, has not yet been found. It is hardly conceivable that 17 cubic miles of material, much of it solid lava, could collapse, be again melted, and sink away into the earth without a correlative effusion at some other point.

The bottom of the caldera at its deepest portion is at an elevation of 4,200 feet above sea level, and it is not to be expected that the point of escape would occur at any higher level. Klamath Marsh, which lies at the eastern base of the Cascade Range, is over 200 feet higher than the bottom of the caldera. This would indicate that the effused mass should be sought on the western slope of the range, where the 4,200-foot contour occurs, along Rogue River, at a distance of less than 12 miles from the rim of the lake. The correlative lavas might perhaps be expected to be dacites closely related to the final flow of Mount Mazama, but on Rogue River the lavas are generally basalt, and there is no suggestion of the escape of such an enormous mass of lava as recently as the time of the great collapse. Whether or not we are able to discover the corresponding effusion, there seems no reasonable doubt that Mount Mazama was once a reality and that it was wrecked by engulfment.

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 2¼ 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 observa-

[a] Mazama, Vol. I, No. 2, p. 232.

tions, it seems certain that the waters of Crater Lake are still receiving heat from the rocks upon which they rest."[a] His observations were made with a Negretti-Zambra deep-sea thermometer, tripped by means of a propeller. Dr. Evermann says:[a]

"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."

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, 3¼ 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

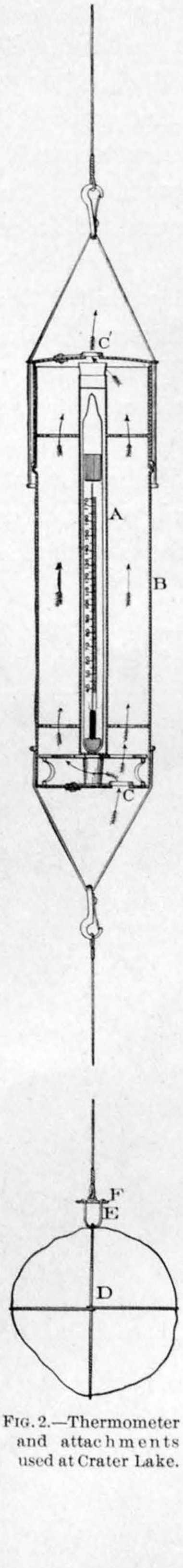


FIG. 2.—Thermometer and attachments used at Crater Lake.

[a] Op. cit., p. 234.

in each case 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.

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.
Feet.	*Degrees.*	*Degrees.*	*Degrees.*	*Degrees.*	*Degrees.*
1	48	50	51	50	52
100	....	....	....	....	[b] 42
200	....	....	....	....	[a] 40. 5
300	....	....	....	....	[b] 39. 5
400	....	....	....	....	[a] 39. 5
500	[a] 39	[a] 39	....	[b] 39	[b] 39
972	....	....	....	....	[b] ?
1, 000	....	....	....	[a] 39	....
1, 306	....	....	[a] 39 (Bottom.)	....	....
1, 442	....	....	....	[b] 38. 5	....
1, 472	....	....	....	....	[a] 39 (Bottom.)
1, 942	....	....	....	[a] 38. 5 (Bottom.)	....

[a] Common form of thermometer with thick glass jacket inclosed in brass tube and suspended in bucket $3\frac{1}{4}$ by 12 inches.

[b] Negretti-Zambra deep-sea thermometer.

No. 1. July 8, 1901, 8 a. m., $\frac{1}{2}$ 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., $\frac{1}{4}$ 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., $\frac{1}{4}$ 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., $\frac{1}{4}$ 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.

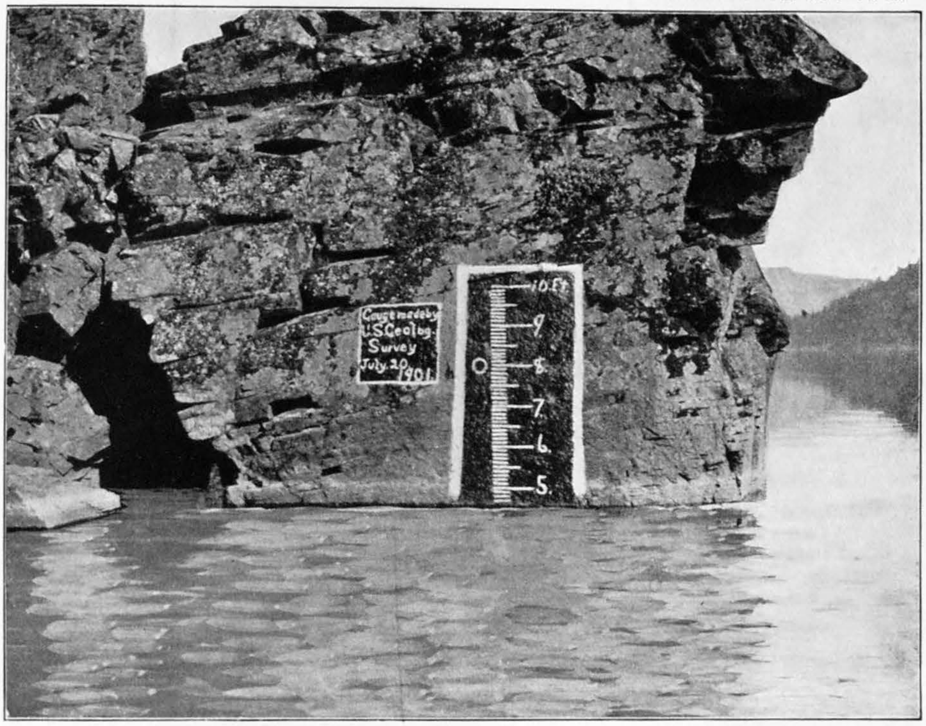
It may be noted also that Crater Lake, although over 6,000 feet above the sea, does not freeze over in winter, as do the Klamath lakes, at a much lower level, upon the eastern side of the mountain. Mr. E. W. Herchberger, a trapper, saw Crater Lake March 15, 1895, without ice. The winter was very cold. 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.

CHANGES OF WATER LEVEL IN CRATER LAKE.

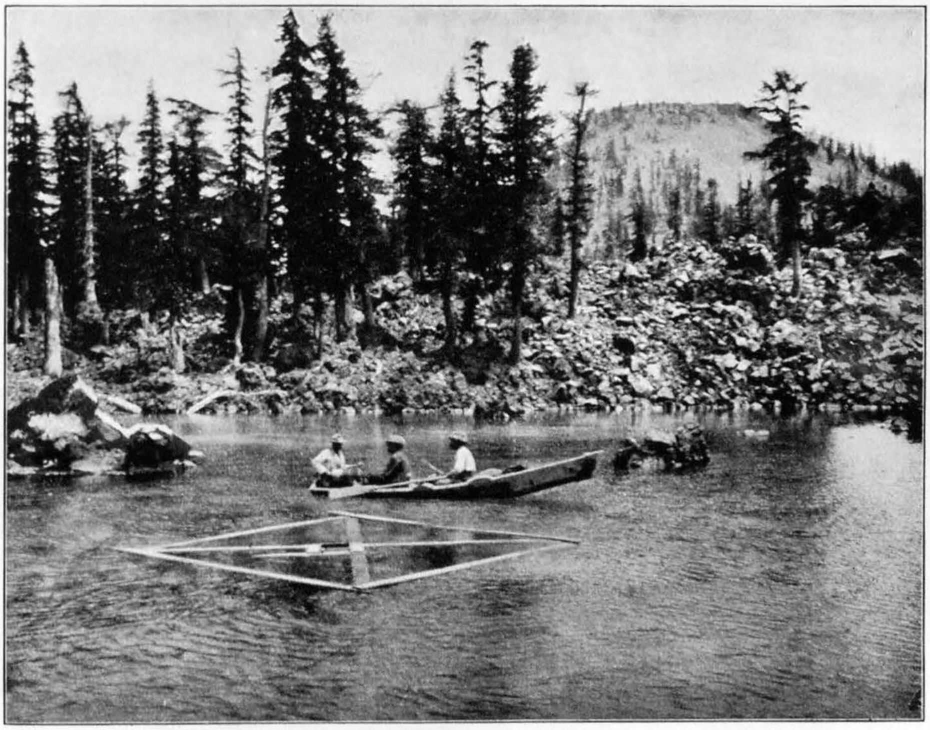
An examination of one of the embayed shores of Crater Lake in August or September will convince anyone that the lake changes level. Late in June a little crustacean, *Daphnia pulex pulicaria*, swarms along the shore and attracts other minute forms in abundance to the same place. A white deposit composed of the remains of these organisms marks the shore line at the upper limit of their abundant appearance, and as the season advances lower levels are marked in the same way. During the summer, when there is rapid evaporation and little or no precipitation, the surface of the lake subsides, but during the rainy winter it rises again. The oscillation is limited to about 4 feet. The rising and the sinking balance each other, so that the lake maintains in general nearly the same level. No observations whatever have been made when the water was at its highest stage, which is supposed to be early in May, but the lowest turning point was reached in 1901 about the 1st of October. The high and low points vary from year to year with the seasons, but the change is so gradual and on the whole so small that distinct beach levels are not developed. The lowest water known was observed September 26, 1893, when it was less than a foot below its level on September 15, 1901.

August 22, 1896, a gage was erected on the shore of Crater Lake, for the Mazamas, by C. H. Sholes, president, and Earl M. Wilbur, secretary. The gage was made of a board 5¾ inches wide and 10 feet long, with scale subdivided to tenths of a foot. It was nailed to a log extending from the shore into the water, and zero of the scale was placed just 4 feet beneath the water surface, thus allowing the water to sink 4 feet without leaving the scale. A copper pocket fastened to the upper part of the gage contained a record book, in which visitors at the lake were asked to note the height of the water. Fearing that this fragile gage might not escape accident from rolling stones or sliding snow, W. W. Nickerson, of Klamath Falls, was requested to insert a bolt in a cliff near the gage and carefully determine the height of the bolt above the water and read the gage. In the record book, September 25, 1896, Mr. Nickerson records the height of the water on the gage 3.425, and adds: "Also strengthened the gage, as requested by Messrs. Diller and Steel, and put up copper bolt 50 feet to the west of the gage at an elevation of 5.75 feet above the present level of the water." The gage was broken off during the following winter and cast adrift on the lake.

August 13, 1901, James Storrs and Fred. Larsen, while making stream measurements, found the copper box containing the record book in 5 feet of water along the shore of Danger Bay, about 3½ miles east of Eagle Cove, where the gage had been established. The records were well preserved in the book, notwithstanding the five years' soaking, and enabled us to find Mr. Nickerson's bolt and reestablish the Mazama gage level. We painted the scale shown in Pl. XIII, *A*, on a rock a short distance northwest of Nickerson's bolt, and added a scale also on the rock containing the bolt, the rock at the last place being too rough for small divisions. The zero of these scales has the same level as that of the Mazama gage, and all known readings of the lake level have been reduced to that scale in the following table.



A WATER GAGE, CRATER LAKE.



B. RAFT AND EVAPORATING PAN.

Water level of Crater Lake with reference to scale established by Mazamas, August 22, 1896.

Date.	Height of water.	Remarks.
	Feet.	
September 10, 1892	4.142	Mr. F. V. Coville found "O. H. Herchberger, Sept. 10, 1892" painted on a detached bowlder a few yards west of boat landing, and reports that Aug. 1, 1897, "the lower end of the 9 was 7½ inches beneath the surface of the lake."
September 26, 1893	2.52	Mr. F. V. Coville found "Dr. Kirchgessner, Heath Kirchgessner" [a] painted on a rock in place a few yards east of the landing, and reports that "the lower part of the H was 27 inches beneath the surface of the lake."
August 22, 1896	4.00	C. H. Sholes and Earl M. Wilbur, president and secretary of the Mazamas, Portland, Oreg., established for the society a wooden gage. Zero of the scale was 4 feet beneath the surface of the lake. [a]
August 30, 1896	3.90	(The record 4.9 should evidently be 3.9, as the lake surface was sinking.)
September 4, 1896	3.825	J. S. Diller, observer. (Rate of fall a day for 13 days, 0.0135 foot.)
September 5, 1896	3.820	E. B. Barrows, observer.
September 13, 1896	3.500	Thomas Croxton, observer.
September 25, 1896	3.425	W. W. Nickerson, observer, who fixed bolt in rock west of gage and 9.175 feet above zero of Mazama scale. (Rate of fall a day for 34 days, 0.0169 foot.)
August 1, 1897	4.77	F. V. Coville made a mark "3 ft." on rock 250 yards east of foot of trail, and another "*c*" on a rock 60 yards west of trail. Zero of Coville's scale=4.77 of the Mazama scale. The remnant of the old Mazama gage has subsided considerably since Mr. Coville's observations.
July 1, 1901	4.905	J. S. Diller, observer.
July 20, 1901	4.613	J. S. Diller, observer. (Rate of fall a day for 19 days, 0.0155 foot.)
August 1, 1901	4.42	E. W. Herchberger, observer. (Rate of fall a day for 12 days, 0.0158 foot.)
August 16, 1901	4.11	E. W. Herchberger, observer. (Rate of fall a day for 15 days, 0.0266 foot.)
September 1, 1901	3.92	E. W. Herchberger, observer. (Rate of fall a day for 16 days, 0.0118 foot.)
September 15, 1901	3.24	E. W. Herchberger, observer. (Rate of fall a day for 14 days, 0.0486 foot.)
October 12, 1901	3.39	E. W. Herchberger, observer. (Rate of *rise* a day for 29 days, 0.0051 foot.)

Average rate of fall from July 1 to September 15 (77 days), 0.0236 foot per day.

[a] These marks could not be found in July, 1901.

Summary of fluctuations of Crater Lake.

Period.	Number of days.	Rate of subsidence.
1896.		*Foot.*
August 22 to September 4	13	0.0135
September 4 to September 25	21	.0190
1901.		
July 1 to July 20	19	.0155
July 20 to September 15	58	.0236
Average for	111	.0179

At this rate in 365 days it would sink only 6.53 feet, i. e., 78 inches, which is much more than the annual precipitation. However, in this consideration it must be remembered that the rate of loss noted is entirely too great for the winter, when evaporation is much slower than in summer.

No positive evidence has been observed anywhere on the inner slope of the rim that the lake was ever considerably higher or lower than it is to-day. The complete absence of beach lines above those of the present level of the lake is conclusive that the lake never stood higher, but marks of any kind as to lower levels would be submerged. The shore line at many points is a steep bluff of rocks, but at many places, especially at the foot of small gulches, of which there are a great many, an alluvial cone shallows the water sufficiently so that the bottom is visible for nearly 200 feet from the water's edge. Where widest these shore deposits are relatively a very narrow fringe about the margin of the lake, making only a slight shoulder on the steep slope which extends from the top to the bottom of the rim.

It may be of sufficient interest to warrant mentioning here certain misleading evidence which may appear. In 1896 a tree was found near the west shore of Wizard Island standing erect in 37 feet of water. The trunk was broken off just above the water level, and the roots at the base were seen through the clear water on the bottom as if the tree grew where it was standing. It could not be shaken from the boat, and it was evident that if the tree grew where it was standing it proved the lake to have been much lower than now at a recent time. Sufficient baling wire was secured to reach the shore, and it was discovered that the tree had no hold upon the bottom. It had drifted from the shore of the island. In July, 1901, the same tree was off the north edge of the island, at least one-fourth mile from its position in 1896. Owing to the steep slopes of the rim a tree frequently slides into the water in an erect position, and the lower part becoming water-logged it floats about the lake with only a few feet of the top projecting above the water, and thus furnishes a spectacle curious enough to excite the imagination.

EVAPORATION FROM CRATER LAKE.

The observations upon the oscillations of the lake surface appeared to show a greater loss of water than would be accounted for by evaporation alone, but to get more definite data concerning the matter arrangements were made to determine approximately the rate of evaporation on the lake surface. For this purpose a tin evaporating pan 13 inches square and 6 inches deep was used. To avoid the bright reflections its inside was painted dirt brown with pitch and soil. It was supported on a raft (Pl. XIII, *B*) so that the lower part of the pan was in the water of the lake. The raft was anchored in an open bay where the water was 7 feet deep and freely agitated by the winds, but the waves did not move quite so high as on the lake. For this reason the evaporation from the pan was possibly less than that of the lake.

The following table gives the observations made at the lake in 1901:

Observations of evaporation from Crater Lake.

Date.	Time of observation.	Temperature. Air.	Temperature. Water. Lake.	Temperature. Water. Pan.	Height of water.	Time of exposure.	Amount of water lost by evaporation.	Remarks.
		Degs.	*Degs.*	*Degs.*	*Feet.*	*Days.*	*Feet.*	
July 7......	12.20 p. m.	58	52	52	0.420	......	....	
8......	12.45 p. m.	58	52	58	.410	1	0.01	Filled to 0.42.
9......	3.20 p. m.	58	56	60	.405	1	.015	
11......	2 p. m.	64	54	60	.380	2	.025	Filled to 0.44.
13......	8 a. m.	48	48	48	.420	2	.02	
16......	9.30 a. m.	52	48	50	.360	3	.06?	Disturbed by brood of wild ducks—no good. Filled to 0.41.
17......	12.15 p. m.	55	48	54	.400	1	.01	Filled to 0.42.
20......	4.45 p. m.	58	52	56	.375	3	.045	
Total....................................						10	.125	(Omitting observations of July 16.)

During the day the air and the water in the pan became warmer than the water of the lake, and during the night they became colder. Twice a day the temperature of lake, air, and water in pan agreed, but generally the temperature of the water in the pan was nearer that of the air than was that of the lake. If the amount of evaporation is in large measure proportional to the difference of temperature between the air and water, the rate of evaporation from the lake must have been greater than from the pan. However, it is believed that the higher temperatures of the pan water under the dry summer atmosphere of Crater Lake more than counterbalanced the effect of greater temperature difference, and that the rate of evaporation from the pan was as great as that from the lake.

The average evaporation for the 10 days' record used is 0.0125 feet per day. At this rate per annum the evaporation would be 55 inches. During cloudy winter weather evaporation is much reduced, so that 55 inches must be greater than the annual rate.

Professor Russell, in his map[a], makes the evaporation per annum for the Crater Lake region about 46 inches, which appears to be a close approximation.

Observations on evaporation were made also in camp on the rim of Crater Lake. Two pans 13 inches square and 5 inches deep were used. One pan (1) was bright and the other (2) browned like that on the raft by pitch and soil, and both were placed in the sun. Observations were made twice daily and the temperature of the air and water noted, as in the accompanying table. The rate varied considerably. The average loss per day in the bright pan was 0.0186 of a foot, while that in the browned pan by its side for the same time was 0.0256 of a foot. The dirt-colored pan unexpectedly gave the highest rate of evaporation, and the rate from both pans exceeded that on the lake. The temperature of the water in this case was nearer that of the air than that in the case of the raft pan, and yet the evaporation was so much greater on account of the higher temperature. These observations tend to indicate that the evaporation from the lake can not be greater than that measured by the pan on the raft, and this gives me more confidence in the conclusion concerning the amount of water that escapes by filtration.

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[a] Fourteenth Ann. Rept. U. S. Weather Bureau, Pl. VI.

Observations to determine evaporation at Crater Lake.

Date.	Time of observation.	Temperature.			Height of water.		Loss of water.	
		Air in shade.	Water.		Pan 1.	Pan 2.	Pan 1.	Pan 2.
			Pan 1.	Pan 2.				
		Deg. F.	*Deg. F.*	*Deg. F.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
July 8	5.45 a. m.	48	40	40	0.410	0.400		
8	6 p. m.	54	69	68	.400	.380	0.01	0.02
9	6.30 a. m.	48	40	38	.390	.360	.01	.02
9	5.30 p. m.	52	69	68	.380	.350	.01	.01
10	5.30 a. m.	48	38	37	.375	.340	.005	.01
10	6.30 p. m.	(Sun) 62	66	66	.365	.320	.01	.02
11	5.45 a. m.	44	40	40	.355	.315	.01	.005
11	do				[a] .395	[a] .380		
12	6.30 a. m.	42	42	41	.375	.365	.02	.015
12	7.40 p. m.	43	50	50	.372	.360	.003	.005
13	5 a. m.	35	35	36	.370	.355	.002	.005
13	6 p. m.	43	62	62	.360	.340	.01	.015
13	do				[a] .410	[a] .380		
14	6 p. m.	56	68	68	.390	.360	.02	.02
15	6 a. m.	44	41	40	.385	.345	.005	.015
15	7 p. m.		60	60	.370	.320	.015	.025
16	6.30 a. m.	48	42	42	.360	.325	.01	.005
16	6.30 p. m.	55	66	64	.350	.295	.01	.03
16	do				[a] .400	[a] .390		
17	do	58	68	68	.375	.365	.025	.025
18	do	56	66	66	.350	.340	.025	.025
19	7 p. m.		66	66	.335	.315	.015	.025
Total loss of water in 11½ days							.215	.295
Average evaporation per day							.0186	.0256

[a] Pans refilled to height indicated.

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, therefore, 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.

PART II

THE PETROGRAPHY OF CRATER LAKE NATIONAL PARK

By HORACE BUSHNELL PATTON

CONTENTS OF PART II.

ILLUSTRATIONS IN PART II.

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 (1$\bar{1}$0). 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 notedly 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 12½ per cent, contain such inclosures; out of twenty-one sections of the hypocrystalline type, eleven, or 52½ 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

[a] Mikroskopische Physiographie, 3d edition, Vol. II, 1896, p. 867.

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."

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.

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

PLATE XIV

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.

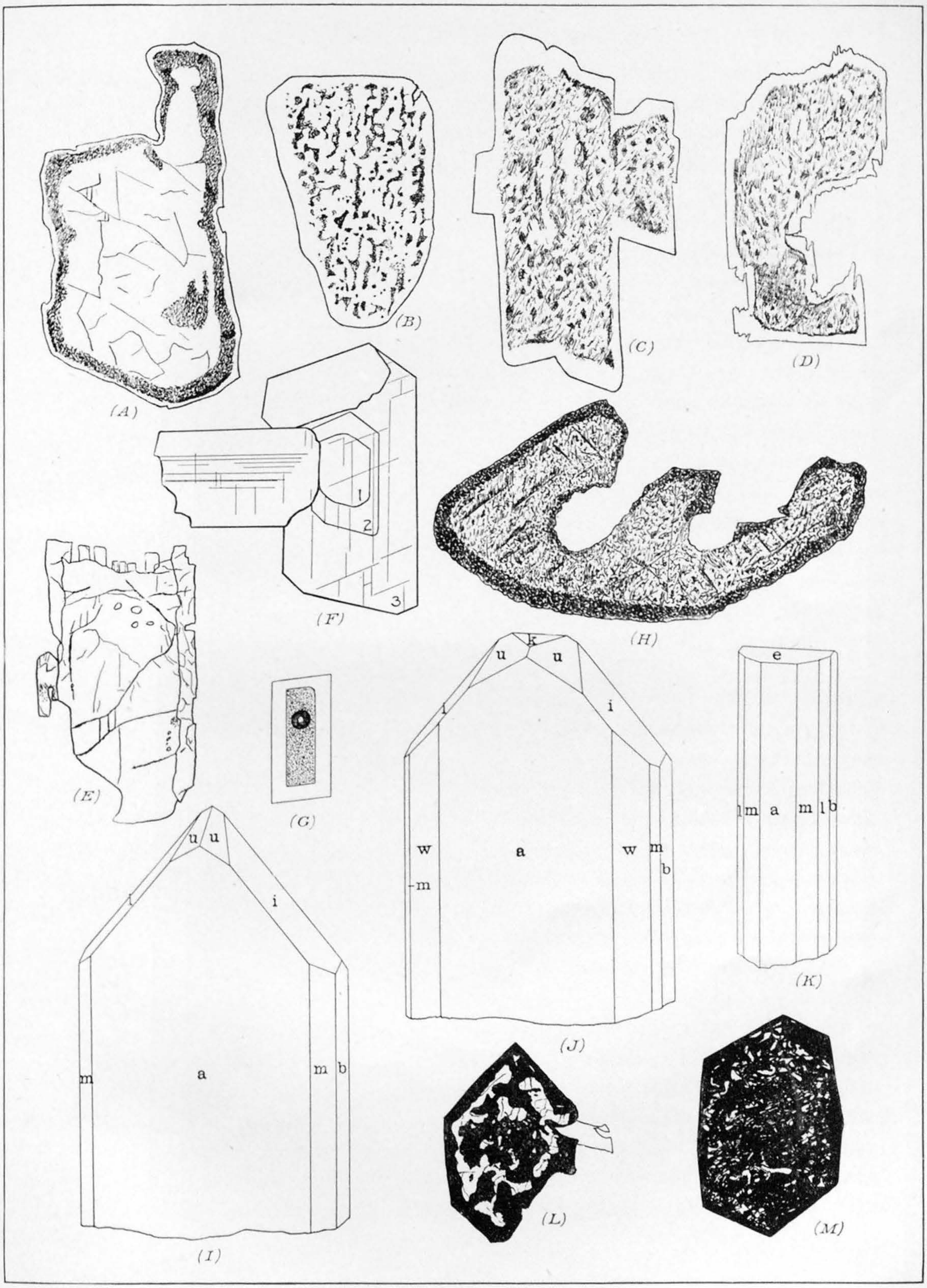
FIG. *G*.—A minute feldspar crystal containing a large inclosure of brown glass with outlines parallel to the sides of the crystal. From the vitrophyric dacite of Llao Rock. Magnified 400 diameters. Specimen No. 101. This glass inclusion contains a single gas bubble which appears like a broad black ring.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



CRYSTALS IN ANDESITE, DACITE, AND BASALT.

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 striæ, 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

PLATE XV

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 an 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.

(A)

(B)

(C)

(D)

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angles to this axis. These rocks are so fine grained that they require rather thin sections, so that the hypersthenes show much paler colors; but even in the very thinnest 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: $a=\mathfrak{a}$, $b=\mathfrak{b}$, $c=\mathfrak{c}$. 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 1½ 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).

CLASSIFICATION OF ANDESITES.

While the phenocrysts fluctuate greatly in abundance and relative importance, they do not serve as well as does the groundmass as a ready means for classifying the widely different appearing varieties of the andesitic rocks. Certain structural types in the groundmass, on the other hand, recur with great frequency and are worthy of detailed description. The andesites of Crater Lake, therefore, may be divided into four main types, based upon the character of the groundmass, namely, hyalopilitic type; hypocrystalline type, with two subtypes (A and B); holocrystalline type; dacitic type.

Although each of these four types is quite distinctive, it is not to be supposed that all the examples cited in each case are equally so. Rather it may be said that they all grade into each other in such a way as to make the separation not always easy. Neither can the rocks of any one lava stream or of one locality be said to be limited to any one type.

HYALOPILITIC TYPE OF ANDESITES.

The following specimens are included here: Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9,10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, and 21.

This variety of andesite has mainly a very dark-gray to black, dense groundmass, and when it is not porous is apt to break in smooth, slightly lustrous surfaces. The specimens that contain less glass, as well as the more porous ones, have a much lighter color and rougher fracture. On account of the dark groundmass the plagioclase phenocrysts are usually prominent, and for the same reason the pyroxenes are hardly noticeable. Most of the hyalopilitic andesites are characterized in thin sections by the presence of light to deep brown glass, which is usually very abundant and perfectly clear and unaltered (6, 9, 11, 13, 16, 17), or else this brown glass is more or less clouded by the presence of countless hosts of minute brown to black-looking globulites (brown in 8, 15, 19, 1, 5; black in 14, 21). In case these globulites are thicker than usual, the glass base between the microlites becomes lighter or even almost colorless, but still the effect of the globulites in such cases is to lend a brownish color to the whole. In a few cases a decided change of color in the glass is to be noted, in that blackish spots appear locally in a glass otherwise brownish (12, 20). These black spots have the globulites very thick and somewhat larger, while the inclosing glass base is colorless. It is more than likely that magnetite dust is developed in addition to the customary globulites, which would explain the black color. These darker spots are similar to the whole groundmass in some of the hypocrystalline andesites.

This all-pervading glass base invariably incloses myriads of perfectly sharp and straight augite microlites; also plagioclase feldspars in slender strips of microlitic size or in larger laths and in rectangular individuals. The size of the augite microlites may vary considerably in the same thin section. Thus in No. 2, where they are uncommonly small, they vary from 0.001 to 0.003 millimeter in width and from 0.01 to 0.03 millimeter in length. In general, the width may be said to average about 0.005 millimeter, with extremes of 0.001 and 0.01 millimeter, and the length to average about 0.02 millimeter, with extremes of 0.01 and 0.08 millimeter. It will be seen that they are about five to ten times as long as wide. These microlites are very commonly free from inclosures, but perhaps more frequently inclose minute magnetite grains, or octahedral crystals of the same. The plagioclase microlites and laths vary extremely in size and form. In the majority of cases their form is either distinctly microlitic or, at least, slender lath shaped and minute (5, 14). When very small, the customary twinning is not easily distinguishable, but in the larger and broader individuals polysynthetic twinning is strongly in evidence. Interspersed with these slender plagioclases are others with short, rectangular forms that sometimes show twinning and sometimes do not. In a few rocks these rectangular forms are very numerous, and partially or almost completely supplant the lath form (11, 19, 21). Still larger plagioclases of rectangular form connect these rectangular plagioclases of the groundmass with the phenocrysts, so that a sharp discrimination is not always possible. Fluidal arrangement of all these groundmass ingredients is more or less conspicuous in all thin sections.

Intermediate stages between andesites of this type and the next are very common, and are mostly included in those listed under the following type. In one specimen, however, No. 18, collected about one mile southwest of the base of Red Cone, we have what is common, namely, a transition to the holocrystalline type. In the thin section from this rock there appears to be very little glass, but the appearance of dust-like globulitic material between the abundant feldspars of the groundmass indicates the presence of more glass than is at first apparent.

HYPOCRYSTALLINE TYPE OF ANDESITE.

This may fairly be said to be the normal type of Crater Lake andesites; at least, it is more abundantly represented than any other. It may be divided into two subtypes, which, though united by numerous connecting links, are upon the whole readily distinguished. In the hand specimen, however, this distinction between the two subtypes can not be made. Neither can the two be readily distinguished from the hyalopilitic type except in thin section. Taken as a whole, they are decidedly dark-colored rocks with a basaltic look, but the darker varieties distinguish themselves by the relative prominence of the plagioclase phenocrysts. Not a few are as dark as the darkest of the hyalopilitic andesites, but they lack the glossy luster common to some of that type. The average color is naturally lighter than in the hyalopilitic type, as they are more decidedly crystalline. In fact, not a few included under both of the two subtypes have a gray or even a light gray or drab color, break with rough fracture, and approach to the holocrystalline andesites. The pyroxenes, as usual, are inconspicuous and have a slightly resinous luster with green to brown colors.

HYPOCRYSTALLINE ANDESITE, SUBTYPE A.

This variety includes the following specimens: Nos. 22, 23, 24, 25, 26, 27, 28, 29 30, 31, 32, 33.

The groundmass of these rocks, as seen under the microscope, is very dense. It is crowded with microlitic crystallizations similar to but more abundant than those in the hyalopilitic groundmass. Glass is probably always present, impregnating the whole, but, with one or two exceptions (26, 28), it is not at all conspicuous. In the two exceptions, which are rocks connecting this type with the preceding, the glass is readily recognizable and has a distinct brown color; otherwise the glass base appears to be almost colorless. As stated above, in discussing the plagioclase phenocrysts, these rocks, with a small amount of colorless glass base, are very apt to contain clear brown glass inclosures in the plagioclase. The marked feature of this subtype A, as distinguishing it from subtype B, is the presence of innumerable minute plagioclase microlites with their customary fluidal arrangement. These microlitic plagioclases are mostly very minute, being often no larger than the augite microlites (26). The larger, squarish, or short-rectangular plagioclase crystals, with and without twinning striæ, that are to be seen commonly in the groundmass of the preceding type, are usually conspicuously absent. Hence the contrast between the plagioclases of the groundmass and of the phenocrysts is very pronounced, as connecting types are absent. In one or two specimens the appearance of faintly developed allotriomorphic feldspar (27, 29) connects this type with the holocrystalline andesites.

In the finest-grained varieties the plagioclase microlites are hardly discernible in white light. In such rocks the groundmass presents a dirty-brown or grayish-brown and minutely granular appearance, owing to the development of thickly crowded augite microlites, which are interspersed with minute grains and octahedral crystals of magnetite. The brown color is doubtless due in part to the glass base, and in part also to the presence of brownish globulites. Globulitic forms are, however, by no means as common or abundant as in the hyalopilitic type. On the other hand, both magnetite and augite in microlitic form are much more abundant in this type of andesite. The augite microlites are, as a general thing, not as sharply crystallized, although they do not differ greatly in size from the similar microlites in the hyalopilitic andesites. As the groundmass becomes more distinctly crystalline the size of these microlites tends to become larger and the form less sharp.

A few crystals of apatite of a brownish color measuring 0.1 millimeter in length and 0.015 millimeter in width were noticed. They are faintly pleochroic, with the customary absorption $E>O$.

Hypersthene in two generations—one in short, stout, and relatively large crystals, the other in slender prisms of much smaller size—are usually to be seen, but the distinction between the two is not as well defined as is the case mentioned in the hyalopilitic type.

In all but one case (33) these andesites appear to be very fresh, the alterations being hardly more than iron stains. In the one case referred to, the groundmass has undergone considerable alteration, which has attacked mainly the glass base and the augite microlites. The decomposition products are carbonates and a nearly homogeneous greenish substance which, in polarized light, appears to be formed of extremely minute scales that polarize light strongly. This green substance appears to be delessite.

The groundmass of subtype A corresponds closely to what Rosenbusch calls the pilotaxitic type of andesites, in that it may be described as a densely felted aggregate of plagioclase and augite microlites impregnated to a more or less extent with an inconspicuous glass base.

HYPOCRYSTALLINE ANDESITE, SUBTYPE A.

This variety of hypocrystalline andesites is represented by the following specimens: Nos. 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, and 58. It is a more abundant type, therefore, than is subtype A. As above stated, these andesites do not differ materially in the hand specimen from the subtype just described. Under the microscope the chief distinction lies in the comparative suppression of the distinctly microlitic plagioclase and in the greater abundance of the larger and broader feldspars that are not always to be sharply distinguished from the phenocrystic plagioclases. In this subtype the rock also is strongly inclined to develop allotriomorphic feldspar, and in this way, as well as in the development of more and more lath-shaped and broad rectangular-shaped feldspars, to pass into the holocrystalline andesites.

Those specimens that are transitional to subtype A (40, 43, 47, 49, 53, 54) have plagioclase laths very abundantly developed, but these are usually so much larger than the microlitic feldspars above described that they may hardly be designated as microlites. At the same time the augite microlites become larger and lose their sharp outline, and glass is hardly distinguishable. Other specimens, transitional to the holocrystalline andesites of the third type, show the development of a small amount of allotriomorphic plagioclase or quartz and contain a great amount of the rectangular feldspar forms (50, 52). It even happens that both these tendencies are manifest in the same rock (54), so that numerous small plagioclase laths in fluidal arrangement occur with a rather vague paste of allotriomorphic material.

The more normal members of this type, although subject to considerable variation in size and relative abundance of the component minerals, as well as in their structural arrangement, may be said to contain numerous phenocrysts of hypersthene and augite, and especially of plagioclase, embedded in a hypocrystalline, or at most very finely crystalline groundmass of plagioclase, augite, and magnetite, with probably a little hardly distinguishable colorless glass base. The glass base may be presumed to be present on account of the presence of a little brownish globulitic matter in the interstices between the feldspars. The augite of the groundmass rarely has as sharp forms, and is also rarely as small as in the two already described types. In a number of the thin sections studied it has a granular or roughly prismatic granular habit. The sharpness of outline seems to disappear almost regularly with the increasing size of the grain of the groundmass. The plagioclase of the groundmass is the most fluctuating ingredient both as to amount and as to size and habit. In some the slender lath-form, in others the short-rectangular habit predominates. The color of the groundmass is in most cases lighter than in subtype A, owing to the greater coarseness of grain and to the scarcity of glass. These andesites even more than those just described possess the strongly felted structure characteristic of the so-called pilotaxitic groundmass of Rosenbusch.

Mr. Diller has briefly described a hypersthene-andesite from the later lavas of Mount Shasta, in California,[a] that is almost identical with several of the Crater Lake andesites included in subtype B. The resemblance extends both to the groundmass and to the phenocrysts of plagioclase, hypersthene, and augite. It would, in fact, be impossible to tell from the thin section alone from which of the two volcanic areas this rock came. This andesite from Mount Shasta is No. 87 of the Educational Series of Rock Specimens collected and distributed by the United States Geological Survey, and was collected at Horse Camp, near the timber line upon the western slope of the mountain.

Another well-known hypersthene-andesite that resembles this type as far as the groundmass is concerned is the rock from Buffalo Peak, Park County, Colo., described by Whitman Cross.[b] This rock is No. 86 of the above-mentioned series. It differs considerably from all the Crater Lake andesites, not only of this but of other types, in the much greater abundance of the hypersthene and augite phenocrysts.

HOLOCRYSTALLINE TYPE OF ANDESITE.

The following specimens are placed under this type: Nos. 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, and 74. These are mostly light-gray rocks with comparatively rough fracture and with relatively inconspicuous plagioclase phenocrysts. A few specimens of darker color are not thoroughly characteristic of the type.

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[a] Bull. U. S. Geol. Survey No. 150, 1898, p. 227.

[b] Idem, p. 224.

Under the microscope these andesites do not differ very materially in appearance from those of the hypocrystalline type, when viewed in white light, except that they are much lighter in color and are entirely free from globulitic matter. Between crossed nicols, however, there is a marked difference between these andesites and all the preceding types. This difference is to be seen in the groundmass. The colorless constituents are of two distinct kinds, first, plagioclase laths not markedly different from the similar laths in the other andesites; and, second, a sort of residual product of crystallization occurring in irregular, allotriomorphic patches that have a poikilitic appearance, owing to crowded inclusions of the other groundmass ingredients. These patches vary considerably in size and in conspicuousness, but in general are from 0.2 to 0.5 millimeter in diameter. They do not show polysynthetic twinning, but very often possess a more or less undulous extinction. They are quite distinct from the plagioclase laths which lie embedded in them and appear to play the rôle of a glass base. The individual patches show usually simultaneous extinctions and are bounded only by meeting other similar patches.

This allotriomorphic material is in some cases undoubtedly quartz; in others it is probably feldspar. It was proved to be quartz in Nos. 63, 66, 71, and 73 by its slightly higher refractive power as compared with adjacent feldspar and by its giving a positive, uniaxial image in convergent polarized light. It is considered to be sometimes feldspar for the following reasons: First, failure to show uniaxial images; second, occasional undulous extinction; third, some of the plagioclase laths have allotriomorphic extensions that extinguish with the outer part of the lath and resemble these patches (63, 64); fourth, in a few of these andesites the lath-shaped plagioclase is nearly missing, so that the groundmass is almost entirely composed of these patches, except for the inclosed augite microlites and magnetite grains. If in this last case all this material were quartz, it would give a rock far too acidic in composition to be classed as an andesite, whereas the close association and resemblance between all of these rocks make it impossible to separate any one of them from this family.

The more characteristic of these holocrystalline andesites have a great abundance of well-defined plagioclase laths with fluidal arrangement, as well as innumerable augite microlites and octahedral crystals and grains of magnetite embedded in a base of these allotriomorphic patches of feldspar and of quartz (60, 61, 66, 71, 74). The augite microlites are, as a rule, somewhat larger and not quite so sharply developed as is the case in the other andesites. The phenocrysts of plagioclase, hypersthene, and augite differ in no essential respect from the descriptions given for all the Crater Lake andesites. Fig. *C* of Pl. XVI (p. 98) gives a fair idea of the allotriomorphic patches that characterize these holocrystalline andesites.

The presence of quartz in the groundmass of these rocks suggests a much more acid rock than the chemical analyses of Crater Lake andesites given elsewhere in these pages allow. As the only analysis made of this holocrystalline type is of No. 68, which is not thoroughly representative, inasmuch as the allotriomorphic patches are not very well developed, it will be of interest to compare these rocks with a similar rock collected by Mr. Diller and alluded to by Mr. H. W. Turner in his article on the Age and Succession of the Igneous Rocks of the Sierra Nevada.[a] The rock in question was taken from Crater Peak, California (Lassen Peak quadrangle), and is No. 1829 of the Cascade Range collection. Mr. Turner does not describe the rock, but he refers to it as a pyroxene-andesite, and gives the chemical analysis made by W. F. Hillebrand.[b] This analysis will be found repeated on page 94 of this paper. Through the kindness of Mr. Diller the writer was enabled to study a thin section of this Crater Peak andesite and to compare it with the thin sections of the rocks here under discussion. Without any noticeable difference it appears to be identical with the Crater Lake holocrystalline type of andesite. This is true not only of the groundmass, with its allotriomorphic patches inclosing plagioclase laths and augite microlites, etc., but also of the phenocrysts. It will be seen, in comparing the analysis with the analyses of other andesites from Crater Lake, that this contains between 6 and 10 per cent more silica. It is, in fact, closely analogous to the dacites, such as, for instance, those from Lassen Peak, analyzed by T. M. Chatard and W. F. Hillebrand.[c] It is highly probable, therefore, that these andesites are, in part at least, dacites, although no well-defined quartz is to be seen in them.

No. 198 probably belongs with the holocrystalline andesites, but owing to extensive alteration its characteristics are not readily made out. The groundmass consists of much homogeneous-looking chloritic matter, with rather faint lath-shaped plagioclase and not a little allotriomorphic, colorless material that is probably feldspar. The magnetite has been altered to leucoxene and the pyroxenes of both the phenocrysts and of the groundmass to chlorite. The phenocrystic plagioclases are partially altered to carbonates and probably to kaolin. A good deal of quartz is to be seen in distinct grains, two or three of which are quite large, while the rest occur in bunches of allotriomorphic grains. As this is the only andesite from Crater Lake that shows well-defined quartz, this mineral is in this case probably secondary in origin.

These holocrystalline andesites, as is the case with the other types, are widely distributed over the Crater Lake area. There may be some significance in the fact that six out of a total of fifteen are situated at the water's edge; that is, a large proportion of them belong to the oldest lava flows exposed. No. 63, which comes from the basaltic cone called Crater Peak, south of the lake, is taken from an ejected fragment, and was doubtless torn loose from a deep-lying rock below.

[a] Jour. Geol., Vol. III, 1895, p. 410. [b] Idem, p. 407. [c] Bull. U. S. Geol. Survey No. 150, 1898, p. 218.

DACITIC TYPE OF ANDESITE.

This fourth type of andesite is intermediate between the andesites and dacites, but seems to possess characteristics that ally the rocks here included more closely with the andesites than with the dacites. It is possible that a chemical analysis would place one or two of them in the list of dacites.

Of the six specimens placed in this group, three (75, 76, 77) have the dacitic features particularly prominent. The groundmass in these three consists very largely of a nearly colorless glass in which lie myriads of the extremely minute rod-like augite microlites characteristic of the glassy dacites (77). In two (75, 76) the groundmass consists of somewhat larger microlites of the same mineral inclosing minute black specks of magnetite, or possibly of globulites, suggestive rather of the andesites. In addition to these augite microlites very slender feldspar microlites, as well as a few other larger and broader plagioclase crystals, are sparingly developed. The glass base is rendered dark looking, especially in No. 76, by globulitic inclusions and by the presence of a very little magnetite. In Nos. 76 and 77 occur deep rusty-brown and somewhat granulated spots that tend to form around the pores and also to some extent around the plagioclase phenocrysts. The pores are apt to contain a little tridymite, partially or entirely filling them. These darker, iron-rusted spots bear a slight resemblance to the spherulitic growths in the dacites, but do not appear to possess radiated structure.

The three other specimens (78, 79, 80) are similar, so far as the augite microlites are concerned; but they contain little or no glass base, instead of which there is to be seen much more abundant plagioclase laths, as well as squarish or short rectangular feldspars with undulous extinction, or, rather, with zonal structure but no twinning; likewise small irregular or allotriomorphic colorless shreds of feldspar or, perhaps, of quartz.

The phenocrysts in these six rocks are not essentially different from those in other andesites (brown glass inclosures, abundant in plagioclase of 75). Hypersthene in two generations—the older in short, stout, and relatively large crystals, the younger in small, long, and slender prisms—is clearly developed in No. 78.

The last three rocks, without perceptible glass, are very light colored in the hand specimens while the glassy varieties are much darker.

UNCERTAIN TYPES.

With the exception of those of Wizard Island, the andesite lavas of Crater Lake do not appear to be distributed in accordance with the types herein described, but the various types occur over all the area, among both the older and the younger andesite flows. In the case of Wizard Island a partial exception may be noted in that the more thoroughly crystalline types are almost wanting. The andesites of Wizard Island are unusually black and basaltic-looking, and contain much brown glass. Occasionally they are stained a deep brownish red by iron oxide (87, 89). Some of the more glassy black portions seem to have cracked in the process of cooling, the cracked surfaces being left with a decided gloss. This was particularly noted on a specimen collected by the writer from a large block in the crater on the summit of the island.

Of the thirteen rocks from Wizard Island studied in thin section, five are of the hyalopilitic type; six of the hypocrystalline type, subtype A; two of the same type, subtype B; while only one, and this a somewhat doubtful one, is of the holocrystalline type.

Among the andesites collected by Mr. J. S. Diller on Wizard Island are ten, Nos. 81 to 90, inclusive, the exact location of which is not given. Of these No. 83 has no corresponding thin section. The others do not vary greatly from the other specimens from this island enumerated above. Nos. 82, 86, and 88 are placed in the hypocrystalline type, subtype A; or possibly 82 might equally well be put in the hyalopilitic type. No. 84 is a hyalopilitic andesite. Nos. 88, 89, and 90 are so strongly impregnated with red hematite powder as not to be easily classified. They are probably of the hypocrystalline type, subtype A. No. 85 is a holocrystalline andesite with basaltic appearance. It contains small augite prisms, too large to be called microlites, and also considerable allotriomorphic feldspar in the groundmass, but no poikilitic patches such as occur in most of the holocrystalline andesites.

At the head of Steel Bay, just to the east of Llao Rock, occurs an andesitic rock close to the dike from which No. 96 (page 93) was collected. This andesite is represented by No. 91, and is a nearly holocrystalline rock with very abundant phenocrysts and with a groundmass that resembles that of some of the basalts, notably Nos. 176 and 177 of the porphyritic interstitial basalts. The main features that distinguish this rock from the basalts are the absence of olivine and the very marked porphyritic development. This andesite does not closely resemble any other andesite from Crater Lake, at least not close enough to justify putting it in any of the above-described types. It more closely resembles the basalts than any other rock collected on or within the crater rim.

ANDESITE DIKES.

With the exception of two dikes under Llao Rock all the dikes that cut the walls surrounding the lake belong, as far as may be judged from the specimens collected, to the andesites.

Two specimens were collected from the rather large dike that runs diagonally down from The Watchman to near the lake level. These two specimens (92 and 93) may be classed with the hypocrystalline andesites, subtype B. The phenocrysts do not present any specially distinctive features, but the groundmass of the two specimens shows two extremes. No. 92 is relatively coarse grained and presents a transition to the holocrystalline type, in which, however, the allotriomorphic patches are suppressed. It is further characterized by the presence of unusually abundant plagioclase laths of a very uniform and fairly large size. No. 93, on the other hand, may be considered as transitional to subtype A in that the plagioclase laths sink to minute size. But this groundmass also contains a great many squarish or short rectangular feldspars that suggest an affinity with the dacites.

From the upper part of the dike that lies between Glacier Peak and The Watchman No. 94 was collected. In the hand specimen this presents a strikingly uniform appearance. It has a rather light-gray color, is very porous, and at a casual glance appears to be free from phenocrysts. On the contrary, phenocrysts are very abundant, as in thin section they appear to form about one-half of the entire mass. This is, in fact, a thoroughly characteristic andesite and is very strongly porphyritic, with great contrast between the phenocrysts and the groundmass. Plagioclase, hypersthene, and augite are all abundant. The pyroxenes occur both in sharp crystals and in nests of granular individuals. The feldspar occurs in two distinct types; in the larger many-faced forms having the customary glass inclusions, and in the smaller rectangular forms. From the character of the groundmass this may be considered a typical illustration of the hypocrystalline type, subtype A, characterized by the abundance of minute plagioclase microlites.

The analysis of this rock is given on page 94. It indicates that this is thoroughly representative of the Crater Lake andesites.

Under the north end of Llao Rock occurs a dike of which No. 95 is a sample. It very closely resembles the rock just described. Under the microscope it appears that the phenocrysts are not quite so abundant and not so uniform in size. The groundmass contains considerable allotriomorphic feldspar, which to a certain extent hides the microlitic plagioclases. It belongs, with the above-described rock, to subtype A of the hypocrystalline andesites.

At the head of Steel Bay, a little to the east of Llao Rock, occurs a dike from which No. 96 was collected, which shows under the microscope a very pretty development of the hyalopilitic structure. Very abundant phenocrysts of the customary characters lie embedded in a groundmass consisting of a deep-brown glass that appears to impregnate a loosely felted aggregate of slender augite and plagioclase microlites. The glass base is free, or nearly free, from globulitic matter, but contains, in addition to the above-mentioned microlites, octahedral crystals and grains of magnetite.

On the east side of the lake are to be seen two dikes near Sentinel Rock. One of these (33) occurs exactly below Sentinel Rock and the other (21) about a third of a mile to the northeast. Both of these rocks have already been referred to in connection with the description of the andesites. No. 33 belongs to the subtype A of the hypocrystalline andesites and No. 21 to the hyalopilitic type. As these types have been fully described above, a repetition here is hardly necessary.

In concluding the description of the andesites in dike form, we may note that many of the various types found in the andesite flows are repeated in the dikes, while no markedly different types have been met with in the dike andesites.

CHEMICAL ANALYSES OF ANDESITES.

The analyses given in the following table are all of Crater Lake rocks, with the exception of the last, which is from Crater Peak, California, and is given for comparison. The analyses were made by the chemists of the United States Geological Survey. The numbers at the heads of the columns are the specimen numbers.

Analyses of Crater Lake andesites.

[Analyses by H. N. Stokes, except of 1829.]

	25.	26.	31.	68.	94.	1829.
SiO_2	59.39	60.98	58.48	62.09	60.09	68.12
Al_2O_3	18.45	17.82	17.85	17.03	17.85	16.24
Fe_2O_3	1.79	1.83	2.67	2.38	2.03	1.26
FeO	3.90	3.33	3.29	2.69	3.45	2.08
MgO	3.13	2.67	3.61	3.08	3.50	1.35
CaO	6.29	5.73	6.81	5.65	6.28	3.80
Na_2O	4.29	4.26	3.77	4.10	4.17	3.89
K_2O	1.29	1.43	1.23	1.67	1.31	2.54
H_2O-	.10	.13	.34	.04	.12	.40
H_2O+	.42	.45	.86	.13	.26	....
TiO_2	.41	.71	.69	.65	.54	.25
ZrO_2	None.	None.	None.	None.	None.	....
CO_2	None.	None.	None.	None.	None.	....
P_2O_5	.22	.17	.24	.19	.23	.14
SO_3	None.	None.	None.	None.	None.	....
Cl	Trace.	Trace.	Trace.	Trace.	Trace.	....
F	Undet.	Undet.	Undet.	Undet.	Undet.	....
S	None.	None.	None.	None.	None.	....
Cr_2O_3	None.	None.	None.	None.	None.	None
NiO	None.	None.	None.	None.	.05	....
MnO	Trace.	Trace.	Trace.	Trace.	Trace.	.10
BaO	.05	.06	.05	.07	.05	.09
SrO	.04	.05	.05	.07	.05	.02
Li_2O	Trace.	None.	Faint tr.	None.	Faint tr.	Trace.
Total	99.77	99.71	99.87	99.84	99.98	100.28

NOTE.—O=Cl.

No. 25. Hypersthene-andesite, hypocrystalline type, subtype A, west edge of Wizard Island. See page 86.

No. 26. Hypersthene-andesite, hypocrystalline type, subtype A, rim, just south of The Watchman. See page 86.

No. 31. Hypersthene-andesite, hypocrystalline type, subtype A, at the lake level under Llao Rock. See page 86.

No. 68. Hypersthene-andesite, holocrystalline type, Palisades, under Round Top on the northeast portion of the rim. See page 88.

No. 94. Hypersthene-andesite, hypocrystalline type, subtype A, from a large dike entirely transsecting the rim between Glacier Peak and Llao Rock. See page 86.

No. 1829. Of the Cascade Range collection, a rock called by Mr. Turner a pyroxene-andesite, holocrystalline type. From Crater Peak, California. Analysis by W. F. Hillebrand, taken from Bull. U. S. Geol. Survey No. 60, p. 157, No. 19. See page 90.

It is a little surprising and also unfortunate that out of five specimens of andesite selected by Mr. Diller for chemical analysis four should turn out to belong to one type, and this not the most common one. It is surprising, because these specimens were selected with a view to representing typical occurrences. As the selection was made before an opportunity was given for microscopic study, it was impossible to distinguish the different types from the hand specimen alone.

SECRETIONS IN ANDESITES.

In a number of the andesite rocks at different localities are found inclosures or nodules that appear to be secretions of the more basic minerals. Sometimes these inclosures have more or less roundish form and are evidently inclosed in the sense that they are not literally formed in place. This is particularly evident in a specimen (97) collected in 1883 from the southern rim of the crater. The rock itself, of which no thin section has been made, has a nearly black groundmass—which is probably hyalopilitic—inclosing numerous and very conspicuous plagioclase phenocrysts. Embedded in this rock is a roundish mass 2 or 3 inches in diameter from which the andesite appears to have shrunk away in cooling as though from a foreign inclosure. The inclosure is blackish gray, compact, without phenocrysts, and slightly porous. It has a very basaltic look.

In thin section this specimen is fairly characteristic of most of the inclosures. It consists of a deep clear-brown glass in which lie in loosely felted arrangement slender and very sharply defined laths of plagioclase and equally slender but not always so sharply cut prisms of hypersthene and augite; also a little magnetite in the customary octahedral form. Hypersthene is more abundant than augite, but both are much more abundant than is usual in the andesites. The two pyroxenes appear to form about as large a percentage of the rock as does the plagioclase. Parallelism of growth between the augite and hypersthene is common. The length of these pyroxenes is often ten times as much as the width. The plagioclase is rather simply twinned with but two or three bands and shows large extinction angles. They have square cross section with diagonal extinction. Phenocrysts are entirely wanting.

Fig. *A* of Pl. XVI presents a photograph of this thin section in polarized light and Fig. *D* of Pl. XVI a photograph of thin section of No. 9 in white light, showing both the secretion and the inclosing hyalopilitic andesite.

Analogous to the above are No. 9, from the path that leads from the camp ground down to the water's edge; No. 16, from Kerr Notch, at the head of Sand Creek; and No. 75 from near the road on Anna Creek. These three specimens consist of small inclusions in rather glassy andesites, the first two of the hyalopilitic and the last of the dacitic type. The inclusions form only a small part of the thin section in each case. They do not, however, appear to be foreign to the rock. On the contrary, the junction of the secretion with the surrounding andesite is such as apparently to preclude the idea of an entirely separate origin. The clear glass of the secretion is exactly of the same color as that of the main rock and the junction is not sharp, but the ingredients seem to have grown from the secretion out into the surrounding rock mass. The first two contain phenocrysts of plagioclase, and to a less extent of hypersthene similar to the corresponding phenocrysts in the inclosing andesite. In some cases one of these plagioclase phenocrysts appears to belong about equally to the secretion and to the main mass. In No. 16 the inclusion greatly resembles an enlarged area like those one frequently meets with in the more glassy andesites of Crater Lake, where a deep and clear brown glass, free from the customary microlites, occurs, filling the space between two or three adjacent phenocrysts.

No. 98 is one of these inclusions from a large bowlder between Sun Creek and Sand Creek. The rock in which this is inclosed (76) belongs to the dacitic type of andesite, and has already been described. This inclusion contains large, characteristic plagioclase phenocrysts that are crowded with the usual inclusions, and that present clear margins; it contains also phenocrysts of hypersthene. The glass is stained a very deep red with ferritic matter.

Nos. 99 and 100 are secretions in the above-described hypocrystalline andesite (40) found at the spring near the camp ground. They both resemble No. 97 in being entirely without phenocrysts and in having the same felted structure and the same composition as that rock, but they differ materially in that crystallization appears to have progressed until but little glass remains, and this little is nearly colorless and not readily discernible. In fact, these two inclusions were at first taken for basalt inclosed in the andesite, and were it not for numerous intermediate stages between these and the more evident secretions the determination as basalt might hold. Other cases of secretions resembling basalts are mentioned in connection with the description of the dacites of Crater Lake.

PLATE XVI

PLATE XVI.

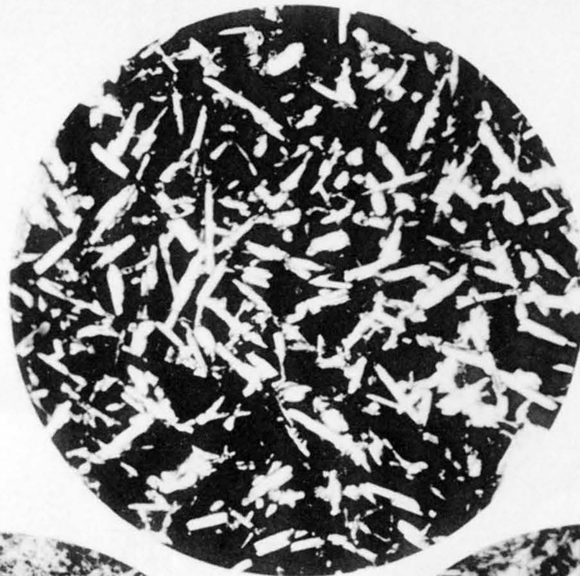
THIN SECTIONS OF ANDESITE.

FIG. *A*.—Secretion in andesite from the southern rim of the crater. Magnified 48 diameters. Specimen No. 97. A photomicrograph in polarized light with crossed nicols. The secretion consists of a deep-brown glass in which lie well-defined laths of plagioclase and equally slender prisms of hypersthene and augite; also a little magnetite. The pyroxenes can not well be distinguished from the plagioclase in the photomicrograph. See page 96.

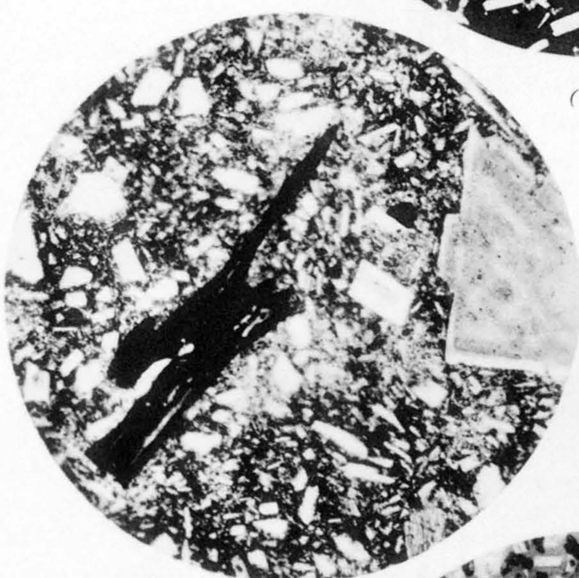
FIG. *B*.—Andesite of the hypocrystalline type, from Cathedral Rock. Magnified 20 diameters. Specimen No. 45. A photomicrograph in white light. The ragged black crystal is a brown hornblende almost completely altered through resorption to a black aggregate of magnetite and augite. The section also shows two generations of plagioclase. The large phenocryst on the right represents the oldest generation with glass inclusions. For description see page 83.

FIG. *C*.—Andesite from the water's edge at the head of Sun Creek. Magnified 48 diameters. Specimen No. 73. A photomicrograph in polarized light with crossed nicols. Illustrates the third or holocrystalline type of andesite and is characterized by the presence of allotriomorphic patches of feldspar, which appear as light spots in the photomicrograph. See page 89.

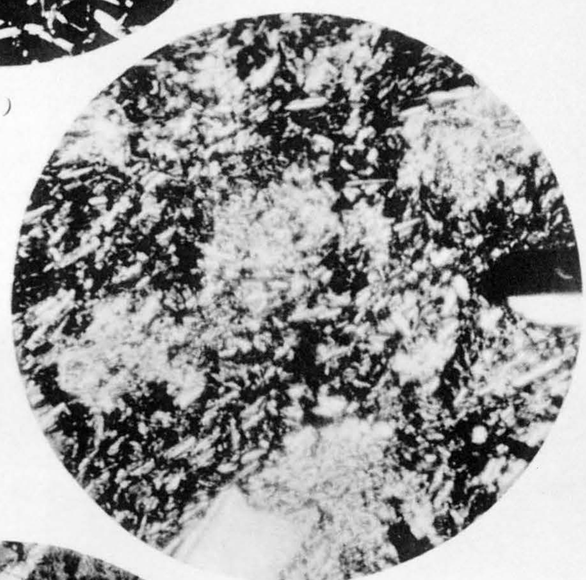
FIG. *D*.—Andesite from the path leading from the camp ground to the water at Eagle Cove. Magnified 48 diameters. Specimen No. 9. Shows the junction between a hyalopilitic andesite on the right and a secretion in the same on the left. The secretion consists of a deep-brown glass and slender laths of plagioclase and prisms of hypersthene and augite; also a little magnetite. See page 96.



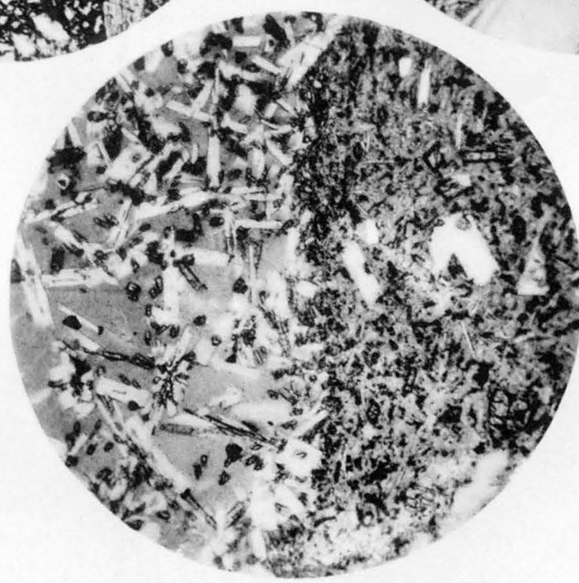
(A)



(B)



(C)



(D)

THE MERIDEN GRAVURE CO.

In No. 25, a hypocrystalline andesite from Wizard Island, is to be seen an inclosure that may with more probability be taken for basalt. This consists of small, irregular, and apparently isolated grains of augite, or possibly of hypersthene—the distinction is not certain in this case—that extinguish simultaneously over considerable areas. The spaces between these grains are filled with short and not very sharp plagioclase laths.

A rock collected by the writer from the bottom of the crater on Wizard Island (2017, 4 of the private collection of the writer) seems to throw some light on these secretions. In the hand specimen it consists of a rather compact and nonporous gray andesite, with irregular, lighter gray patches scattered promiscuously through it. In thin section these lighter patches are seen to be holocrystalline, with a groundmass composed of plagioclase, augite, and magnetite. The plagioclase is largely in the form of short laths, but between these laths the same mineral appears in allotriomorphic form, but not in poikilitic patches. The darker portions of the rock do not appear to differ from the lighter part, except that the allotriomorphic feldspathic part of the groundmass is replaced by a deep clear-brown glass. That several such alternations in the groundmass may occur within the area of a thin section makes it more likely that the apparent inclosures, in which brown glass is so very conspicuous, are only local differentiations in a common magma.

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 tufaceous 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° in No. 101, 31° in No. 104, 30° in No. 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°, which 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° = 43 per cent An = basic andesine.
2 = −21° = 53 per cent An = labradorite.
3 = − 5° = 30 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 $+29°$ instead of 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.

HORNBLENDE.

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 rôle 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. $\mathfrak{c}$ = dark olive green with usually a trace of brown, $\mathfrak{b}$ = dark greenish brown, $\mathfrak{a}$ = lemon yellow to greenish yellow. At times the rays vibrating parallel to $\mathfrak{c}$ are almost a pure deep olive green. In any event brown is most conspicuous in the rays vibrating parallel to $\mathfrak{b}$. This hornblende has a very unusual absorption, in that the absorption parallel to $\mathfrak{b}$ is greater than that parallel to $\mathfrak{c}$, thus, $\mathfrak{b}>\mathfrak{c}>\mathfrak{a}$. In some cases there appears to be very little difference in color and absorption between $\mathfrak{b}$ and $\mathfrak{c}$, 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: $\mathfrak{a}$, light greenish yellow; $\mathfrak{b}$, greenish brown; $\mathfrak{c}$, dark greenish yellow; and $\mathfrak{b}>\mathfrak{c}>\mathfrak{a}$.

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, $\mathfrak{c}$ = dark brownish red, $\mathfrak{b}$ = reddish brown, $\mathfrak{a}$ = yellow, with $\mathfrak{c}>\mathfrak{b}>\mathfrak{a}$. The absorption is normal. The deep brownish-red color of the rays vibrating parallel to $\mathfrak{c}$ are very striking and characteristic. This color is

[a] Mikroskopische Physiographie, 3d edition, Vol. I, 1892, p. 558.

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 hypersthenes, 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.

DISTRIBUTION AND DESCRIPTION OF DACITE MASSES.

LLAO ROCK FLOW.

As far as may be judged from the few specimens collected from this most conspicuous of the Crater Lake dacite flows, the Llao Rock mass shows three quite distinct varieties of dacite—namely, vitrophyric, lithoidal, and spherulitic dacite.

VITROPHYRIC DACITE.

This variety was collected from the extreme southern edge of the lava flow, where it is necessarily very thin. It is represented by Nos. 101 and 102. The hand specimens present the appearance of a perfectly fresh vitrophyre in which the glass base, which constitutes at least four-fifths of the entire mass, has a dark, greenish-gray color. In this glass base are inclosed numerous phenocrysts of plagioclase that measure not over 1 to 2 millimeters, and that are white and glassy and show hardly a trace of cleavage. In addition to these are a very few minute, deep-brown to green and black, resinous-lustered crystals that are hardly to be seen without a magnifying glass, and that, in thin section, prove to be usually hypersthene or hornblende. There are also to be noted a few angular fragments, compact, grayish brown and dull lustered, measuring one-quarter inch to one inch or more in diameter. These are referred to later under the head of nodular secretions. This rock is more or less cracked in different directions owing to shrinkage in cooling. The rock parting along these cracks, which sometimes gap, breaks into very smooth flat surfaces that have a distinct gloss. Otherwise the fracture is rather rough or small-concoidal, owing to the presence of the abundant plagioclase phenocrysts. This vitrophyric dacite may also be streaked by more or less parallel bands of grayish-looking pumice, as may be seen in a specimen collected by the writer on the same spot. (No. 2013.1 of collection of H. B. Patton.)

In thin section the glass base appears to be clear and colorless and to be crowded with very sharp and straight and remarkably even-sized microlites of augite that measure 0.003 millimeter wide by 0.02 to 0.04 millimeter long. (See fig. A of Pl. XVIII, p. 132.) These microlites are too small to show any color, but the strong refraction is evident, as well as double refraction and an extinction angle up to 45°.

There are also to be seen a very few opaque curved black trichites. The straight, colorless augite microlites appear to be the same as are to be seen sparingly developed in a thin section prepared by the United States Geological Survey from the rhyolitic perlite of the Yellowstone National Park.[a] They still more closely resemble in size, appearance, and numbers the straight colorless microlites in the dacite from Lassen Peak, California, No. 82 of the above-mentioned Educational Series.[b] The close resemblance between the Llao Rock dacite and this dacite from Lassen Peak will be again referred to in these pages.

A few feldspar microlites occur in No. 101, but almost none in No. 102. These are in part lath-shaped plagioclase with very small extinction angles, but mainly short-rectangular to square, untwinned feldspar that usually extinguishes nearly parallel to the sides. In No. 101 was seen a nearly rectangular section of feldspar that was not larger than nor even as large as many of the feldspar microlites (0.05 millimeter long), in the center of which was a brown-glass inclusion with sides parallel to the crystal edges and occupying at least one-third of the whole crystal, itself inclosing a comparatively large air bubble. The extinction angle measured to the longest side was 18°. No twinning was apparent. A reproduction of this crystal may be seen in fig. *G* of Pl. XIV, p. 76.

Fluidal structure, which is hardly to be seen in the hand specimen, is very conspicuous in the thin section, owing to the more or less parallel arrangement of the microlites which occur in flowing lines lapping around the phenocrysts of plagioclase, hypersthene, and hornblende, and of accessory magnetite and apatite. Hypersthene is scarce and hornblende still more so. The latter occurs mainly in very small needles and only occasionally in crystals comparable in size with the hypersthene. In one instance a small crystal of hornblende with sharp crystal forms was observed clearly inclosed in plagioclase. This is a decided exception to the rule that hornblende in these dacites is the youngest of the phenocrysts with the possible exception of augite.

The chemical analysis of No. 102 is given on page 140.

LITHOIDAL DACITE.

This rock (103) comes from the summit of Llao Rock. It consists of a light-gray, dense, and somewhat porous groundmass with thickly scattered, small, white feldspar phenocrysts, similar to those in the vitrophyric variety; it consists also of a few almost unnoticeable darker phenocrysts. It breaks with a decidedly rough fracture and does not show any fluidal structure.

In thin section the groundmass is seen to contain small plagioclase laths, similar to, but much more abundant than those mentioned as occurring in No. 101;

[a] No. 61 of the Educational Series of Rocks, described by J. P. Iddings in Bull. U. S. Geol. Survey No. 150, p. 151.
[b] J. S. Diller, op. cit., p. 217.

also a few feldspar crystallites with rectangular outlines and much more feldspathic matter that shows no distinct forms and that is not capable of absolute identification. There is undoubtedly much glass present but, being colorless, it is almost concealed by the abundant crystalline matter inclosed. In white light with weak magnifying powers the thin section has a somewhat dusty appearance. When strongly magnified this dusty matter resolves itself into minute, colorless, straight augite microlites, like those described as characteristic of the vitrophyric rhyolite, together with somewhat larger microlites of the same mineral that inclose a few very minute, black, and opaque grains—presumably of magnetite. Probably the dusty appearance is intensified by the presence of small air bubbles in the glass base. Phenocrysts occur about as in Nos. 102 and 101, with the addition of a very little augite in sharply defined and almost colorless crystals.

This can not be said to be a typical lithoidal dacite. The abundance of plagioclase microlites and the scarcity of the untwinned groundmass feldspar with square or rectangular forms cause this rock to resemble some of the more dacitic andesites of this region.

SPHERULITIC DACITE.

A specimen of spherulitic dacite, No. 108, was collected on Llao Rock in 1883. The field label accompanying the specimen does not state the exact location. In the hand specimen this is seen to consist of a nearly black glass very thickly crowded with brownish spherulites that measure from 3 to 5 millimeters in diameter. So thickly crowded are these spherulites that they often interfere and make up much more than one-half of the mass. The spherulites consist of two, sometimes three parts. The center is of a dark-gray color, and has a very dense, felsitic texture. Around this is a ring or zone about a millimeter wide, of a less dense or even of minutely porous material, and of a brownish, reddish-brown, or light grayish-brown color. Outside of this again occurs usually, but not always, the third part, dense like the central portion, and either gray in color like the center or of a deeper brown than the intermediate zone. Many of the spherulites show gapping cracks that seem to be confined to the middle zone. There is, however, no trace of lithophysal development. The inside of these cavities is rough, and of about the same color as the middle zone of the spherulites in which they lie. They do not appear to contain crystals. Upon cross fracture these spherulites have a distinct radiated appearance. The customary phenocrysts occur quite indifferently in the glassy portion as well as in the spherulites.

Under the microscope the glassy groundmass is almost identically the same as that of the vitrophyric dacite described above. The same colorless augite microlites of about the same size, 0.03 to 0.05 millimeter long by 0.003 millimeter wide, may be seen. A very slight distinction may be noted in that these augite microlites are not perfectly clear, but often have a small amount of black, opaque, dusty matter—probably magnetite—either adhering to the outside or inclosed within. Curved, black microlites were not observed. Most of the spherulites show two or three periods of growth that correspond to the different colored zones noticeable in the hand specimen. One or two appear to have had but one period of growth—that corresponding to the inner portion of the others. This inner part has a dirty-brown or grayish-brown color, lets through but little light, and shows a distinctly fibrous radiating structure. The fibers are very fine, and hardly distinguishable from each other. They polarize light feebly, and have a positive extension. Owing to the partial opacity of this central portion, the usual black cross is hardly discernible.

The portion of the spherulites that belongs to the second or intermediate zone does not seem to be as porous as the rather rough appearance in the hand specimen would indicate. It is, in fact, mostly quite solid. It appears in a light-brown color, very much lighter than the central part, and is composed essentially of distinct shreds of a colorless mineral diverging from the center outward and branching at low angles. These shreds are coarse enough to show extinction angles often quite oblique to their longer axes. They have invariably a positive extension. In polarized light they appear to continue the finer fibers of the central portion. Between the arms of the branching positive shreds occurs frequently unindividualized matter that shows feebly negative polarization—considering this substance to be also fibrous; but all the more distinctly recognizable shreds are positive.

These coarse branching shreds so closely correspond to the feldspar of the spherulites in the obsidian of Obsidian Cliff in the Yellowstone National Park, as described by Iddings,[a] and to that of the spherulites from the region of Rosita and Silver Cliff, Custer County, Colo., as described by Cross,[b] that, after studying thin sections prepared from spherulites from the latter place, the writer has no hesitancy in pronouncing these in the Llao Rock dacite as belonging to feldspar also. In their positive character they correspond to the feldspar in many of the spherulites from Custer County, Colo. The brownish color of this intermediate portion is due to the presence of brown, yellowish, and reddish ferritic matter in the form of dust particles, and occasionally in the form of minute scales. A radial arrangement of this ferritic matter is not marked.

The outer portion of these spherulites when seen in thin sections appears to be identical with the central core. It is often entirely missing, and when present does not usually envelop the whole spherulite, but appears as irregular lobes or prolongations of the same.

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[a] Seventh Ann. Rept. U. S. Geol. Survey, 1888, pp. 276–278.

[b] Constitution and origin of spherulites in acid eruptive rocks: Bull. Philos. Soc. Washington, Vol. XI, 1891, pp. 411–440.

The strings of augite microlites that accentuate the fluidal structure of the glassy part of the rock pass uninterruptedly through these spherulites, and the phenocrysts lie embedded in them as well as in the remainder of the rock, as is universally the case in such bodies. Part of the ferritic matter may be seen to arise from the further oxidation or hydration of the ore particles that adhere to the augite microlites.

The phenocrysts observed in this rock are plagioclase hypersthene, hornblende, and augite, with accessory apatite and magnetite. The order of crystallization is (1) magnetite and apatite, (2) plagioclase, (3) hypersthene, (4) augite and hornblende, (5) the spherulitic forms; to which may be added augite and feldspar microlites of the groundmass, which belong between 4 and 5. The hornblende is very sparingly developed, as is usual, but occurs in both the brownish-green and in the brownish-red varieties.

This spherulitic dacite should be compared with the very similar occurrences in the Cloud Cap flow.

In the thin section of this rock may also be seen a few small inclusions of identical nature with the inclusions of older secretions to be found in No. 102, described immediately below.

NODULAR SECRETIONS.

In the description of the vitrophyric dacite (102) from the south end of the Llao Rock flow, reference is made to inclosed angular fragments of compact, grayish-brown, dull-lustered material. In the thin section of this rock there occur three of these inclusions, the largest of which is about 6 millimeters in diameter. They are composed of a loosely felted mass of slender hornblende prisms and also of almost equally slender plagioclase laths, with a few octahedrons of magnetite. In the interstices of this felt is to be seen a brown glass that composes at most one-quarter of the mass. The hornblende and plagioclase are present in about equal amounts. The hornblende is very uniformly about 0.1 millimeter in width and from 0.5 to 1 millimeter in length; the plagioclase is about the same in width, but not quite so long. In one of these inclusions the color and pleochroism of the hornblende are almost identically the same as that of the reddish-brown hornblende that is mentioned above as occurring in many of the dacites. It is to be distinguished only by the very slender form and by its great abundance. The extinction angles in the prism zone are very small, rarely over 3°.

In another of these inclusions the hornblende has the color and pleochroism of the greenish-brown hornblende of the dacites, while in the third one the color is intermediate between the two. This change of color, corresponding as it does to the variations of color of the hornblende in the different dacites or in the same dacite, forms one of the arguments in favor of this being an older secretion. The form of this hornblende does not vary with the change of color. Usually only the unit prism is to be noted. The terminations are not often sharp. The prisms either taper out at the end, or end roughly, as though broken off.

The plagioclase is usually simply twinned, with only two or three bands visible. The largest extinction in a symmetrical section observed was 30°. These very slender laths contain long brown glass inclosures that often show the form of the host. The prisms of plagioclase and hornblende do not often interfere, but when they do it does not appear that one of these ingredients is older than the other. In addition to these lath-shaped plagioclase, this mineral also occurs in two or three comparatively large and decidedly spongiform, stout crystals that contain much colorless glass, and bits of hornblende of the same color as in the section outside of the feldspar. It is rather remarkable that this mineral should be thus inclosed in the plagioclase, inasmuch as elsewhere in these dacites hornblende belongs to the youngest of the phenocrysts. It is to be noted, however, that, as it occurs thus inclosed in plagioclase, it does not have the same sharp form as is otherwise to be seen. In fact, it presents exactly the appearance of having been formed as a secondary mineral in the feldspar.

Both hypersthene and augite seem to be missing.

There does not appear to the writer to be much doubt that these inclosures are fragments of older secretions from the dacitic magma, although the absence of the pyroxenes is hard to explain on this supposition. But the tendency for the ingredients to assume long slender forms, quite distinct from those in the rock in which they occur, appears to be very characteristic not only of this but of other secretions that will be described later as occurring in the dacites, and also of secretions in the andesites.

Fig. *A* of Pl. XVIII (p. 132) is a photomicrograph from No. 102, and shows both the secretion and the inclosing vitrophyric dacite.

Reference is made elsewhere to the resemblance between some of the vitrophyric dacites of Crater Lake and the dacite from Lassen Peak, California, of which Mr. Diller has given a brief description.[a] In this description Mr. Diller mentions and gives a photograph of angular nodules inclosed in the dacite. His description of the microscopic appearance of these inclusions, corroborated by study of the thin sections kindly loaned the writer for the purpose, discloses a very close resemblance to the inclusions from the Llao Rock dacite. In color, form, and structural relationships of the hornblende and in the occurrence of plagioclase and a small amount of brown glass the resemblance is very close. The main points of difference are these, that the Lassen Peak inclusion is coarser grained, the hornblende prisms are not so slender, and the hornblende not infrequently incloses plagioclase laths; also biotite and pyroxene and a little olivine

[a] Bull. U. S. Geol. Survey No. 150, 1898, p. 217.

and tridymite are present. The appearance of biotite in the Lassen Peak secretion is to be expected, as the same mineral occurs in the dacite itself.

GROUSE HILL FLOW.

The four specimens collected from this mass (105, 106, 107, and 108) are far from being a typical dacite. If this were the only example of this kind of rock in connection with the Crater Lake lavas the rock would naturally be classified as an andesite. As a matter of fact it partakes of the characteristics of both dacites and andesites to such an extent as to represent a thoroughly intermediate type. Taken in connection with both the andesites and the dacites of the surrounding region the dacitic characteristics predominate, so that the rock may well be called an andesitic dacite.

These four specimens are light gray or, in the case of No. 107, brown and gray streaked, rough-fracturing and slightly porous rocks with the usual small and not very conspicuous phenocrysts. Under the microscope the groundmass varies from glassy to hypocrystalline, the variations occurring in irregular streaks to be seen in the same thin section. In general the groundmass contains a good deal of crystalline matter, which consists mainly of small lath-like microlites of plagioclase, together with small, rectangular, untwinned feldspar crystallites, such as are to be found very abundantly in the more typical dacites. The plagioclase microlites are similar to those seen in the dacite of Llao Rock, but are here much more numerous and are the feature that most closely reminds one of the andesites. They are probably oligoclase, as the extinction angles are mostly very small. In addition to these feldspars may also be seen very slender and minute colorless microlites resembling the augite microlites of the Llao Rock flow, but differing in being not quite so sharp or straight, also in having a tendency to taper out at the end. They are undoubtedly augite. A small amount of black, opaque, iron oxide, distributed as minute, dust-like particles, assists the augite microlites in giving to the groundmass a clouded aspect. The brown color of No. 107 is produced by the presence of brownish and yellowish ferritic staining matter.

All four of these specimens contain plagioclase, hypersthene, augite, and reddish-brown hornblende as phenocrysts. The plagioclase has a stronger tendency than is customary in the Crater Lake dacites to become crowded with glass inclusions. Augite is more abundant than in the more typital dacites. It occurs both in sharp but small and often twinned crystals and in irregular grains. The hornblende, which belongs to the reddish-brown variety, is also somewhat more abundant than usual. In No. 106 it occurs in uncorroded crystals, on one of which the forms (110), (010), and (100) were noticed. In the others the hornblende is more or less corroded and has developed resorption rims of magnetite and augite. In Fig. *II* of Pl. XIV (p. 76) may be seen a reproduction of a crystal of hornblende in No. 105.

CLEETWOOD COVE FLOW.

This mass is one of the latest lava flows to be found on the rim of the crater. According to Mr. Diller a part of this stream was fluent at the time the summit of Mount Mazama subsided, and a portion of the stream that ran back into the pit formed by the subsiding cone may be seen at the head of the cove at the water's edge. The lava of this mass, as far as may be judged from the five specimens collected, is of two varieties, a vitrophyric and slightly spherulitic and a lithoidal variety.

The vitrophyric type is seen in Nos. 109, 110, and 111, which were collected on the crest of the rim. These appear in the hand specimens to be very glassy and to consist of mixtures of black to grayish-black and of reddish-brown glass. The reddish-brown portion is a little more abundant than the black and forms more or less continuous streaks, while the black is more frequently in the form of small, angular patches, inclosed in the former. When examined with a pocket magnifying glass the brown portions appear often porous and possess a somewhat ropy structure, while the black portions are solid. Small phenocrysts of white glassy-looking plagioclase abound as usual.

In thin section it is evident that the brownish portions result from the alteration of the black glass simply by a process of hydration of the iron contained in the glass. The fresh and unaltered parts appear in a thin section as a light-brown glass, perfectly fresh and clear, but irregularly dotted with very small colorless glass spots. This light-brown glass contains countless minute and colorless augite microlites which, in No. 109, are identically like those in the glassy dacite from the southern end of Llao Rock. In No. 111 the groundmass contains, in addition to these augite microlites, also a few plagioclase microlites. In No. 110 the augite microlites are more slender and longer, as well as more numerous, and the feldspar microlites occur in lath-shaped plagioclase, and still more conspicuously in the squarish or rectangular untwinned forms that are more especially characteristic of dacites. In all three of these there is a partial development of spherulitic forms. These occur in small reddish to brownish or yellowish spheres that very faintly polarize light and have a not very distinct radial structure.

The brown color of the rock as seen in the hand specimen is due largely to the ferritic matter contained in the spherulites, but is also due to staining of the glass in the vicinity of cracks and pores and around the spherulites.

The phenocrysts, with the exception of plagioclase, are small and very scarce. They consist of hypersthene and a very few minute, reddish-brown hornblendes (not more than three or four in a thin section). Augite is entirely wanting.

The lithoidal variety of dacite from this lava flow is seen in Nos. 112 and 113. The former has a dark-gray, compact, and dull-lustered groundmass and strongly developed fluidal structure; the latter is light gray and lusterless, but not fluidally developed. Both of these probably contain considerable glass, but in No. 112 this is partially, and in No. 113 almost entirely, obscured by devitrification products common to lithoidal dacites. In both, the augite microlites abound, but in No. 113 these are notably larger than in the other dacites heretofore described in these pages, and they are granulated by means of adhering and inclosed magnetite grains. In this rock, too, the colorless crystalline material of the groundmass is coarser than usual. Very little of it can actually be identified as plagioclase microlites. It consists, rather, of allotriomorphic shreds that may be feldspar or quartz, and that have a general elongation parallel to the fluidal planes of the rock. Small plagioclase phenocrysts abound, but other phenocrysts are very scarce. Hornblende is nearly missing and augite entirely so.

A chemical analysis of No. 113 will be found on page 140.

WINEGLASS FLOW.

This embraces only the small dacite flow, about three-quarters of a mile long, that starts near the rim at the Wineglass and extends northeastward. In the hand specimen the rock (114) closely resembles the brown and black vitrophyric dacite from the Cleetwood Cove region, just above described. In this case, however, the black glassy portions appear more as elongated streaks accentuating the fluidal structure.

Under the microscope the darker portions that appear black in the hand specimen are seen to be composed of nearly pure glass, but not of a uniform color. The rock consists of more or less parallel strands of absolutely colorless glass and of glass rendered more or less opaque by means of blackish to brownish minutest dust-like particles of uncertain character. The usual microlites of augite appear to be missing. This interweaving of colorless and dark-colored strands causes the glass to assume a decided stringy appearance. In case two phenocrysts approach each other the strings or strands are apt to assume almost or entirely parallel directions, but elsewhere they show a constantly varying arrangement, frequently becoming wavy or strongly crinkled, like the crinkling of many chlorite- and mica-schists. Furthermore, this stringy structure does not run uninterruptedly through the thin section, but is broken up into more or less separate areas that have lenticular or twisted forms. In general the arrangement of these glassy strands corresponds with the customary fluidal structure of glassy rhyolites and dacites, in that the strands lap or flow around the phenocrysts, after the manner of strings of microlitic inclosures.

The red portion of this dacite does not appear to differ in thin section from the above-described black areas, except that it is stained with dirty looking, brownish, powdery, ferritic matter. It constitutes the greater part of the rock and appears to inclose irregular, frayed out areas of the darker colored glass. This partial alternation of different colored areas lends a brecciated appearance to the whole.

The characteristic structure of this dacite does not differ essentially from similar structures as described by observers elsewhere, but it reminds the writer forcibly of the red obsidian which Iddings has described, and of which he has given a colored reproduction.[a] The phenocrysts of this dacite are not noticeably different from those in the dacites already described. They consist of plagioclase and hypersthene and of isolated, minute, reddish-brown hornblende. The rock also contains small fragments of a holocrystalline, porphyritic, hypersthene-bearing basalt, and in one case at least of a hyalopilitic andesite. These fragments are with a few exceptions hardly noticeable in the hand specimen, as they are small, but they are very numerous, as each of the two thin sections prepared from this rock contains eight or nine such inclosures that measure from 2 or 3 millimeters down to about 0.02 millimeter in diameter.

The chemical analysis of this dacite will be found on page 140. It will be noted that the amount of silica is 2 or 3 per cent less than in the two other dacites analyzed. Unfortunately the presence of the above-mentioned inclosures of basalt vitiate to some extent the analysis. The lower percentage in silica may easily be explained by the presence of these inclosures, which may have been present in the portion sent for analysis to an even greater extent than is indicated by the thin sections.

CLOUD CAP FLOW.

This is an extensive flow that starts at Cloud Cap and extends for about 3 miles in a northeasterly direction with a breadth of about a mile. The rock specimens collected from this flow and included in this description are Nos. 115, 116, 117, 118, 119, and 120. With the exception of one distinctly lithoidal specimen (119), these are mainly very glassy and also largely spherulitic dacites, closely resembling the Llao Rock mass (as seen in Nos. 101, 102, and 104). The glassy portion of these rocks has a light-gray color. Phenocrysts of white glassy plagioclase are abundant, and phenocrysts of the ferromagnesian minerals are scarce. Spherulites are to be found in Nos. 116, 117, and 120, but they are conspicuously visible in the hand specimen only of the last mentioned number. Here they occur from one-fourth to one-half inch in diameter, and have a whitish to light-drab color. The larger spherulites are more or less hollow and show on the cracked surface a fluted or ribbed structure radiating from the center outward.

As this rock does not differ very materially from the spherulitic dacites already described, a brief description of the microscopic characters will suffice for present

[a] Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 274.

purposes. The glassy portions in the spherulitic varieties, as well as in the entirely vitrophyric groundmass of No. 118, contain characteristic streams of minute straight and colorless augite microlites, like those in Nos. 101 and 102 of the Llao Rock mass. Microlitic feldspars, in the form of lath-like plagioclase and rectangular and apparently untwinned feldspar, occur in varying amounts, both in the same and in different thin sections. Some streaks may be almost entirely devoid of such feldspar microlites, while others may be crowded thickly with them, while between these two extremes there appears every conceivable intermediate stage. In two or three thin sections, but more noticeably in No. 117, the untwinned feldspar, or more properly the microlitic feldspar, that does not appear to have the albitic twinning, occurs in very thin leaves that show striking Carlsbad twinning. The two individuals that make up one of these twins have each of them simple quadrilateral form, and the leaves lie over each other joined by the clinopinacoid, which is also the plane parallel to which the little leaves are extended. Professor Rosenbusch refers to such twinned microlitic feldspars as occurring in rhyolite pitchstone and rhyolite obsidian. No. 116, which shows in the hand specimen very strongly developed fluidal structure, consists of alternating, parallel streaks of vitrophyric, spherulitic dacite, and of a more lithoidal dacite free from spherulitic inclusions. The lithoidal streaks have the plagioclase laths very strongly developed and at times bear a marked resemblance to some of the Crater Lake andesitic rocks. On the other hand, No. 115 has a brown glass groundmass, inclosing numberless somewhat granulated augite microlites, and is almost free from feldspar microlites of any description. Slender, straight, and curved opaque black trichites, as well as a very little black ore in minutest grains, may also be mentioned as occurring in some of these specimens.

The spherulites differ somewhat from those in No. 104, in that zones of growth are not so plainly developed. There is, however, often an inner, coarse-grained portion occupying the greater part of the spherulite and an outer, denser, and usually deeper stained zone. The inner coarser part is made up of radiating shreds that show both positive and negative extinctions; usually, however, positive. They also have a tendency to fork at small angles and do not extinguish always parallel.

The phenocrysts do not present any characteristics peculiarly different from those common to the other dacites with the possible exception of hornblende, which is rather more abundant than elsewhere. It has mostly a greenish-brown color, but also occurs reddish-brown in No. 116. It is absent only in No. 115. It is of interest to note in this connection that, although these rocks contain more hornblende than do the other dacites of Crater Lake, still the actual amount is very small indeed. As far as may be judged, a thin section from this flow does not contain one-fiftieth or perhaps one-hundredth part as much hornblende as does the dacite from Lassen Peak, to which reference is made above, and with which these Crater Lake rhyolites are closely allied. It should further be stated that occasional nests of older secretions are to be seen consisting of plagioclase, hypersthene, hornblende, augite, and magnetite, in which hornblende is apt to be very abundant. Zircon, which is so often reported as occurring in such rocks, appears to be a rare accessory mineral in the Crater Lake rocks of all types. It was noticed in a single crystal in No. 117.

SUN CREEK FLOW.

This mass includes all the dacitic area to be seen on both sides of Sun Creek, and stretching to the east as far as Sand Creek. The specimens studied are Nos. 121, 122, 123, 124, 125, 126, 127. No. 144 comes from a secretion in dacite and will be described later. No. 123, which is distinctly different from the others, will be found described on page 139, under the head of secretions. No. 128 is a dacite tuff.

This is the only dacite mass to be seen on the south side of Mount Mazama. It differs from all the above-described dacites, in that, as Mr. Diller has shown, it belongs to an earlier period in the formation of the volcano and is overlain by andesite flows. Although the individual specimens above numerated vary greatly in their outward appearance, they are in general much more thoroughly crystalline than are the more recent dacites on the northern and eastern sides of the lake. A glassy groundmass is not wanting in portions of these rocks, but devitrification, either contemporaneous with the cooling of the rock or subsequent thereto, is well developed. These rocks, therefore, are better suited to a study of the lithoidal types and will receive more individual attention than has been given to most of the specimens thus far.

No. 121, taken from the west side of Sun Creek Canyon, is a light-gray, porous, and rough-fracturing rock, with inconspicuous phenocrysts, and with numerous rough cavities that are lined with minute white glassy crystals. Some of these crystals, scraped from the cavity with a knife, proved to be tridymite, together with some feldspar similar to that described later as visible in the thin section lining the cavities.

Under the microscope the groundmass appears to be in most places holocrystalline, or at least one in which a glass base plays a very subordinate rôle. Here and there, however, the thin section assumes a brownish cast, indicative of abundant glass. The colorless particles, which appear to make up the bulk of the groundmass, are neither elongated nor squarish in cross section, but have ill-defined, roundish, allotriomorphic form. Throughout this granular mass are scattered minute opaque dust-like ore particles, and also many minute yellowish to colorless dust-laden augite microlites. Irregular longish cavities abound, the larger of which are empty; the smaller ones are often filled with tridymite. Between this tridymite and the walls of the cavity is a narrow fringe of colorless grains, the same to all appearances as those that form a large part of the groundmass. Wherever these colorless grains come into contact with the Canada balsam they are seen to have an index of refraction lower, but only very slightly lower, than that of the balsam, so that the edge of the grain can hardly be distinguished. They can not, therefore, be quartz. They are structureless and without twinning bands. In polarized light the polarization colors are much higher than in the adjacent tridymite. Some of the largest of these grains (0.02 to 0.03 millimeter) give biaxial images in convergent polarized light. In one case a distinct cleavage was noticed with an extinction angle of 7½° to the trace of the cleavage plane. Convergent polarized light gave a positive large-angled bisectrix in the center of the field, with the plane of the optical axes inclined 7½° to the trace of the cleavage. These properties would certainly indicate orthoclase, in which case the grain just mentioned is cut nearly parallel to the clinopinacoid. These fringing grains are free from solid inclosures, but they appear to contain gas pores.

That, in spite of the above-described properties, these colorless grains are probably not orthoclase, may appear from the following two considerations: First, the index of refraction is too high for orthoclase, although, like orthoclase, it is lower than that of the Canada balsam, whose index of refraction is taken to be 1.540. Orthoclase, whose index of refraction is about 0.025 less than that of balsam, should present a sharply defined edge at contact with the balsam. Second, many or even most of these grains have an undulous extinction. This second consideration would suggest the presence of anorthoclase, which would also be corroborated by the preponderance of Na_2O over K_2O, as shown in the chemical analyses of the Crater Lake dacites. On the other hand, the index of refraction of anorthoclase as given by Professor Rosenbusch[a] is only 1.527, which is but 0.002 higher than that of orthoclase. Unless, therefore, anorthoclase should prove to possess a higher index of refraction than that here given it would seem that this feldspar must be placed in the albite-oligoclase series in spite of the fact that no twinning is to be seen.

It is more than likely that quartz forms a large part of the crystalline groundmass, but owing to the small size of the particles this could not be demonstrated.

The tridymite of this rock does not possess the customary shingled aspect. It does probably occur in more or less overlapping scales, but the edges are irregular and the overlapping not very conspicuous. The occurrence, however, is exactly like that of the tridymite in the lithoidal rhyolite from Obsidian Cliff in the Yellowstone National Park, as examined by the writer in sections from that

[a] Mikroskopische Physiographie, 3d edition, Vol. I, 1892, p. 157.

rock in the possession of the mineralogical laboratory of Harvard University. In describing the occurrence of tridymite in the rhyolite from Obsidian Cliff, Iddings says:[b] "The spaces * * * are in most instances occupied by tridymite in comparatively large crystals, often twinned and carrying numerous gas cavities." The tridymite in this Sun Creek dacite may be recognized by the following properties. It occurs in minute crystals or grains that measure 0.05 to 0.15 millimeter, usually filling the cavities. Twinning is very common. Sometimes the twins resemble those of orthoclase in the form of Carlsbad twins, the twinned halves having widely differing extinction angles; in other cases there appear to be twinning planes in more than one direction. Undulous extinction is very common, but where the twinning is well marked this is not much in evidence. Exactly similar undulous extinction was also noted in the sections from Obsidian Cliff above referred to. Interference colors are very low, sometimes being almost invisible. The refraction is much lower than that of the adjacent balsam. This great difference in refractive powers is strongly brought out by the extreme roughness of the tridymite, as well as by the sharpness of the edges as compared with the great smoothness of the surface of the feldspar grains fringing the cavities. Except for the presence of gas cavities, the tridymite is free from inclosures.

Among the phenocrysts of this rock are fairly abundant plagioclase, rather sparingly developed hypersthene, and only an occasional minute augite crystal. Hornblende was not to be seen.

Specimen No. 122, collected lower down on the west side of Sun Creek Canyon, not far from No. 121, is a slightly porous light-gray rock of lithoidal character, mixed to a certain extent locally with dark grayish-green glassy portions. Both the lithoidal and glassy portions are crowded with small spherulites, 1 to 3 millimeters in diameter. Most of these spherulites are solid externally, and of a dark-gray color within on the freshly fractured face. Some are hollow and show a slight tendency toward the formation of concentric shells or lithophysæ.

Under the microscope the greater part of the rock is seen to be composed of spherulites of distinctly recognizable fibers and shreds that radiate in branching, feathery forms from common centers. These apparently feldspathic fibers have both positive and negative, but more commonly positive, extension, and extinguish both parallel and oblique. Whether they are actually intergrown with quartz can not positively be asserted. The outer portion of the spherulite usually contains deep brownish-red scales, presumable of hematite, that polarize light strongly. They radiate from the center and branch at low angles. To these brownish-red scales is due the reddish color of the outer portion of the spherulites as seen in the hand specimen. The two thin sections prepared from this rock were both cut from the

[b] Spherulitic crystallization: Bull. Philos. Soc. Washington, Vol. XI, 1891, pp. 445–464.

lithoidal part of the hand specimen, so that they do not show any glass under the microscope. The groundmass outside of the spherulites seems to be holocrystalline, but extremely fine grained. The individual grains are too fine to be determined, but they appear to have no particular elongation. Through this minutely granulated groundmass, as well as through the spherulites, run streams of slender, rod-like augite microlites and of minute but not very abundant black ore particles, to which should be added an occasional lath-shaped plagioclase microlite. Phenocrysts occur the same as in No. 121.

No. 124 is an aggregate of very light-gray, porous, and distinctly crystalline, as well as of very dark-gray, dense parts. In the thin section the granular parts have mostly disappeared in the grinding, but from what is left they seem to be composed of an aggregate of colorless, allotriomorphic grains, probably of feldspar and quartz, with occasional tridymite scales. The dense, darker-colored parts probably contain a glass base completely obscured by the devitrification products, which consist of augite microlites granulated with adhering and inclosed opaque ore particles and of extremely minute, colorless allotriomorphic shreds and grains. As in No. 122, this rock also contains a very few lath-shaped plagioclase microlites.

The phenocrysts consist of the customary plagioclase, with also a little hypersthene and two or three fragments of brown hornblende with black resorption rims.

No. 125, from near the head of the West Fork of Sand Creek, is somewhat similar to the last-described specimen, but the groundmass is much coarser grained. The shredded appearance of the colorless ingredients is very marked, but their exact mineralogical nature can not be made out. These shreds do not reach dimensions greater than 0.05 millimeter, and are too small to clearly disclose twinning striation, although the larger ones leave the impression that polysynthetic twinning is present. In white light the granulated augite microlites show up very clearly and abundantly, even with moderate magnifying powers. Plagioclase and hypersthene are the only phenocrysts noted. This rock bears a close resemblance to No. 113 from the Cleetwood Cove mass.

No. 126, which was collected close to No. 125, has a very dense structure and dark-gray color. It looks decidedly like an andesite. In thin section it does not appear altogether even grained, but discloses coarser-grained patches. It is, however, as a rule, very fine grained, or, at least, appears so in white light, in which it appears to be composed of a uniform white substance very thickly sprinkled with opaque black dust particles. When strongly magnified these dust particles appear as black ore grains, and also as transparent or translucent globulitic matter. The granulated augite microlites so common in other specimens from this lava mass are almost absent. In polarized light the continuous white substance appears to be made of very irregular, interweaving allotriomorphic patches that remind one forcibly of the allotriomorphic feldspar patches of many of the holocrystalline andesites of this region. They are to be distinguished from such by the absence of inclosed plagioclase laths. Plagioclase and hypersthene occur among the phenocrysts, as usual. One augite crystal was noticed; also a grain of magnetite surrounded with a rim of leucoxene.

No. 127, from near Sand Creek, furnishes a beautiful illustration of fluidal structure, both in the hand specimen and in the thin section. In the former it appears in very thin alternating parallel bands of light reddish-gray and of dark-gray and very compact materials. Phenocrysts are small, but quite abundant, and are made more conspicuous by the evident flowing of these thin bands around them.

In thin section the fluidal structure is beautifully brought out, both by the alternation of coarser, white bands with finer-grained and brownish-colored bands and by the presence, especially in the finer-grained portions, of streaks of black dust. When examined with strong powers this apparent ore dust is seen to be composed in part of inclusions of air; in part also of really opaque particles that are usually to be seen inclosed in augite microlites. The white bands appear to be entirely crystalline. They contain comparatively little microlitic material, either in the shape of augite or ore particles. In polarized light the colorless material breaks up into very distinct, longish shreds quite similar to those described above in other specimens from this dacite mass. They are, perhaps, somewhat more distinct here than elsewhere. Occasionally some of the larger and better-defined shreds (0.1 millimeter or more in length) show distinct twinning bands, but this is exceptional. More frequently the extinction is more or less undulous and sometimes markedly so. In general it is nearly parallel to the extension and is always negative.

These shred-like strips show a strong tendency toward grouping themselves around common centers. Three, four, or five or more of these may be seen diverging from a common point, each of them narrowing down wedge-like at the center. As in the case of the more isolated shreds these are also negative. They thus produce what Rosenbusch calls "pseudospherulites" with negative crosses. In the midst of these "pseudospherulites" may also be seen the ordinary "true spherulites" of Rosenbusch, also with negative crosses. These latter do not appear to be composed of any recognizable mineral species. They show the customary black cross with arms parallel to the principal planes of the nicol prisms and remain stationary upon revolving the stage. They do not succeed in developing externally spherical forms, as their growth appears to be interfered with by contact with the coarser-grained portions of the groundmass. Every possible gradation appears to present itself between these so-called "true spherulites" and the radial groups of crystal particles that appear to be undoubtedly feldspathic.

The finer-grained bands with brownish color are composed, apparently, of glass with inclosed dust particles. But upon closer inspection the apparent glass seems to be composed of ill-defined particles that, owing to their parallel arrangement, very faintly polarize light, so that the whole band extinguishes parallel, with negative extensions. This is undoubtedly the substance so frequently referred to in describing such rocks as microfelsite. On each side of these uniformly polarizing bands of microfelsite occurs a very narrow, continuous spherulitic streak, the individual spherulitic parts of which are quite similar to the above-mentioned "true spherulites.

The phenocrysts in this rock are similar to those in the rest of these dacites, namely, plagioclase and hypersthene. Hornblende could not be seen.

DACITE TUFF.

The deposit of fine volcanic materials that is to be seen filling the bottom of the Sand Creek Canyon is represented by No. 128. This is a loose, friable, dark-gray tuff. Examined with a pocket magnifying glass it appears to be composed mainly of dust-covered white grains with an admixture of some black crystals. The white grains turn out to be plagioclase and the black ones hypersthene and hornblende, all of them exactly similar to the phenocrysts of the above-described dacites. In addition to these crystals and grains there occur small (3 to 5 millimeters) angular fragments of compact dacite, or perhaps also of andesite.

The plagioclase does not have the form so well preserved as do the other minerals. The hypersthene crystals show the customary unit prism and two pinacoids, while the hornblende has only the prism clearly shown. The hornblende has the optical properties similar to those given for the phenocrysts in the dacites. That this tuff is undoubtedly dacitic is demonstrated by the presence of these abundant hornblende crystals which are almost entirely confined to the dacites of Crater Lake.

An entirely analogous dacite tuff is to be seen in the bottom of the Anna Creek Canyon (No. 129). This tuff also contains hornblende in great abundance,

DACITE DIKES.

Among the dikes that cut the andesitic rocks of the crater wall are two underneath Llao Rock that rise from the water's edge and consist of dacite. The more westerly of these two dikes, immediately under the summit of Llao Rock, is represented by two specimens, Nos. 130 and 131. The first of these is a very light gray, porous, lithoidal dacite and comes from the central part of the dike. The second is a grayish-black glass and was collected at the margin of the dike. The two together may be taken as the equivalents of Nos. 103 and 102, respectively, which represent the lithoidal and the vitrophyric dacites of the Llao Rock mass. Under the microscope the resemblance is still more striking. Nos. 130 and 131 both contain the same phenocrysts already described in the equivalent rocks above mentioned. There are comparatively abundant plagioclase with large extinction angles and zonal structure, scanty hypersthene and augite, and occasional greenish-brown hornblende, together with accessory magnetite and apatite. The lithoidal rock from the main part of the dike does not differ sufficiently from the lithoidal dacite of the summit to justify a special description. The glassy margin, however, presents minor features that distinguish it from No. 102. Fluidal structure is very perfectly developed and is accentuated both by the straight augite microlites and by streams of roundish, nearly colorless globulites. The color of the glass streams alternates between whitish and brownish. Here and there a little clear brown glass, free from microlites and globulites, is to be seen in close proximity to a phenocryst. The thin section of this specimen also contains several small fragments of a fine-grained holocrystalline, porphyritic basalt, in the groundmass of which are to be seen slender prisms of augite and hypersthene, also grains of magnetite and plagioclase laths.

This dike is undoubtedly one of the feeders of the Llao Rock dacite.

The more easterly of the two dacite dikes is represented by only one specimen, No. 132. It is a light-gray, coarse, rough-fracturing rock. Under the microscope it presents features somewhat suggestive of the Grouse Hill dacite, but the similarity is not marked enough to justify the conclusion that this dike is a feeder for this dacite mass. The rock is not altogether fresh. It contains, in addition to the usual phenocrysts, a very little reddish-brown hornblende in small crystals and fragments with black borders. The groundmass contains the usual short rectangular feldspar and a good deal of feldspathic matter that has no well-defined shape. Brownish and reddish ferritic matter, together with some black magnetite, renders the thin section clouded and dirty looking. Abundant groups of tridymite are to be seen filling what appear to be cavities.

This dike contains an inclusion, No. 133, the nature of which is not clear. It has a slightly greenish-gray color, is distinctly but finely granular, and is decidedly porous. In thin section it is seen to be composed essentially of plagioclase laths and of hypersthene and augite in mostly long, slender prisms. Grains of black magnetite, as well as reddish and brownish ferritic staining matter, are abundant. Porphyritic crystals are entirely absent. The shape and arrangement of the main ingredients, but more especially of the plagioclase laths, are closely analogous to those of interstitial basalts, although it does not agree with any of the basalts from Crater Lake. But there are other respects in which this inclusion distinguishes itself from the basalts of this region. It contains considerable reddish-brown hornblende, and in some of the interstices between the plagioclase laths are colorless aggregates that appear to be tridymite, similar to that in the dike rock. It is probable that there is, or was, considerable glass in the form of a mesostasis. But if so it is largely devitrified and colored a dullish green. The thin section is too thick to allow a satisfactory examination, but the writer is inclined to place this specimen among the secretions of dacite. It calls to mind a not very dissimilar specimen described among the dacite secretions, No. 123, from Sun Creek. (See page 139.)

DACITIC EJECTAMENTA.

The large amount of volcanic ejectamenta that covers the surface of the crater rim in various places, especially on the northern and western sides, and that forms extensive deposits over the so-called Pumice Desert, appears to be almost entirely dacitic in character.

Some dark-colored sand, No. 134, collected on the Pumice Desert is composed of the light- and dark-colored minerals occurring as phenocrysts in the dacites, as well as of brown glass. These are plagioclase, hypersthene, hornblende, augite, and magnetite. The size of these crystals varies from about 2 millimeters downward. Plagioclase forms the most abundant of the sand particles, with forms that are usually roundish but that also may be well crystallized. Hypersthene, on the other hand, is very common in the characteristic prismatic forms with the unit prism and two pinacoids. When finely pulverized and examined under the microscope it is seen that both hypersthene and dark greenish-brown hornblende are very abundant and present in about equal amounts. Augite and magnetite are rather scarce. The latter can readily be separated from the sand by a magnet. This sand exactly resembles the coarser parts of the tuff found in the bottom of Sand Creek Canyon several miles below the crater rim (128) and in Anna Creek Canyon (129). The accumulation of the pyroxenes and of hornblende to a much greater extent than in the dacites is very noticeable in both the tuff and sand deposits.

A sediment brought up from the bottom of the lake on the west side, No. 1357 appears to be composed of somewhat similar material as the above, but as it is very fine—the largest grains being not much over 0.1 millimeter—and entirely composed of angular fragments, the percentage of the dark-colored phenocrysts, or rather of fragments of phenocrysts, is comparatively small. This is particularly true of hornblende, which is very scarce. On the other hand, glass fragments are very abundant. The nature of this sediment is not so well characterized as to make certain whether or not andesitic material is largely mixed with the dacitic ash.

The coarser ejectamenta which have been collected and submitted to the writer for investigation may be divided into three classes, viz, pumice, dark-colored secretions, light-colored granophyric secretions.

PUMICE.

No. 102, from the summit of Llao Rock, is an almost pure pumice of a pinkish-white color and extremely light and porous. With a magnifying glass one can detect a very few glassy plagioclase crystals, and also still fewer dark-colored pyroxene or hornblende phenocrysts, similar to the phenocrysts in the Llao Rock dacite. Under the microscope this rock presents the customary porous, pumiceous structure, with long drawn out gas pores; but the glass differs from the vitrophyric portions of the Llao Rock flow, in that the very characteristic rod-like augite microlites are almost entirely missing. A few phenocrysts of plagioclase in crystals and crystal fragments are to be seen, also an occasional hypersthene and two or three minute brown hornblende crystals. One of the plagioclase crystals was seen to contain numerous inclosures of apatite and also several dark-brown glass inclusions, in one of which was an air bubble. No. 137 is a fragment of pumice collected from the same place, and differs only in being more discolored. It contains similar phenocrysts, and also brownish glass inclosures with gas bubbles in the plagioclase. This pumice evidently is of the same character as the dacite of Llao Rock.

No. 138 is a specimen collected from a large fragment in the Pumice Desert, the north of Crater Lake. It has a brownish-yellow color and looks as though it contained more or less clayey matter. It also has a fragmental appearance as though it were a brecciated rock composed mainly of pumice. It also contains a few small fragments that appear to be andesite. Plagioclase grains are very abundant in the hand specimen, but the thin section contains hardly any, as they have probably disappeared in the grinding. A very few minute hypersthene and augite crystals and one small fragment of reddish-brown hornblende were noted.

In addition to this ordinary pumice are also fragments of a distinctly pumiceous rock of light color in which are readily seen numerous black crystals, mostly hornblende. These hornblende crystals vary in size from one-fourth of an inch downward. Probably one-eighth of an inch in length is a fair average size. One of these fragments was collected on the northeast rim of Crater Lake, east of Round Top, and another (146) from the summit of Red Cone, while two others were collected by the writer on the crater rim just south of Llao Rock (2011, a and 2013, 2 of the private collection of H. B. Patton). The ferromagnesian minerals which are very conspicuous in the hand specimen are still more apparent in the thin section, as, indeed, are also the colorless plagioclase phenocrysts. The groundmass of these specimens does not appear to differ materially from that of the more typical pumice. It is a nearly pure glass, full of elongated air cavities and more or less stained with yellowish to brownish ferritic matter. Only a few augite microlites and but little magnetite dust is to be seen. On the other hand all the minerals that have been mentioned as occurring among the phenocrysts in the Crater Lake dacites and that are there sparingly developed are unusually numerous in these specimens. The minerals here included are plagioclase, hornblende, hypersthene, and augite All but the hornblende appear to occur in about the same sizes as in the dacites. In the case of plagioclase there is developed a very strong tendency to inclose comparatively large and irregularly lobed and more or less connected inclusions of very deep brown glass. These inclusions are not arranged around the margin in a well-defined zone, as is so frequently the case with the plagioclase phenocrysts of the andesites, but they are more evenly distributed throughout the crystal and produce a structure that may fairly be characterized as spongiform. These spongiform plagioclases are by no means as common or characteristic as they are in the dark-colored secretions whose descriptions follow; neither do all or even most of the plagioclase phenocrysts have these inclusions, but their appearance here is important as forming a link between the dacites and the inclusions in the same. Fracturing of the feldspars is very noticeable.

Hypersthene and augite occur in the same forms and with the same general properties as in the dacites. Perhaps a stronger tendency is to be noted toward rounding of the edges, particularly at the ends. Likewise inclusions of glass and especially of brown glass are more abundant. The most interesting mineral is hornblende, whose abundance is increased relatively much more than is the case with the other phenocrysts. It also occurs in very much larger crystals than are to be seen in the dacites. Except for abundance and size, however, these hornblende crystals do not present any marked peculiarities. They show a strong tendency to develop the unit prism and the clinopinacoid, but they are usually broken into fragments like the plagioclase. In color they are similar to the hornblendes of the dacites. Greenish brown predominates, but the more reddish colors are also to be seen, notably in No. 139. Magnetite occurs rather sparingly in these rocks in the form of distinct grains inclosed in the phenocrysts as well as scattered through the glass groundmass.

DARK-COLORED SECRETIONS.

These are found as ejected fragments together with pumice. They occur as extremely dark, almost black, very porous and rough feeling bombs, and contain a great abundance of black pyroxenes and black hornblende as well as of the glassy plagioclase. They have a wide distribution, as may be seen from the following list: No. 141 comes from the Pumice Desert to the north of Crater Lake; No. 142 from near the summit of Dutton Cliff to the south of the lake; No. 143 from the summit of Llao Rock; No. 145 is a fragment from a conglomerate that overlies a small sheet of dacite just above Grotto Cove; and 2011, b (private collection of the writer) forms part of a large bomb attached to the pumice specimen, 2011, a, above described. This last was collected just south of Llao Rock. In spite of the dark color of the rock the ferromagnesian minerals are quite conspicuous. This is particularly true of No. 2011, b, where hornblende is more abundant than in the other specimens and is recognized by means of the brilliantly flashing cleavages. This mineral occurs here in crystals that measure up to 10 millimeters in length and 2 to 3 millimeters in width.

Under the microscope in thin section these rocks are seen to contain a very dark-brown, glassy groundmass that incloses but few augite microlites but is crowded with air cavities. In color and general appearance the groundmass closely resembles the glass inclusions to be seen on the plagioclase crystals of the hornblendic pumice above mentioned. It forms from one-third to one-half of the rock mass, the rest being composed of phenocrysts and fragments of phenocrysts.

The plagioclase crystals belong to the type described under the dacites as occurring in rather large, plump crystals, with numerous crystal faces. Rectangular sections are rare, so rare, in fact, that they are probably only chance sections of crystals of the type just mentioned. The plagioclase crystals show a strong tendency to assume idiomorphic forms except in so far as they occur in shattered fragments, but they are generally crowded with irregular brown glass inclusions so as to assume a thoroughly sponge-like appearance, similar to but much more pronounced than the spongiform crystals in some of the pumice fragments. These ramifying glass inclusions are not confined to the interior of the crystal, but come to the surface and often appear as embayments filled with brown glass exactly like and continuing the glass of the groundmass. Figs. *A*, *B*, and *C* of Pl. XVII are reproductions of some of these spongiform plagioclase crystals and give a fair idea of their appearance. The plagioclase is probably all basic, and, in some cases, demonstrably so. For instance, in No. 143 a honeycombed plagioclase crystal, with zonal structure, and cut symmetrically to the plane of twinning gave an extinction angle of 47° in the center and 37° at the margin. This indicates an extremely basic anorthite, more basic, in fact, than the most basic of the plagioclases whose extinction angles were measured in either the andesites or basalts of Crater Lake. Not all of the plagioclase crystals show polysynthetic twinning, but most of them show either this twinning or a zonal structure, and no reason was apparent for considering any of them to be orthoclase. They contain inclusions of ores, apatite, and hypersthene.

The hornblende in these dark-colored secretions is partially idiomorphic and partially allotriomorphic, with the latter tendency decidedly the stronger; that is, crystal forms may be developed on part of a crystal while the rest has a very irregular outline. The observed forms are the customary unit prism and clinopinacoid and flat terminal faces. The color is mostly like that of the greenish-brown hornblende of the dacites, and the absorption is $\mathfrak{b} \geq \mathfrak{c} > \mathfrak{a}$. The customary colors in

PLATE XVII

PLATE XVII.

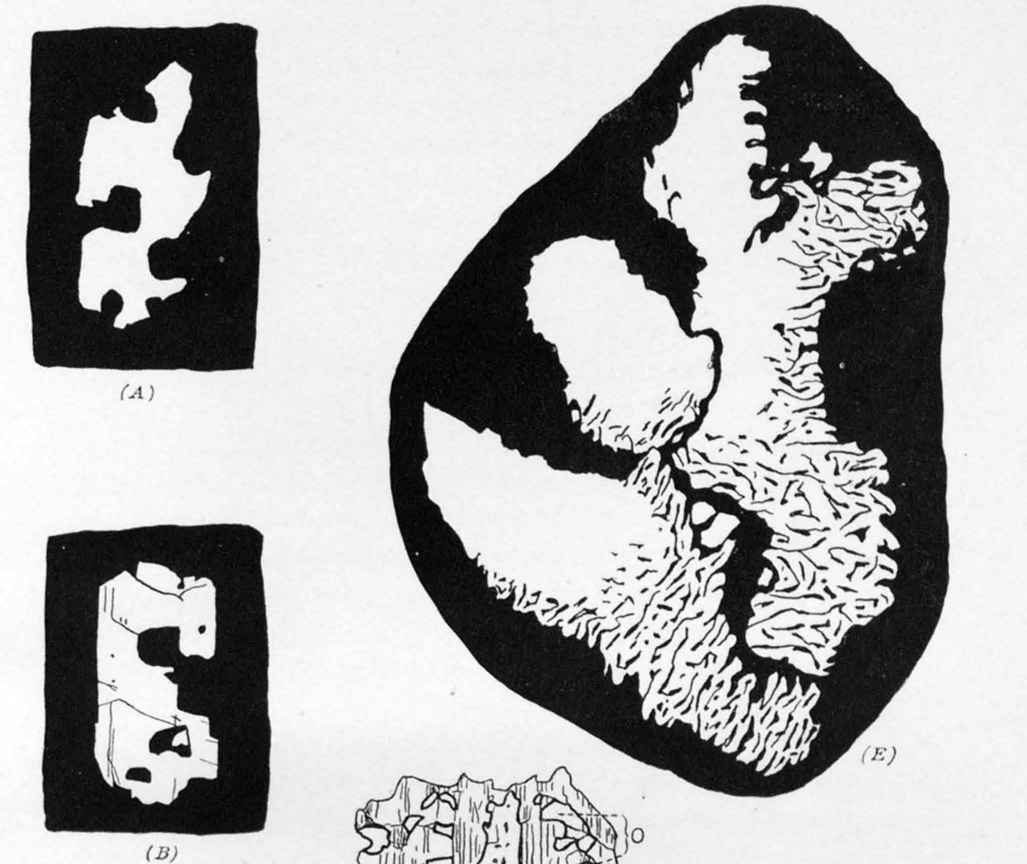
THIN SECTIONS OF MINERALS IN SECRETIONS IN DACITE.

FIGS. *A*, *B*, and *C*.—Magnified respectively 40, 25, and 15 diameters. All from Specimen No. 145. From a dark-colored secretion among the dacitic ejectamenta. Show spongiform plagioclase crystals inclosing deep-brown glass similar to that composing the groundmass, from a dark-colored secretion among the dacitic ejectamenta. See page 126.

FIG. *D*.—Magnified 18 diameters. Specimen No. 144. From a dark-colored secretion among the dacitic ejectamenta. Shows a grain of hypersthene inclosing numerous plagioclase grains, and two irregular grains of olivine marked 0. See page 129.

FIG. *E*.—Magnified 50 diameters. Specimen No. 148. A light-colored, granophyric secretion among the dacitic ejectamenta. Shows crystals of plagioclase with fringes of spongiform sanidine containing inclusions of brown glass and resembling granophyric intergrowths. Illustrates a section as seen in polarized light with crossed nicols, the glass appearing black. See page 136.

FIG. *F*.—Magnified 10 diameters. Specimen No. 142. From a dark-colored secretion among the dacitic ejectamenta. Shows a large crystal of brownish-green hornblende inclosing crystals of hypersthene = H, plagioclase = P, and magnetite. See page 129.



THIN SECTIONS OF SECRETIONS IN DACITE.

thin section for rays vibrating parallel to the vertical axis is a deep brownish green to greenish brown, in accordance with the thickness of the section. The absorption and pleochroism parallel to 𝔟 are almost exactly like that parallel to 𝔠, with the absorption usually a little stronger parallel to 𝔟 than to 𝔠. In No. 145 this mineral appears to be unusually scarce and the color in rays vibrating parallel to 𝔠 a deep brownish red. Those parallel to 𝔟 can not be determined in this section. In No. 141 there is a peculiar mingling of the reddish with the greenish-brown colors. Most of the crystals belong to the greenish-brown variety, but others have both colors shading into each other on the same crystal. This shading of colors occurs on perfectly fresh crystals. In fact, all the hornblende crystals in these specimens are absolutely fresh, and do not show any tendency to resorption or to the development of black borders. The extinction angle of the hornblende, as measured on cleavage fragments from No. 143, is 8° to the vertical axis. The optical axial plane lies in the plane of greatest and least absorption; that is, in the plane of the clinopinacoid. A section of this mineral in No. 143 that gave a prism angle of 104°, as measured by the trace of the prism faces with the plane of the section, gave a bisectrix in the center of the field.

The hornblende of these secretions does not contain inclusions of glass, but it is very apt to contain inclusions of the other phenocrysts so as sometimes to be filled with them, somewhat after the manner of inclusions in the hornblende of the crystalline schists. Fig. *F* of Pl. XVII gives one of these hornblende crystals containing inclusions of hypersthene, plagioclase, and magnetite. In other cases augite may be seen inclosed in hornblende. These minerals when thus inclosed may have idiomorphic forms, but they are more apt to be hypidiomorphic. At least their forms are not always so sharp as when they occur embedded in the glass base.

Hornblende occurs in much larger crystals than do the other minerals. It is very fluctuating in quantity, being very sparingly developed in No. 145, or at least in the thin section prepared from this specimen, and extremely abundant in No. 2011b. Fig. *B* of Pl. XVIII reproduces a portion of thin section of No. 2011b, showing the relative abundance of the hornblende. This is not a fair average of the whole section, but shows the hornblende somewhat more abundantly than in the rest of the section. The crystal form is unusually sharp in this rock.

Hypersthene is by no means so abundant as hornblende, nor does it occur in so large crystals. It is more inclined to idiomorphic forms, but it also shows a tendency to contain inclosures of other minerals. Fig. *D* of Pl. XVII gives a section of hypersthene from No. 144 containing inclosures of plagioclase and two irregular inclusions of olivine. This is exceptional. As a rule, hypersthene is older than plagioclase, and even in this case the irregular form of the plagioclase crystals indicates that their period of formation did not greatly precede that of the hypersthene. The optical properties of the hypersthene are in no respect different from what may be seen in the hypersthenes of the dacites.

Olivine is to be found very sparingly developed and always inclosed in either hypersthene or hornblende.

Augite is much less common than hypersthene. It has a pale-greenish color and but little pleochroism. It is younger than plagioclase and hypersthene and older than hornblende. It occurs both in roundish grains and in fairly developed crystals similar to those in the dacites.

The order of crystallization of the phenocrysts of these secretions is in general as follows: 1, ores and apatite; 2, olivine; 3, hypersthene; 4, plagioclase; 5, augite; 6, hornblende. At times the plagioclase appears to change places with hypersthene.

That these dark-colored bombs are in reality secretions from the dacitic magma may fairly well be established by the similarity of the mineral contents with the phenocrysts of the dacites. This is more especially true of hornblende, which, with possibly one minor exception, is absolutely foreign to the andesites as well as to the basalts of Crater Lake, but which occurs with the same colors and other properties, although very sparingly, in nearly all the thin sections of dacites studied. That these fragments were erupted at the same time as the dacites is indicated by their occurring with the pumice of the dacites, and more immediately by the finding of a bomb in the midst of the pumiceous deposit south of Llao Rock consisting in part of pumice and in part of this black, glassy, hornblendic rock.

The chemical analysis of No. 143 will be found on page 140. In spite of the evident relationship of these dark-colored secretions to the dacites the analysis shows a marked difference. This is particularly noticeable in the large amount of lime and in the corresponding decrease in the alkalies. The analysis, in fact, bears a close resemblance to the analyses of the more acid basalts Nos. 158 and 189.

LIGHT-COLORED GRANOPHYRIC SECRETIONS.

These are not to be considered secretions in the sense that this term is frequently used in describing the accumulations of older minerals that form dark-colored inclusions in igneous rocks, which is the sense in which the word is used in describing above the dark-colored secretions. But, rather, these light-colored secretions appear to represent local crystallizations or differentiations of the same minerals that are to be seen in the dacites in general, but so aggregated together as to appear in totally different structural relationships. They have not been found in place or inclosed in dacite, but only as loose fragments or bombs on the surface.

No. 146 is a small fragment about an inch square that formed part of a conglomerate overlying the small dacite flow immediately above Grotto Cove. Two other

PLATE XVIII

PLATE XVIII.

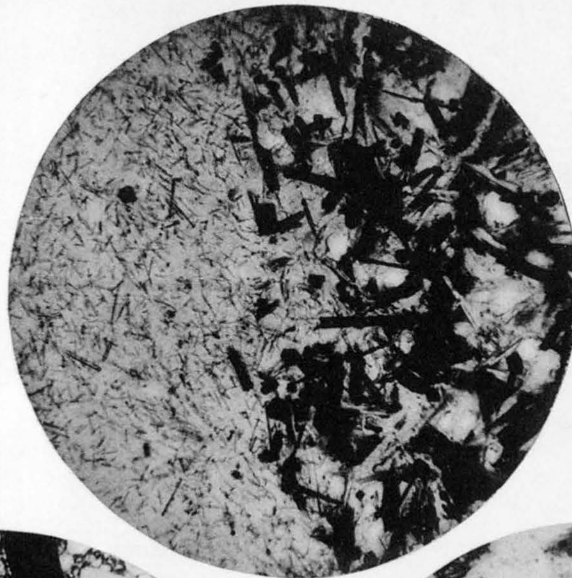
THIN SECTIONS OF SECRETIONS IN DACITE.

FIG. *A*.—Vitrophyric dacite and secretion in the same, from Llao Rock. Magnified 48 diameters. Specimen No. 102. A photomicrograph in white light. On the left is the dacite, consisting of a glass with a multitude of augite microlites. On the right is the secretion, composed of a felt of plagioclase laths and slender prisms of reddish-brown hornblende, which appears nearly black in the figure. The interstices of this felt are filled with light-brown glass. The lack of a sharply defined line of junction between the rock and the secretion is characteristic. See pages 105 and 110.

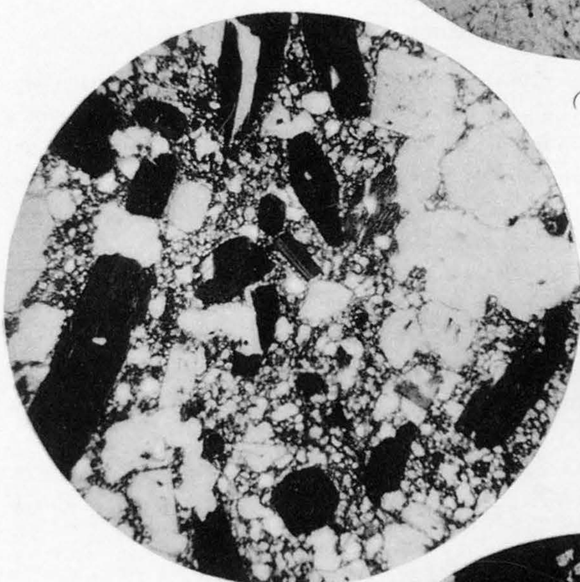
FIG. *B*.—A photomicrograph in white light. Magnified 20 diameters. Specimen No. 2011 b. Illustrates the abundance of reddish-brown hornblende in one of the dark-colored secretions. See page 129.

FIG. *C*.—A light-colored granophyric secretion from the dacitic ejectamenta. Magnified 20 diameters. Specimen No. 151. Shows a dark-colored brown glass and spongiform mantles of sanidine around plagioclase. See page 136.

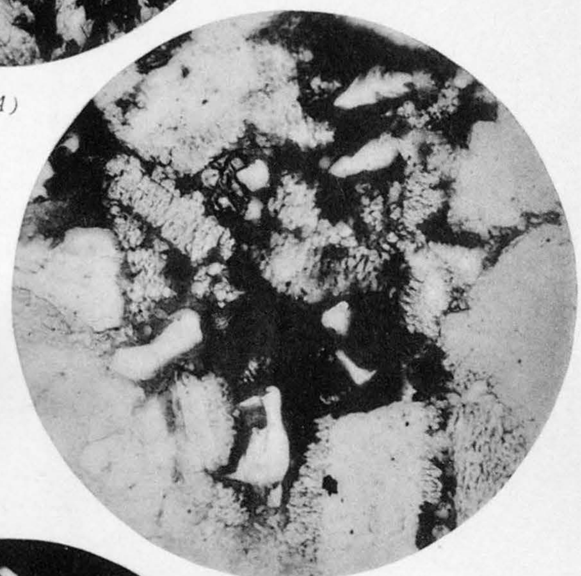
FIG. *D*.—A photomicrograph in polarized light with crossed nicols. Magnified 86 diameters. Shows an enlarged portion of fig. *C*, giving an individual plagioclase grain with mantle of spongiform sanidine. The black portions are glass.



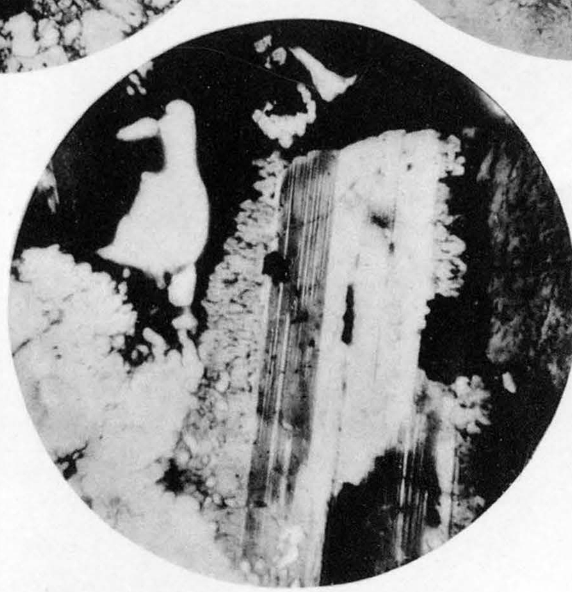
(A)



(B)



(C)



(D)

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fragments from this same conglomerate have already been described. These are No. 139, a pumice fragment containing much hornblende, and No. 145, one of the dark-colored secretions. This association would suggest the same source as that of the dark-colored secretions. In the hand specimen this appears to be a fairly coarse-grained, holocrystalline rock of very light color and composed of a whitish, glassy appearing, granular aggregate dotted with small, dark-colored grains. It is quite brittle and crumbles in the fingers. In thin section the rock is seen to consist mainly of plagioclase, which constitutes perhaps one-half of the whole or a little less, in addition to which there are hypersthene, augite, hornblende, and a very little biotite. All these ferromagnesian minerals together form but a small part of the whole. They are perhaps a little more abundant than is usual in the dacites of Crater Lake, but not markedly so. The rest of the rock forms a sort of groundmass either surrounding these older minerals or filling the spaces between them wherever the phenocrysts are close enough to touch each other. This groundmass consists in part of a deep brown and perfectly clear glass, but mainly of a beautifully sharp and characteristic granophyric or micropegmatitic intergrowth of quartz and sanidine. The presence of quartz could be demonstrated by observations in convergent polarized light, in which it gives the positive uniaxial cross, as well as by the more readily observed properties characteristic of the mineral. In the case of sanidine the demonstration is not complete, but is based upon the following observations: It is perfectly clear and colorless and contains no inclusions except minute air cavities; both the refractive power and the double refraction are less than in the adjacent quartz; its index of refraction is less than that of the surrounding balsam; in convergent polarized light it gives a biaxial image; it is entirely free from twinning striation or from zonal structure; this sanidine usually forms a mantle around the plagioclase crystals, so that either the outer part of the sanidine mantle is intergrown with quartz in granophyric fashion or, more usually, this granophyric intergrowth begins close to the plagioclase edge, with little or no free mantle growth visible; the contrast between the plagioclase and the sanidine mantle is usually rather sharp; the plagioclase very frequently shows no twinning striæ, but the concentric zonal structure is always visible, whereas the sanidine mantle is entirely free from all twinning and extinguishes simultaneously. Becke's method for determining the index of refraction, as compared with that of Canada balsam, by focusing sharply on the edge of a crystal in contact with balsam and then observing the movement of the white band upon raising or lowering the focus, was found very applicable in studying this sanidine mantle. Where a crystal of plagioclase was broken and in contact with balsam it was invariably found that the portion of the crystal that showed twinning or zonal structure had a higher index of refraction than balsam, while the outer, untwinned, and unbanded portion was lower in refractive power than balsam. The same method is equally applicable in this case in distinguishing between sanidine and quartz.

Wherever the quartz or the sanidine comes in contact with the brown glass base it breaks up at the edge into an irregularly lobed fringe, with the roundish lobes interwoven or intergrown with the glass in a way suggestive of the granophyric intergrowths themselves. This interweaving of glass with the fringed edges of the crystals is so much more beautifully developed in other specimens whose description follows that a detailed description of this phenomenon will be postponed for the present. The quartz is not present except in these granophyric aggregates. It incloses air cavities similar to the sanidine.

The plagioclase in this rock does not have as sharply developed forms as in the dacites. This is true even when the surrounding sanidine mantle is disregarded. Sections suitable for determining the extinction angles were not found, but such extinction angles as were noted indicate a basic plagioclase. This is further corroborated by the fact that the plagioclase even at the edge has an index of refraction greater than Canada balsam, i.e., greater than 1.540. A few inclosures of brown glass with gas bubbles and also small apatite prisms were noted.

The ferromagnesian minerals all have poorly developed forms. Hypersthene and augite occur mostly in small prismatic grains, some singly, but more commonly in more or less parallel arranged groups, together with magnetite and hornblende and with dark greenish-brown biotite. The hornblende has a greenish-brown color and occurs quite abundantly in longish granular or prismatic individuals. Biotite is scarce, but its presence is the more noteworthy as it appears to be entirely wanting in the dacites proper.

The writer has not seen a full description of rocks similar to this, but Professor Rosenbusch[a] makes brief reference to several quite analogous occurrences in Iceland, the original descriptions of which are not at the time of preparing this paper accessible to the writer. In these Icelandic rocks, which occur as inclosures in basalt and in loose fragments, are to be seen a similar mineral aggregation with plagioclase crystals surrounded with orthoclase mantles and granophyric growths.

Among the Crater Lake rocks collected in 1883 there are five specimens, Nos. 147, 148, 149, 150, and 151, which are labeled as being ejected volcanic fragments from the top of the divide between Sand Creek and Anna Creek, near the south rim of Crater Lake. These five specimens are closely analogous to No. 146, just described, and in one or two cases practically identical in all essential points. No. 149, for instance, is very light colored, distinctly granular, and very friable. It differs slightly in color, in that the feldspars have a distinctly pinkish color.

[a] Mikroskopische Physiographie, 3d edition, Vol. II, 1896, p. 590.

On the other hand No. 148 is very much darker and looks as though it were composed about equally of a white granular feldspar and of black glass.

Under the microscope the practical identity of all of these specimens with No. 146 is very evident. There are the same marginal growths of sanidine around the plagioclase crystals, and the same granophyric intergrowths of sanidine with quartz. The deep-brown glass interweaving with the sanidine is also present, but in much greater abundance in two or three of the specimens. The most striking difference between the two occurrences is in the fact that both hornblende and biotite are totally lacking here. Owing to better prepared thin sections, as well as to the opportunity to study sections from a number of similar although not quite identical specimens, some of the features not very clearly observed in No. 146 can be presented here with greater fullness and certainty.

The plagioclase does not, upon the whole, appear to be quite so basic as is the same mineral in the dacites. Twinning striations are abundant and disclose the presence not only of the albite law but also of the pericline and Carlsbad laws. But sections suitable for determining the maximum symmetrical extinction angles do not seem to be common, which is doubtless due to the fact that the rather large average size of the crystals does not allow many of them in any one thin section to be cut in the right direction. The largest extinction angle measured on a section cut at right angles to the albitic twinning plane was 27° in the central part of the crystal. As all of the plagioclase has a well-defined zonal structure the margin of the crystal is necessarily much more acid. Usually the sections that give symmetrical extinctions give very small extinction angles, even on the interior of the crystal. This is so often the case as to indicate that at least some and probably most of the plagioclase is oligoclase. This supposition is further borne out by the fact that such crystals, when broken so as to have Canada balsam in contact with the plagioclase, are seen to have an index of refraction almost identical with that of the balsam, which would indicate a feldspar about on the border of oligoclase and andesine. While the index of refraction thus indicates that some of the plagioclase, even in the interior of the crystal, is hardly more basic than oligoclase, in all cases where the observation was made the outer portion of the plagioclase has this degree of acidity. It seems more than likely that there are two kinds of plagioclase crystals present, a fairly basic and not very abundant variety and a more commonly developed and presumably younger variety. But in any case all the plagioclase crystals have the mantle of sanidine which, where a glass base is very abundant, or wherever this glass base comes into contact with this mantle, is very remarkably fringed or lobed, so that the roundish feldspar lobes appear to be interwoven with the glass in a most intricate way but which, in the absence of a surrounding glass, forms with quartz a beautifully distinct and rather coarsely developed granophyric aggregate. While these marginal growths around the plagioclase crystals may be seen around every individual plagioclase they do not necessarily entirely surround the crystal, nor does the fringing mantle have constant width. In this respect the mantle is very irregular and even erratic. As above stated, the interweaving of the brown glass with the fringed sanidine gives almost exactly the impression of the granophyric growth when seen in polarized light, except that a portion of the intergrowing substance remains extinguished when the specimen is rotated. Even in white light this resemblance to granophyric growths is often pronounced whenever the glass has an unusually light color, and this is the case in those specimens in which the glass base is not abundant (149), or in which the section is unusually thin. Further, this resemblance is made still more marked by the fact that at times the glass that appears interwoven with the feldspar breaks up into rectangular or otherwise polygonal forms with more or less parallel arrangement. Or, to express it in another way, the sanidine margin develops into a skeleton growth with the brown glass base filling the interstices. The variations of structure that are produced in these marginal growths, owing to constantly varying amounts of glass and the consequent appearance and disappearance of real granophyric growths, fairly baffle description. It would require a large number of drawings or photographs to give a fair conception of these almost fantastic structures. An effort has been made to reproduce some of the most striking effects in fig. *E* of Pl. XVII (p. 128), figs. *C* and *D* of Pl. XVIII (p. 132), and figs. *A* and *B* of Pl. XIX (p. 138).

The amount of quartz present appears to be inversely proportional to the amount of glass base. Where much glass is present it is not inclined to form granophyric growths but to occur in rather isolated, roundish, or irregular grains. Although it may have very irregular outlines, it does not break up into lobes or fringes at contact with the glass, as does the sanidine, at least not to any marked extent. In the more thoroughly crystalline specimens and therefore more thoroughly granophyric varieties, the quartz seldom occurs in separate grains. The sanidine is not absolutely confined to the granophyric margins but also occurs very sparingly, as does the quartz, in separate but irregularly formed grains.

Inclosures in the central portions of the plagioclase are not common. Glass inclusions appear to be entirely wanting, but not infrequently a crystal may contain small augite grains, or individual grains of magnetite or prisms of apatite. Minute air cavities, however, are very abundant, both in the plagioclase and in the surrounding fringes of quartz and sanidine.

It should, perhaps, be added that no additional reason can be given for the presence of sanidine in these specimens than those already given in the description of No. 146.

PLATE XIX

PLATE XIX.

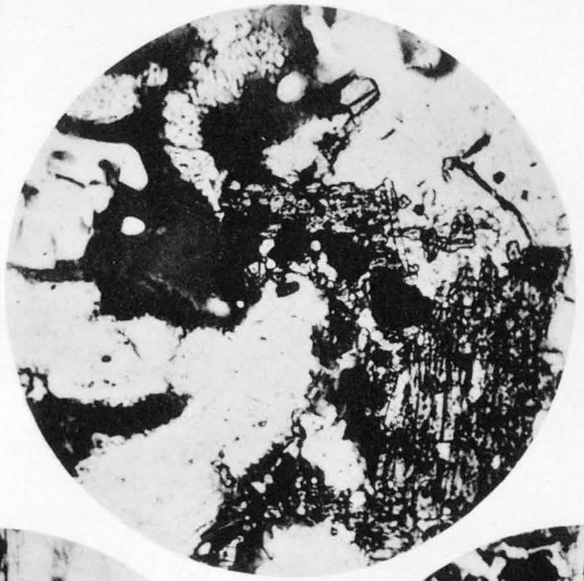
THIN SECTIONS OF BASALTS AND OF SECRETIONS IN DACITE.

FIG. A.—Light-colored granophyric secretion from the dacitic ejectamenta. Magnified 48 diameters. Specimen No. 148. A photomicrograph in white light. Shows the occurrence of dark-brown glass, plagioclase, spongiform sanidine, parallel growing prisms, and grains of hypersthene and augite, also a little magnetite. See page 136.

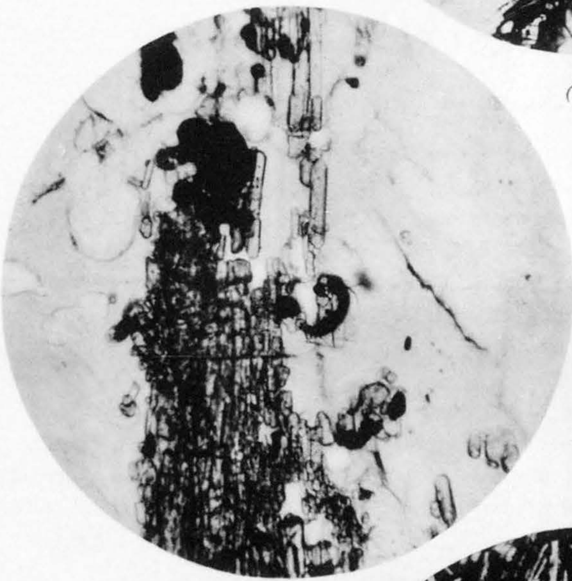
FIG. B.—Light-colored granophyric secretion from the dacitic ejectamenta. Magnified 86 diameters. Specimen No. 149. A photomicrograph in white light. Shows a bundle of parallel arranged prisms of hypersthene and augite, which can not be distinguished from each other in the photograph. See page 139.

FIG. C.—Magnified 48 diameters. Specimen No. 2029 (private collection of H. B. Patton). A photomicrograph in white light. Shows the interstitial structure of some of the basalts. See page 142.

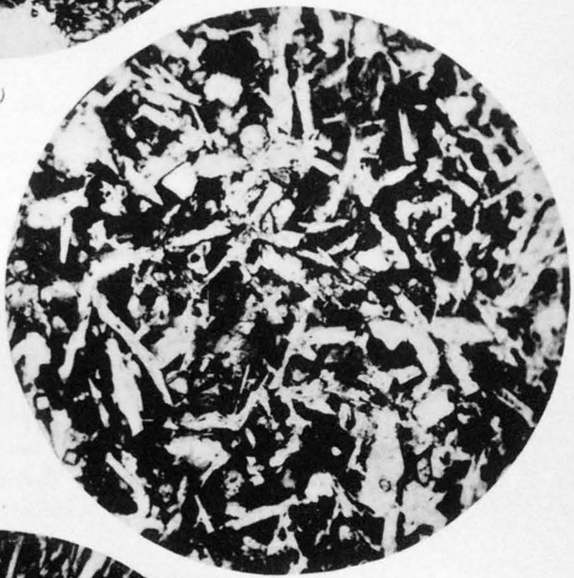
FIG. D.—Basalt, Timber Crater. Magnified 48 diameters. Specimen No. 165. A photomicrograph in white light. Illustrates the fluidal-interstitial structure of some of the basalts. See page 149.



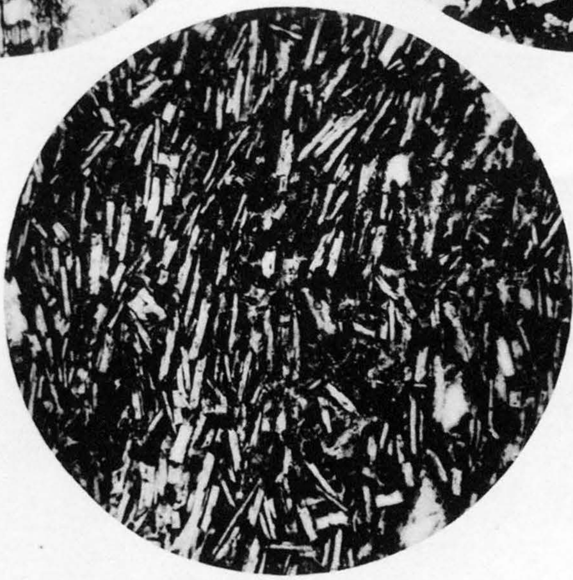
(A)



(B)



(C)



(D)

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Hypersthene and augite are both very abundant. 'Neither of them occur in the customary idiomorphic crystals but either in perfectly irregular grains or—which is generally the case—in various shaped aggregates, or more especially in clusters or bunches of loosely aggregated and parallel-growing roundish and rather slender prismatic grains. Both of these minerals assume this same form and usually both of them occur together in parallel growths. All conceivable variations may be observed between isolated individuals of hypersthene or augite of the shape just mentioned and parallel aggregates of the same that contain hundreds of the small prismatic grains. Some idea of this occurrence may be derived from fig. *B* of Pl. XIX. Hypersthene seems to be the more abundant of the two. In color the hypersthene is not quite so dark as it is in the ordinary dacites of Crater Lake. Pleochroism, therefore, can not readily be seen in such sections as are necessary for proper study of the aggregates. The augite appears almost colorless in thin section. With these two pyroxenes there is constantly associated considerable magnetite, which occurs mostly in very minute grains inclosed in the individual pyroxene grains or clustered with them in these bunches.

The chemical analysis of No. 151 will be found on page 140, together with the other chemical analyses. While somewhat more basic than are the dacites proper, the analysis of this specimen will be seen to compare fairly closely with that of No. 114. The excess of lime may perhaps be attributable to the abundance of the pyroxene. It can hardly be due to the relative abundance of the feldspar, as the plagioclase present does not appear to be particularly basic, and the sum of the alkalies present is rather less than is the case with the dacite whose analyses are given.

In conclusion, we may say that the absolute freshness of these specimens would seem to preclude the possibility of a secondary origin for the granophyric growths.

SECRETIONS WITH BASALT-LIKE STRUCTURE.

In addition to the above-described secretions there remains a specimen collected in the bottom of the Sun Creek Canyon and already mentioned on page 123, that can not be classified with any of these varieties. The specimen in question (123) has a grayish color and is rather fine grained, but is distinctly granular and porous. In thin section the structure appears at first glance to be distinctly basaltic, with dark-brown glass in the angular interstices formed by the intersections of rather short, thick-set plagioclase laths. Both hypersthene and augite abound and occur in irregular grains not dissimilar to the basaltic pyroxenes, also in long, slender, prismatic forms. In addition to these minerals, hornblende in dark reddish-brown grains and prisms is quite abundant, and magnetite in occasional black grains. Occasionally a plagioclase or hypersthene crystal assumes somewhat larger form and appears in the rôle of a phenocryst. What appears to be dark-brown glass inclosing slender augite microlites and filling the interstices between the plagioclase laths is seen in polarized light to be small, spherulitic crystallizations. In spite of the general structure this rock is quite different from any of the Crater Lake basalts. Its association with dacites and the presence of abundant hornblende, as well as the spherulitic base, lead to the conclusion that this is in reality a secretion in a dacitic magma.

An inclusion in a dacite dike below Llao Rock, described on page 122, is considered to be a similar occurrence.

CHEMICAL ANALYSES OF DACITES.

The following analyses were made in the laboratory of the United States Geological Survey:

Analyses of Crater Lake dacites.

[Analyses by H. N. Stokes.]

	102.	113.	114.	130.	143.	151.
SiO_2	70.77	70.10	68.17	71.87	56.85	67.41
Al_2O_3	14.83	15.18	15.60	14.53	18.31	15.76
Fe_2O_3	1.35	1.78	2.31	1.28	2.88	1.88
FeO	1.25	1.09	.94	1.02	3.15	1.76
MgO	.64	.74	1.02	.48	3.92	1.35
CaO	2.12	2.27	2.76	1.59	7.20	3.36
Na_2O	5.07	5.15	5.15	5.08	3.89	4.54
K_2O	2.68	2.58	2.46	2.84	1.23	2.36
H_2O-	.07	.10	.09	.06	.16	.09
H_2O+	.33	.19	.45	.22	.95	.54
TiO_2	.38	.48	.54	.41	1.08	.56
ZrO_2	.05	.04	None.	.04		
CO_2	None.	None.	None.	None.	None.	None.
P_2O_5	.13	.13	.13	.10	.22	.12
SO_3	None.	None.	None.	None.	None.	
Cl	.11	.03	Trace.	Trace.		
F	Undet.	Undet.	Undet.	Trace.		
S	None.	None.	None.	None.	None.	[a].02
Cr_2O_3	None.	None.	None.	None.	None.	None.
NiO	None.	None.	None.	None.		
MnO	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.
BaO	.08	.08	.06	.08	.04	.06
SrO	.02	.03	.03	.03	Trace.	Trace.
Li_2O	Trace.	Trace.	Trace.	Faint tr.	None.	Trace.
Total	99.88	99.97	99.71	99.63	99.88	99.81

[a] Or SO_3 = .04. Whether present as S or SO_3 undetermined.

NOTE.—O = Cl.

No. 102. Hypersthene-dacite, vitrophyric type, south edge of Llao Rock flow. See page 106.

No. 113. Lithoidal hypersthene-dacite, water's edge, head of Cleetwood Cove. See page 113.

No. 114. Streaked, vitrophyric hypersthene-dacite, near Wineglass, Grotto Cove, on the east side of the lake. See page 114.

No. 130. Hypersthene-dacite, lithoidal type, from a small dike that cuts the older flows immediately below Llao Rock.

No. 143. A dark-colored secretion found among the dacitic ejectamenta. See page 130.

No. 151. A light-colored secretion found among the dacitic ejectamenta. See page 139.

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 1½ 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 rôle. 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 hypersthenes. 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.

HYPERSTHENE

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 hypersthenes 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 hypersthenes 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 magn.atic 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 $SiO_2=55.18$ 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] The description here given is the work of Dr. C. Palache.

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.

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

a, 100	*n*, 210	*i*, 121
b, 010	*w*, 310	*u*, 322
m, 110	*k*, 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]

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.

	Measured.		Calculated.		Number of readings.
	φ	ρ	φ	ρ	
	° ′	° ′	° ′	° ′	
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.

[a] Zeit. für Kryst., Vol. X, 1885, p. 210.

[b] This 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.

[c] Bull. Soc. min. France, Vol. I, 1878, p. 47.

[d] The description here given is the work of Dr. C. Palache.

[e] Among 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.
	φ		ρ		φ		ρ		
	°	′	°	′	°	′	°	′	
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.

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

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

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.

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

[a] Mikroskopische Physiographie, 3d edition, Vol. II, 1896, p. 993.

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."

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

[a] Geologic Atlas U. S., folio 43. [b] Jour. Geol., Vol. III, 1895, p. 409.

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_2O	1.37
Na_2O	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.

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

[a] Rosenbusch, Elemente der Gesteinslehre, Stuttgart, 1898, p. 309.
[b] A late volcanic eruption in northern California and its peculiar lava: Bull. U. S. Geol. Survey No. 79, 1891, p. 29.
[c] Origin of primary quartz in basalt: Am. Jour. Sci., 3d series, Vol. XXXVI, 1888, p. 220.

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 anyalysis 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 rôle, 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.

ANDESITIC BASALTS.

In nearly all of the basalts thus far described in these pages the structures have been distinctly different from what has been described as characteristic of the andesites. To a certain extent this may also be said of the composition. But in the rocks here designated as andesitic basalts these differences in structure and also in composition to a large extent disappear, so much so that were it not for close association with more distinctly basaltic types, some of those here included would certainly be classed with the andesites. In the absence of chemical analyses the correctness of these determinations must be taken with some reserve. A general statement of the differences noted between the andesitic basalts and the andesites will be given at the close of the more detailed description. As compared with the foregoing basalts, these may be said to be distinguished, with one or two exceptions, by the presence of a hypocrystalline groundmass or of one with an evident glass base, as well as by the presence of well-developed phenocrysts of plagioclase.

Four somewhat distinct structural types may be recognized. They are designated as types A, B, C, and D.

ANDESITIC BASALTS, TYPE A.

This may be studied in three specimens (179, 180, 181) from Crater Peak, about 4 miles south of the lake, and in one specimen (182) in the extreme southwestern corner of the Crater Lake area. These are black to blackish-gray, very fine grained and mostly porous rocks that have, with the exception of No. 182, small, but rather conspicuous, plagioclase phenocrysts. The groundmass of these rocks consists of a brownish glass base clouded with black dust and very thickly crowded with prismatic augite microlites and with minute magnetite octahedrons, and containing microlitic crystals that consist of very long and slender plagioclase laths. These laths have straight sides, while the ends are sometimes cut squarely off, but are more often somewhat frayed. They inclose usually small amounts of the dusty looking, almost opaque, glass of the groundmass. The inclosures take the form of minute specks that are strung together parallel to the longest axis of the lath, so as apparently to divide the lath into two or more longitudinal sections. The laths are not numerous enough to interlace to any marked extent. The occurrence of these slender lath forms is the most distinctive feature of type A.

The phenocrysts are mainly plagioclase crystals which in No. 182 occur in broad-shaped laths, and are similar to and grade into the more slender and much smaller laths of the groundmass, and disclose almost no inclosures, except an occasional bit of brown glass containing crystallizations similar to those of the groundmass. The rocks from Crater Peak, however, contain in addition to rectangular or broad lath-shaped individuals also larger and stouter crystals that exactly resemble the older plagioclase phenocrysts of the typical andesites. These usually have clear margins and clear centers, but between the two have a narrow zone that is clouded with brownish glass inclosures. Some of the larger crystals also show rounded forms with embayments due to resorption, in which case the clouded zone follows the contours of the corroded crystal, being still separated from the edge of the crystal by a narrow clear margin. This case is exactly identical with what has already been described under the andesites.

Augite occurs among the phenocrysts in mostly small and inconspicuous and not very well-defined crystals, also in grains, and is not very abundant. Hypersthene appears to be entirely wanting in one thin section, while in the other three only eight individuals altogether were noted. The habit is prismatic, but the form is not distinct. Six out of the eight individuals have rims of augite in parallel position.

Olivine is fairly abundant in small crystals and grains and occurs occasionally in better-formed, larger crystals of the ordinary type. In No. 179, however, and to a less extent in No. 181, this mineral also occurs in a very unusual form. It is in long slender prisms that show squarish cross section. The elongation is parallel to the crystallographic axis a and corresponds to the axis of least elasticity. These slender prisms extinguish parallel and exhibit the usual refractive properties of olivine. A section cut parallel to the brachypinacoid disclosed a negative bisectrix with large optical axial angle, the axial plane being parallel to the elongation. In No. 181 one section, cut so as to show squarish cross section, disclosed in convergent polarized light a bisectrix with the axial plane in a diagonal direction. This observation, coupled with the fact that all squarish sections extinguish in the direction of the diagonal, indicates that the prismatic habit is due to the extension of the crystal parallel to the a axis and that the form is really the brachydome (021). These olivines show a slight corrosion, and have developed narrow resorption rims of magnetite. They often contain inclosures of glass that are black and nearly opaque with inclosed magnetite grains. Such glass inclosures are often of irregular shape, but commonly they are arranged in longish forms stretched parallel to the elongation of the crystal. These long inclosures do not extend the whole length of the crystal. They are more apt to be in the center of the crystal and, when seen in cross section, are square, the sides of the inner black square being parallel to the sides of the crystal. This appearance is very suggestive of the black squares to be seen in cross sections of chiastolites.

ANDESITIC BASALTS, TYPE B.

This is represented by three specimens collected 2 or 3 miles west and northwest of Red Cone. They are distinctly andesitic in appearance, being gray, rather compact rocks with numerous but small and inconspicuous plagioclase phenocrysts. These might readily be taken for andesites, but, aside from certain differences in structure that alone might not be decisive, their association with distinctly basaltic rocks may justify their being classed under the basalts.

Under the microscope the groundmass is quite different from type A. One specimen (183) is apparently holocrystalline, one (184) contains a very little, and the third (185) quite a perceptible amount of glass. The holocrystalline specimen has a groundmass composed of minute prismatic crystals of augite, octahedral magnetite, and abundant plagioclase. The plagioclase consists in part of distinctly recognizable laths, much smaller and less well defined than in type A, also a sort of residual feldspathic paste that does not show distinct form and can not be clearly demonstrated to have polysynthetic twinning. It has, however, a more or less undulous extinction, and resembles the feldspathic residual paste of some of the andesites. In the more glassy variety the augite is not so abundant, and the plagioclase appears clouded and indistinct because of the dusty-looking glass that impregnates the whole, but still can not be plainly recognized.

Phenocrysts are abundant and well formed. They are plagioclase, hypersthene, augite, and, in the case of No. 183, olivine. The plagioclase is characteristically andesitic in type, showing zonal structure and containing inclosures of hypersthene, magnetite, and glass in its accustomed distribution. Hypersthene and augite are in sharply defined crystals, except where they occur in nests, which is commonly the case. They have the color and pleochroism common to these minerals in the andesites. They both contain inclosures of colorless glass with air cavities, also of magnetite. Parallel growths of augite around hypersthene allies two of these (184 and 185) to the basalts. The olivine of No. 183 is not abundant. It occurs mostly in grains and in rounded forms with magnetite rims. Magnetite occurs in the customary octahedral crystals.

ANDESITIC BASALTS, TYPE C.

This is, perhaps, the least andesitic in appearance and the least deserving of being classified as a distinct type of all the basalts of this region. The two specimens that belong here (186 and 187) were collected from the basaltic rocks in the extreme southwestern part of the mapped area, about 1 mile from No. 182. As these two specimens bear a closer resemblance to this rock, perhaps, than to any othei one, they may be looked upon as a facial development of No. 182. These are blackish-gray, very dense rocks with a basaltic rather than andesitic appearance, being apparently free from phenocrysts. In thin section, however, they are seen to contain numerous but small phenocrysts of plagioclase with broad lath-form, suggestive of a basaltic rather than an andesitic type. In addition to these there are only a few olivine and augite (but no hypersthene) phenocrysts in roughly idiomorphic or in granular form. The groundmass consists of a feldspathic paste thickly crowded with roundish, roughly prismatic or irregular augite grains, and with magnetite. Glass appears to be wholly wanting.

ANDESITIC BASALTS, TYPE D.

This type is preeminently andesitic, either through the development of plagioclase phenocrysts or through the presence of an abundant glassy base. The rocks here represented are confined to the lava flows to the northwest of the lake. Nos. 188 and 189 come from the eastern slope of the second summit north of Desert Cone, No. 190 comes from the summit of the first hill north of Desert Cone, and No. 191 about half a mile south of this same summit and not far from the saddle between that hill and Desert Cone. Nos. 192, 193, and 194 were collected at, or not far from, the summit of Bald Crater, and Nos. 195 and 196 from the nearly flat region west of Red Cone.

These basalts are dark to black, dense and partly vesicular rocks with a more liberal development of minute feldspar phenocrysts than is the case with most of the other andesitic basalts. In spite, however, of the distinctly andesitic type, these rocks when examined under the microscope are seen to be almost entirely free from the larger, stout plagioclase phenocrysts that are so characteristic a feature in most of the andesites, and that may also be seen occasionally in some of the above-described basalts. Certainly they are free from all resorption phenomena and from the intermediate clouded zone characteristic of the larger plagioclase phenocrysts of Nos. 179, 180, and 181 of type A. In form they are usually rectangular or broad lath shaped, and they vary in size from one-half millimeter or even one millimeter down to the microscopic dimensions of the groundmass laths. There is, in fact, no sharp line to be drawn between the plagioclases of the groundmass and of the phenocrysts. They vary greatly in the character and amount of inclosures. At times the centers are thickly crowded with irregular glass inclusions; at times these glass inclusions are scattered or even altogether missing. Less commonly one may note inclusions of hypersthene or of augite.

While plagioclase is by far the most abundant phenocryst, the pyroxenes are also abundant. These are usually well developed, especially in No. 196, and have the customary properties already frequently described. With the exception of the three specimens from Bald Crater (192, 193, 194) both augite and hypersthene are present. In these three specimens hypersthene could not be found. On the other hand, olivine, as is usually the case when hypersthene is absent or scarce, is much more abundant than is the case with the other basalts of type D. The pyroxenes, however, fluctuate greatly in amount and in definition. In Nos. 188, 189, 190, and 191 hypersthene is the more abundant, the augite being almost confined to the groundmass. Olivine is never entirely wanting, but it is conspicuous only in the three rocks just referred to. In these it is not always easy to distinguish between the olivine and the very light green augite, as the color is almost alike in the two. This difficulty is greater in sections of olivine that are cut nearly perpendicular to one of the bisectrices, as in this case the interference colors are no higher than in augite. The most conspicuous form developed is the brachydome (021), in addition to which there occurs either a prism or a pinacoid. One section cut perpendicular to this brachydome gave in the center of the field a positive bisectrix with large optical axial angle. The trace of the sides measured 82°, which is about one degree larger than is given for the angle of the brachydome (021).

The groundmass of these basalts contains not a little glass which is either brown or is colorless, but rendered brown by the presence of dust-like globulitic material. This brownish glass is thickly crowded with minute augite prisms and, to a much less extent, with magnetite and with plagioclase microlites, the last named being, in fact, almost absent from the Bald Crater basalt.

CHEMICAL ANALYSES OF BASALTS.

The following analyses were made in the United States Geological Survey laboratory:

Analyses of Crater Lake basalts.

[Analyses by H. N. Stokes.]

	158.	173.	189.
SiO_2	56.95	52.99	58.65
Al_2O_3	18.84	16.71	18.35
Fe_2O_3	2.06	3.80	1.59
FeO	4.28	3.55	4.21
MgO	4.37	6.95	3.49
CaO	7.45	8.49	6.95
Na_2O	3.89	3.56	3.70
K_2O	.82	1.29	1.32
H_2O-	.19	.18	.20
H_2O+	.31	.59	.70
TiO_2	.79	1.18	.81
ZrO_2	....	None.	....
CO_2	None.	None.	None.
P_2O_5	.19	.42	.17
SO_3	....	None.	None.
Cl	....	Trace.	....
F	....	Undet.	....
S	Trace.	None.	None.
Cr_2O_3	None.	None.	None.
NiO	....	.02	....
MnO	Trace.	Trace.	Trace.
BaO	.04	.07	.06
SrO	Trace.	.12	Trace.
Li_2O	None.	None.	None.
Total	100.18	99.92	100.20

NOTE.—O=Cl.

No. 158. A hypersthene-bearing basalt of the interstitial type, from Anna Creek. See page 145.

No. 173. Hypersthene-bearing basalt, porphyritic interstitial type, transitional to the andesitic type, from the base of Red Cone. See page 155.

No. 189. A hypersthene-bearing basalt of the andesitic type, from north of Desert Cone. This rock is doubtfully placed among the basalts, based upon structural and geological relationships. See page 160.

CONCLUDING REMARKS ON BASALTS.

At the time these rocks were studied no analysis of the andesitic types of basalts had been made, and the rocks were named in accordance with their structural features. In individual cases the resemblance of these andesitic basalts of type D could not well be distinguished from certain of the Crater Lake andesites. It was only by taking all the specimens collected from a particular volcanic center that the real differences could be made to appear. The surmise that these rocks are nearly if not quite the equivalent of the andesites is borne out by an analysis made later and found on page 161. This rock, No. 189, comes from the lava flow northwest of the Pumice Desert on the extreme northern edge of the area mapped. The analysis is not far different from the average analysis of the Crater Lake andesites. It is very closely similar to the analysis of the andesite No. 31, given on page 94.

From a comparison of these analyses it is evident that chemically there is no marked distinction between this andesitic basalt and some of the rocks that may be considered as true andesites.

If this individual rock sample could well be considered apart from the immediately surrounding rocks it should be designated as an andesite, but the preponderating evidence seems to point to the general rock mass from which this was taken being a basalt.

The features that distinguish these rocks from the andesites are, first, the abundance of olivine which, though very fluctuating, is a nearly constant ingredient, supplanting in whole or in part hypersthene; second, the frequent disappearance of the hypersthene; third, the relatively greater abundance of augite both among the phenocrysts and in the groundmass and, in the latter case, their greater size and less distinctly microlitic form; fourth, the comparative scarcity of a glassy base; fifth, the greater abundance of magnetite.

The basalts of Crater Lake of all types are, like the andesites and dacites, almost completely unaltered. With the exception of olivine, the ingredients are apparently as fresh as when first formed. The only forms of alteration in the olivine as far as noted are the partial serpentinization and the development of magnetite and hematite. The development of the homogeneous pseudomorphs after olivine, described by Iddings from somewhat similar rocks in the Eureka district, Nevada,[a] and named iddingsite by Lawson,[b] have not here been noticed.

The hypersthene-bearing basalts of the Eureka district, Nevada, which have been described by Mr. Iddings in the monograph just above quoted, appear from

[a] Geology of the Eureka district: Mon. U. S. Geol. Survey, Vol. XX, 1892, p. 387.
[b] Bull. Dept. Geol. Univ. California, Vol. I, pp. 31-36.

Mr. Iddings's description to be closely related to the basalts of Crater Lake, more especially, however, to the andesitic basalts, except that the Eureka district basalts are much less feldspathic. Not only is the general character of the groundmass the same, but also the pyroxenes and the fluctuating olivine that comes in with the disappearance of hypersthene. Furthermore may be noted the relationship of the generally older hypersthene to the younger augite and the parallel growths of augite around hypersthene phenocrysts, which is an almost universal occurrence in the Crater Lake basalts of all types. Comparison may also be made with the quartz-bearing basalt of Cinder Cone, north of Lassen Peak, in northern California, described by Mr. Diller in a paper on A Late Volcanic Eruption in Northern California and its Peculiar Lava.[a] With the exception of quartz, the resemblance is quite close. More especially may be mentioned the magnetite rims around the olivine crystals and the plagioclase phenocrysts with their frequently corroded forms and glass inclusions, as well as the development of the monoclinic and orthorhombic pyroxenes.

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[a] Bull. U. S. Geol. Survey No. 79, 1891.

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	4,400
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		

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[Professional Paper No. 3.]

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