CRATER LAKE

by Howel Williams

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Crater Lake lies inside the collapsed top of an ancient volcano called Mount Mazama. The bowl-shaped depression holding the lake is known as a caldera. The Mount Mazama volcano is one in a north-south chain of huge cones built during the last few hundred thousand years along the crest of the Cascade Range, stretching about 600 miles from Lassen Peak in California northward to Mount Garibaldi, near Vancouver, British Columbia. Other conspicuous volcanoes in the chain include Three Sisters, Glacier Peak, and Mounts Shasta, Jefferson, Hood, Saint Helens, Adams, Rainier, and Baker.

Volcanic eruptions in the area of the present Cascade Range began about 35 million years ago, and they have continued at intervals down to historic times. The lava and ash discharged by the early eruptions over a period of more than 30 million years accumulated in some places to a thickness of more than 3 miles; they can now be seen all along the western slopes of the Cascade Range. Strangely enough, no unusually high mountains were formed by these vast piles of volcanic rocks, for erosion wore them down and the underlying floor sank as the rocks accumulated. Thus lush coniferous forest continued to grow in eastern Oregon until about 10 million years ago, as there was no mountain range like the present Cascades to check rain-laden winds from the ocean from spreading far inland. Subsequently, the ancient lava and ash were warped up to produce the original Cascade Range, and ever since that uplift began, the rich flora on the wet slopes to the west has contrasted with the desert flora on the plateau to the east.

During and after the uplift, rising magma (molten rock) forced open many north-south cracks beneath the present summit of the Cascade Range. Countless eruptions of fluid, wide-spreading flows of basaltic lava from these fissures gradually built a chain of coalescing "shield volcanoes", shaped like giant, overturned saucers, and not unlike those now active on the island of Hawaii. By the middle of the Pleistocene Epoch, about 1 million years ago, the crest of the Cascade Range had become a high plateau capped by many of these gently sloping shields. Shield volcanoes of that age are now much carved away by erosion, their originally smooth slopes cut by deep valleys. In the area around Crater Lake, eruptions of basaltic lava occurred off and on until perhaps 30,000 years ago and there is little doubt that they will occur again. Many of the younger vents (eruption sites) are marked by prominent cinder cones such as Red Cone and Crater Peak. Timber Crater is an example of a young shield surmounted by a cinder cone. Union Peak, 7 miles southwest of Crater Lake, is the glacially eroded core of a shield which originally resembled Timber Crater.

The prominent snowcapped volcanoes of the modern Cascade Range began to grow during the last part of the Pleistocene, that is to say during the last Ice Age. The lavas they erupted, changing in composition from basalt to andesite, became more viscous and therefore could not spread as far from their source vents as did those of the earlier shield volcanoes. Hence, the broad low shields were partly or entirely buried beneath steeper sided volcanic cones. Some of these cones have been deeply eroded by glaciers, so that the hard fillings of their central feeding pipes now stand out as summit pinnacles, like miniature Matterhorns. Among such eroded cones is Mount Thielsen, 12 miles north of Crater Lake.

Mount Mazama, the volcano that encloses Crater Lake, began to grow more than 400,000 years ago, near what is now the southeast shore of the lake. It rose from a foundation of older volcanic rocks approximately 6,000 feet above sea level, and it probably attained a maximum elevation of about 11,000 to 12,000 feet. At no time was it merely a single cone; rather, Mount Mazama was composed of a cluster of overlapping cones, each of which was active for a comparatively short time. The volcano grew almost entirely by eruption of andesitic lava and bombs (explosively ejected blobs of magma) from these closely spaced vents. Because basalt continued to be erupted in the area around the andesitic vents of Mount Mazama, it is believed that dense basaltic magma lay beneath the lighter andesitic magma bodies which fed the growing volcano. The oldest known part of the cluster of cones includes Mount Scott and the lavas exposed low in the south and east caldera walls. Andesitic vents gradually shifted northwest, laying down sheets of lava and bombs, culminating in eruptions near Hillman Peak about 70,000 years ago. Toward the end of this period, thick flows of andesitic lava descended the northeast flank of Mount Mazama; these flows now form the great cliffs at the caldera rim near Grotto Cove. There followed many eruptions of dacitic pumice and lava from widespread vents. Pumice Castle on the east caldera wall is composed of layers of this dacitic pumice that fell near a vent while still very hot and welded together to form resistant rock. Ash from these eruptions is found in sediments at Summer Lake, 70 miles east of Crater Lake. By 50,000 years ago Mount Mazama was again producing andesite lava, including flows on the southwest caldera rim and at Steel Bay. The Watchman dacite flow also dates from this time; its feeder dike can now be seen as a dark fin below the flow on the caldera wall.

About 40,000 years ago, dacite domes were emplaced near the summit of Mount Mazama, probably growing in the same manner as the lava dome in the crater of Mount St. Helens following its May, 1980 eruption. These domes became oversteepened, were blown apart by steam explosions, and formed avalanches of hot rock fragments which came to rest in the head of Munson Valley and on the west flank as far north as Devils Backbone. Because these avalanche deposits are not found on the remaining north or east flanks of Mount Mazama, we can infer that the dacite domes were erupted southwest of the former summit. Williams Crater (named in honor of the late Professor Howel Williams) and its complexly mixed lavas of basalt, andesite, and dacite are younger still, perhaps no older than about 25,000 years.

While Mount Mazama grew, glaciers advanced and retreated on its flanks many times. The glaciers carved deep U-shaped canyons on the slopes of the volcano, such as those that now form Sun and Kerr Notches on the caldera rim. Some andesite flows, such as the one that forms Sentinel Rock, partly filled valleys previously carved by glaciers. Other lava flows encountered glacial ice and were rapidly chilled to glass, fracturing into small blocks or cracking into spectacular radiating columns. One of these flows outlines the "stem" of the Wineglass. The glaciers, moving slowly down the sides of the volcano, polished, grooved, and scratched the lava surfaces in their path. Such markings that were made by the last glaciers can be seen today in many places along the rim of Crater Lake caldera and are especially well displayed between Devils Backbone and Merriam Point. As the glaciers melted they left moraines of bouldery debris far down the flanks of Mount Mazama.

When the last glaciers reached their maximum size, about 18,000 years ago, some of them were more than 1,000 feet thick, and some spread down the mountainside for distances of 10 to 17 miles. Except for a few narrow ridge-crests, the entire volcano was sheathed in a mantle of ice. By about 12,000 years ago the glaciers had retreated, and forests spread upward in their wake. Trees three feet or more in diameter grew along what is now the south rim of the caldera.

At the same time, the volcano was changing its character. Eruptions of viscous rhyodacite built a small dome above Steel Bay and the thick lava flows of Grouse Hill and Redcloud Cliff approximately 30,000 years ago, hinting at growth of the magma chamber that later erupted catastrophically to form the caldera. Several hundred thousand years of andesitic volcanism had transferred vast amounts of heat to the earth's crust and gradually set up the necessary conditions for formation of a large volume of rhyodacitic magma at the relatively shallow depth of perhaps 3 to 6 miles below the surface. Growth and separation of crystals rich in calcium, iron, and magnesium from the magma caused a relatively light, gas-rich rhyodacitic liquid containing only a few crystals to accumulate above a heavier liquid containing many crystals but less gas. By about 7,000 years ago rhyodacite magma had erupted from the chamber to form the domes at Sharp Peak and the great lava flow, and associated pumice, at Llao Rock. The explosion craters that formed at the beginning of the eruptions subsequently were filled to overflowing by the lava flows that form Redcloud Cliff and Llao Rock. Pumice and ash from the Llao Rock vent were carried great distances by winds; ash evidently from this eruption is found as far afield as northern Washington and western Nevada. Perhaps other rhyodacitic lava flows or domes that had been emplaced at higher elevations were engulfed and their record lost when the caldera formed.

Between 100 and 200 years after the Llao eruption a fourth immense rhyodacitic lava flow, the Cleetwood flow, was erupted from a vent just northeast of Cleetwood Cove. The stage was now set for the climactic outbursts that were to destroy the top of Mount Mazama and produce the colossal basin, or caldera, that holds Crater Lake, for it is known that the Cleetwood flow was still hot when the catastrophic eruption began.

The rhyodacitic magma first discharged in the great eruption was blown high above the mountaintop from a vent thought to have been located near what is now the deepest part of the lake. Rising in a towering Plinian eruption column (see diagram A below), the ejected magma fell to earth as fragments of frothy white pumice and as volcanic ash consisting of fine shards of volcanic glass mostly of sand or dust size. As the eruption continued, the size of the pumice fragments increased, and the winds veered northeast. Some of the fine ash has been identified as far away as Alberta, Canada, and much of it must have risen into the stratosphere to cause brilliant sunrises and sunsets all over the Northern Hemisphere. The total areas covered by falling pumice and ash at least one millimeter thick (about four hundredths of an inch) was more than 1,000,000 square miles, and no less than 5,000 square miles were buried to a depth of more than 6 inches, as shown on the map below. All of eastern Oregon and eastern Washington, blanketed by white pumice and ash, must have had a wintry aspect, as if covered by a heavy snow fall. How long these initial Plinian eruptions lasted cannot be told with certainty, but by comparison with the famous 1883 eruptions of Krakatau in Indonesia, they probably lasted no more than a few months and possibly as little as a few days.

As the eruption progressed the vent enlarged to the point where the expanding gas could no longer carry all the pumice and ash high into the air. The eruption column became unstable and collapsed to play at a much diminished height. This "collapsed column" generated pyroclastic flows, fast-moving glowing clouds of pumice, ash, and hot gas, that traveled down valleys on the north and east flanks of Mount Mazama (diagram B) to form the Wineglass Welded Tuff, an orange to brown layer that can be seen near the caldera rim. These pyroclastic flows retained their volcanic heat so effectively that when they came to rest the hot pumice and ash welded together to form dense rock. Lack of any of the Wineglass Welded Tuff on the west or south rim of the caldera indicates that the vent for this and the preceding Plinian eruption was located northeast of the summit of Mount Mazama and that the caldera had not yet formed.

The eruptions then changed radically in character. Ejection of more than five cubic miles of rhyodacitic magma to form the widespread airfall deposits and the Wineglass Welded Tuff had withdrawn support from beneath the roof of the magma chamber and the mountain began to collapse. At the same time, new vents opened in a ring around the foundering block (diagram C). Eruption columns were higher than those that produced the Wineglass Welded Tuff, and far more mobile pyroclastic flows rushed down all sides of the mountain at speeds in excess of 100 miles per hour, surmounting all obstacles in their path. The flows carried not only glowing pumice, but also blocks of rock up to 15 feet across that were brought up the vents from deep within Mount Mazama. These flows were so energetic that they left deposits of such rocks on top of virtually all the hilltops within 6 miles of the caldera rim and even near the summit of Mount Scott. Some pyroclastic flows rushed down the old U-shaped glacial valleys; those that emptied into the valley of the Rogue River did not stop until they had traveled 35 miles, even though much of their path lay through dense forest. North and east of the volcano where there were no deep canyons to confine the flows, they spread in wide sheets, some pouring into Klamath Marsh while others swept by the present site of Chemult with such speed that they traveled 25 miles from their source, across a plateau, and even uphill. Such was the mobility of these turbulent, incandescent avalanches that lumps of pumice 14 feet in diameter were carried for a distance of 20 miles.

Shortly before the eruption of pyroclastic flows ended, the lower levels of the feeding chamber were tapped, so that the sheets of white rhyodacitic pumice were buried in places by darker andesitic to basaltic scoria very rich in crystals. These deposits are still visible on the walls of Castle and Annie Creeks and, even more clearly, at the Pinnacles on Wheeler Creek. During the catastrophic eruption of pyroclastic flows, the caldera was forming by collapse of the mountaintop. We know when the caldera formed because the part of the Cleetwood flow that was thickest, and therefore still very hot and able to flow, oozed down the caldera wall at Cleetwood Cove and formed a tongue of lava known as the Cleetwood backflow. As the lava moved, the relatively cool and brittle top of the Cleetwood flow fractured, breaking the thin layer of the Wineglass Welded Tuff lying on the flow's surface. These fractures developed into faults bounding subsided blocks of the flow's top; scarps along the faults exposed the Wineglass Welded Tuff and underlying airfall pumice in cross section. The scarps were then covered by deposits of the later pyroclastic flows, showing that the backflow began to form--and the caldera was already present--before the last pyroclastic flows traveled over the Cleetwood flow. Where it was thickest, the Wineglass Welded Tuff also began to slump into the caldera before completely cooling to hard rock. Thus the entire climactic eruption and formation of the caldera took place virtually without interruption, probably during a period of only a few days.

Finally, after a few weak, dying explosions, the eruptions ceased. All of the wooded glacial canyons on the slopes of Mount Mazama had been utterly devastated, choked to depths of 300 feet or so by deposits of hot pumice and scoria, which continued to give off acid fumes for many years. Each canyon had been changed to a "Valley of Ten Thousand Smokes," like the one formed at Katmai, Alaska, in 1912, when a green valley was similarly filled by glowing avalanches of pumice and ash. Even more dramatic was the change in the form of Mount Mazama. The high peak, long a familiar landmark to the Indians, had vanished, and in its place was an awesome pit, a caldera between 5 and 6 miles wide and 4,000 feet deep, on the bottom of which volcanic gases and steam were emitted from countless fumaroles and boiling pools (diagram D). The collapse was eccentric with respect to the former top of Mount Mazama, for the top lay well to the south of the center of Crater Lake; that is why the southern wall of the caldera is much higher than its northern counterpart. And for miles in all directions, the dreary wastes of pumice and scoria were made still more desolate by the charred ruins of the former forests.

Between 10 and 13 cubic miles of the mountaintop had disappeared. How did it happen? Surely the volcano had not simply "blown its top." Had the peak been demolished by explosions, enormous volumes of coarse, blocky debris would be found along the rim of Crater Lake and stretching thence for many miles. Such debris as is present was deposited by pyroclastic flows and that is too little to account for the missing mountaintop; in many places, indeed, ice-scratched surfaces of lava are still exposed along the caldera rim, and elsewhere the old lavas of the volcano are thickly covered by pumice.

By far the greater part of the material blown out during the climactic eruption was fresh magma emptied from the chamber beneath the volcano. The volume of material that fell as fine ash (some of which may have been derived from clouds of gas rising from the pyroclastic flows) and in showers of coarser particles is equivalent to at least 8 cubic miles of dense rock, of which only a very small proportion consists of bits of old lava torn from the top of Mount Mazama; the rest consists of fragments of pumice and their included crystals. The volume of the glowing avalanches of white pumice and dark scoria amounts to over 4 cubic miles of dense rock. Perhaps 20 percent of this volume is made up of fragments from the old mountaintop; the remainder represents fresh magma from the underlying reservoir. Weak, dying explosions added about a quarter of a cubic mile to the total volume. Preclimactic rhyodacitic lava flows (Llao Rock, for example) and pumice account for another 1 to 3 cubic miles of magma lost from the chamber shortly before collapse. All told, the equivalent of approximately 13 to 15 cubic miles of rock were discharged, a figure very close to that estimated for the missing volume of Mount Mazama. As at Krakatau in 1883, it was principally the rapid escape of enormous volumes of fresh magma which, by draining the feeding reservoir, caused the top of the volcano to collapse.

When did these dramatic events take place? After the radiocarbon method of dating was developed in the 1950's, tests revealed that charcoal logs within the glowing avalanche deposits were burned about 6,600 years B.P. (for consistency, radiocarbon dates are given in years "before present" with the year 1950 arbitrarily used as "present"). Later and more refined radiocarbon determinations give dates averaging about 6,850 years B.P. Crater Lake caldera formed, therefore, around the year 4,900 B.C. Discovery of obsidian tools, spear throwers, sandals, and other artifacts beneath the pumice to the north and east of Crater Lake indicates that Indians must have witnessed the destruction of Mount Mazama.

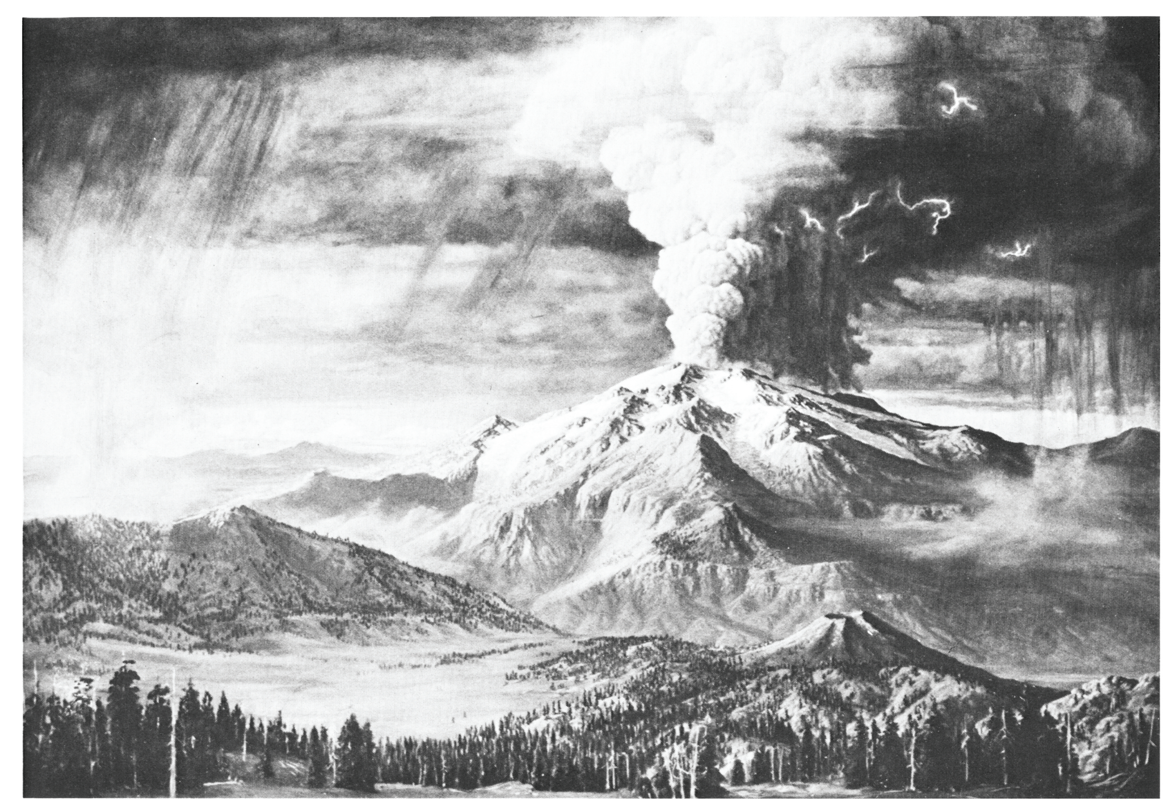
After a quiet period of unknown duration, eruptions began anew but were confined to the floor of the caldera. A detailed bathymetric survey of Crater Lake made by the U.S. Coast and Geodetic Survey in 1959 (shown below) and samples dredged from the lake floor reveal a record of this postcaldera volcanic activity. The oldest such volcanic feature may be the broad mound just west of the center of the lake. This is believed to be composed of andesite lava domes. Wizard Island (diagram E) evidently is younger and is the "tip of the iceberg" of a great pile of andesitic lava, built when the lake was about 250 feet shallower than now. Many flows of andesitic lava were discharged from fissures on the flanks of the cinder cone that forms the peak of the island, the last of them after the explosions of cinders had ended. A small submerged rhyodacite dome rises to within about 100 feet of the water's surface on the east flank of Wizard Island. This dome is younger than Wizard Island and may be the most recent volcanic feature on the lake floor.

Another submerged cone, almost a mile wide and 1,300 feet high, lies not far from the northern wall. This has been named Merriam Cone, and samples dredged from its sides show that it is built of andesitic bombs. An extensive flat area, including the deepest part of the lake (322 fathoms or 1,932 feet), adjoins this submerged cone. This area is flat because sediments washed down from the caldera walls have ponded in a former depression.

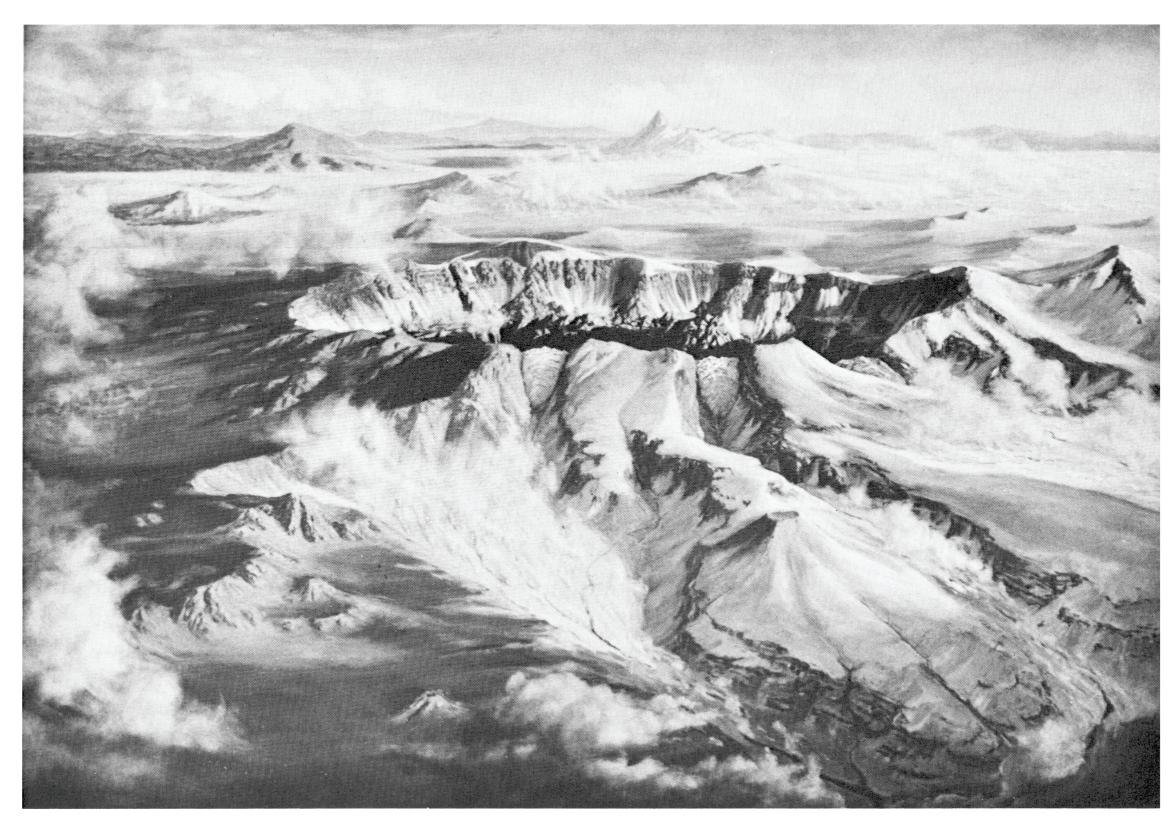
Crater Lake is the deepest body of fresh water in the United States, and its water is of exceptional purity. It was formed almost entirely by infalling rain and snow and seepage of ground water from the remains of Mount Mazama; springs and cascades from the walls presently contribute relatively little to its volume. The level of the lake varies only slightly with the seasons, being highest during the early summer when the snows are rapidly melting, and lowest at the end of the summer. Otherwise, the amount of water added every year keeps pace with that lost by evaporation and by percolation through the caldera walls. Lake water, however, has not been identified in any of the springs on the flanks of Mount Mazama.

Chemical analysis of the lake water and studies of the heat flowing upward through the lake bottom indicate that warm water enters the lake from below, heated by hot rock beneath the fractured caldera floor. It is not certain that any magma remains underground, and whether Mount Mazama is dead or merely dormant we cannot say.

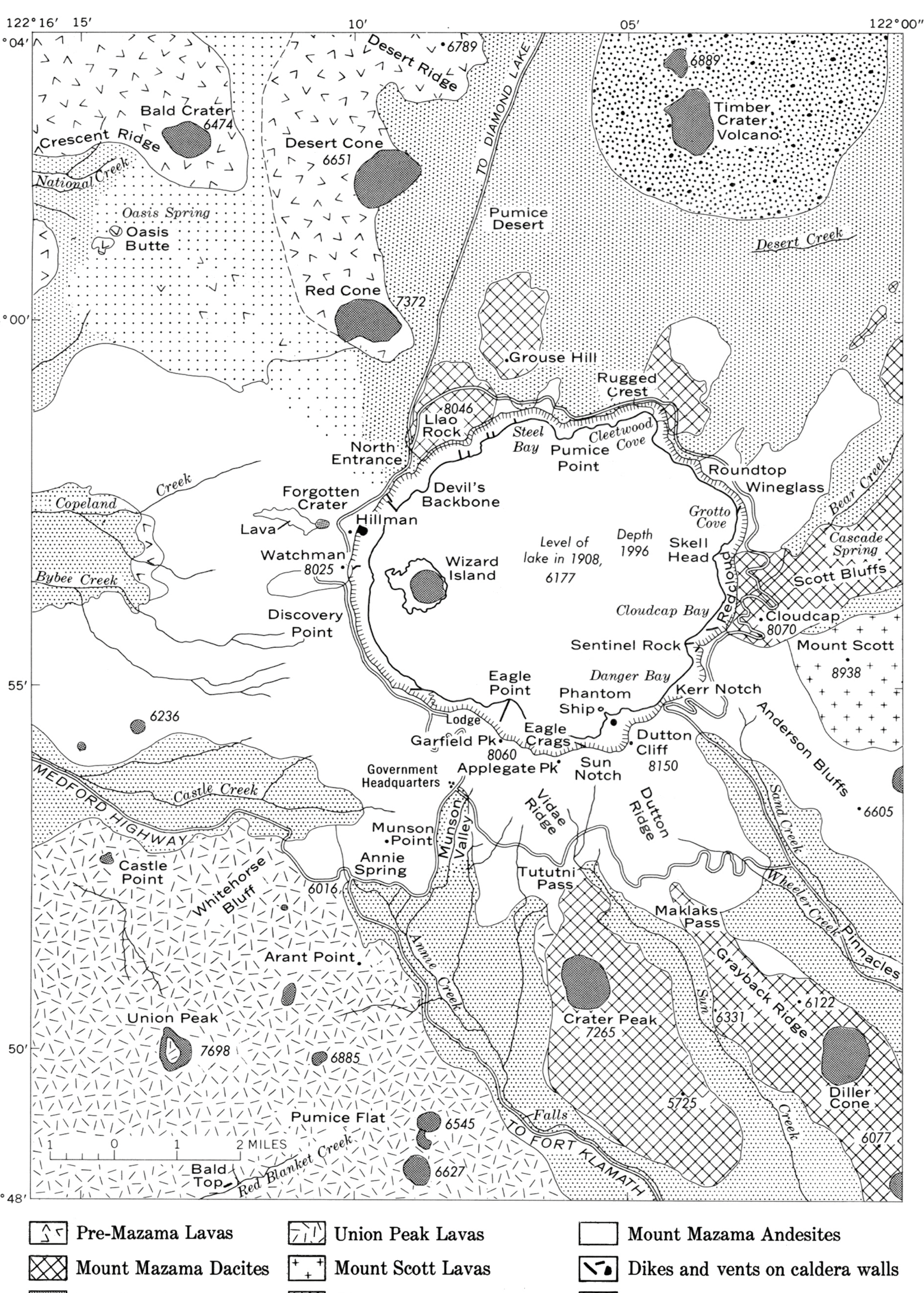
General aerial view of Crater Lake, looking east. Delano Photographics photo. Published in Bulletin 57, figure 32, Oregon State Dept. of Geology & Mineral Industries.



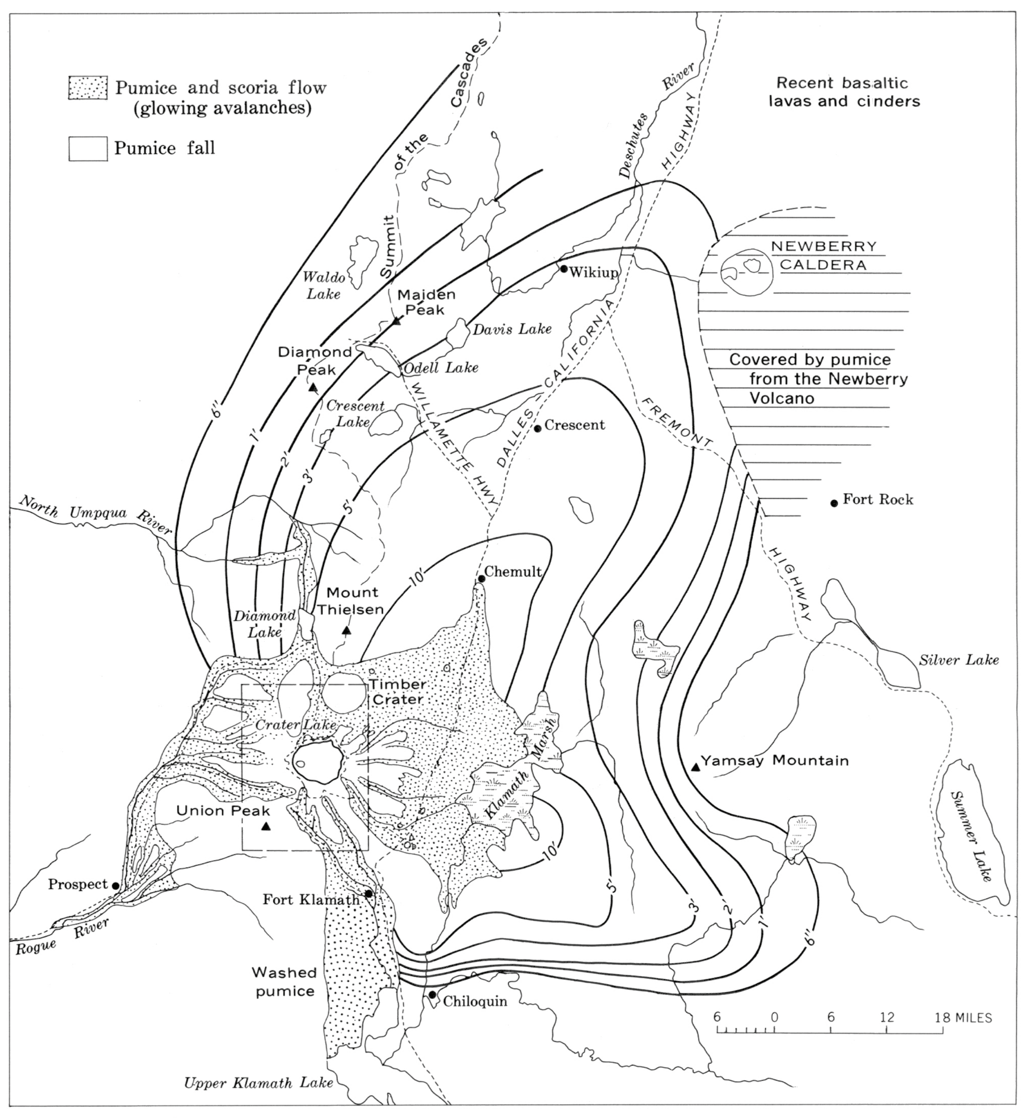
Mount Mazama at the start of the culminating eruptions, as envisioned by Howel Williams. Painting by Paul Rockwood.



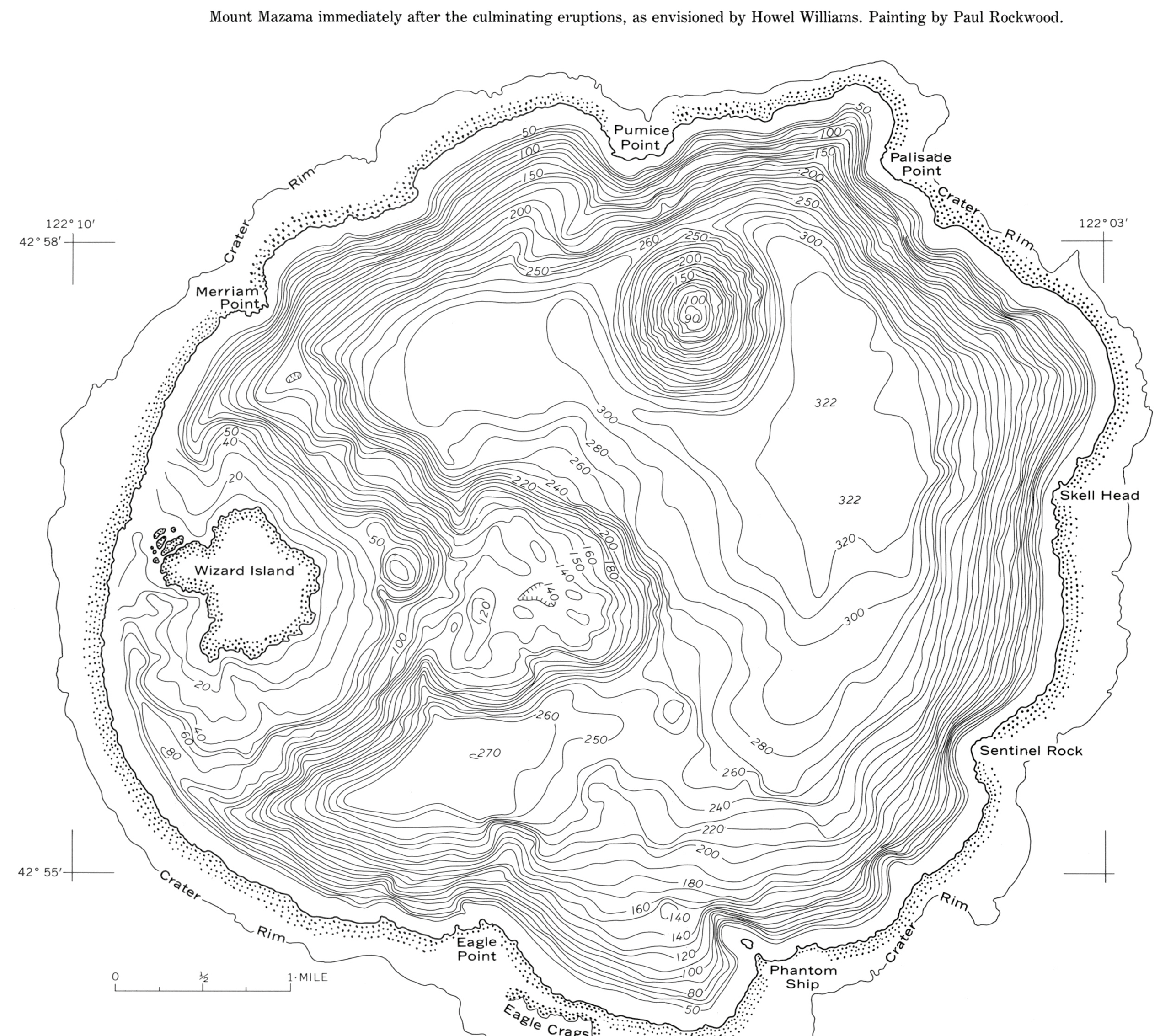
Mount Mazama immediately after the culminating eruptions, as envisioned by Howel Williams. Painting by Paul Rockwood.



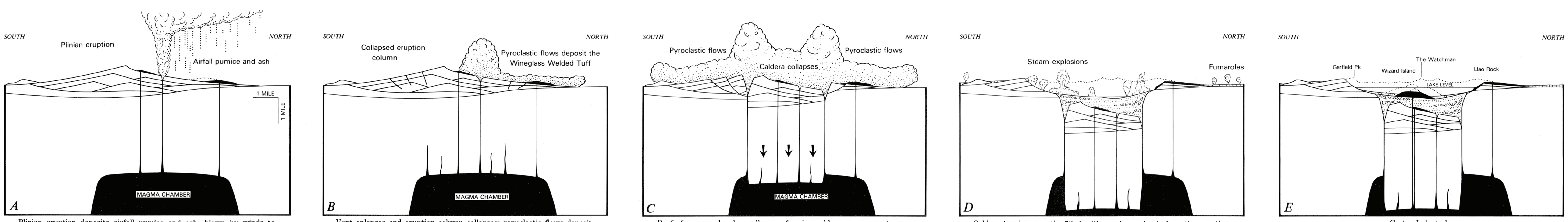
Generalized geologic map of Crater Lake and Vicinity by Howel Williams. Plate 3, Carnegie Inst. of Washington Pub. No. 540, 1942.



Map by Howel Williams showing distribution of pumice deposits. Contours give the thickness of the deposits.



Map of the floor of Crater Lake. Made by U.S. Coast and Geodetic Survey; contoured by Dr. John V. Byrne. Contour interval: 10 fathoms.



A. Plinian eruption deposits airfall pumice and ash, blown by winds to north and east.

B. Vent enlarges and eruption column collapses; pyroclastic flows deposit the Wineglass Welded Tuff on north and east flanks.

C. Roof of magma chamber collapses, forming caldera as new vents open above fractures; pyroclastic flows deposit pumice and ash on all flanks of Mount Mazama and in valleys below.

D. Caldera has been partly filled with pumice and ash from the eruption shown in C and with blocks of rock from the caldera walls; weak, dying explosions within the caldera deposit ash on the caldera rim; pyroclastic-flow deposits develop fumaroles and gradually cool.

E. Crater Lake today.

Diagrams by Charles R. Bacon showing the eruption of Mount Mazama about 4,900 B.C.