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A GEOLOGIC MAP of the BEND QUADRANGLE, OREGON And A RECONNAISSANCE GEOLOGIC MAP of the CENTRAL PORTION OF THE HIGH CASCADE MOUNTAINS

By

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GEOLOGY OF THE BEND QUADRANGLE, OREGON

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Acknowledgments

This report is an outcome of a cooperative project by the State of Oregon Department of Geology and Mineral Industries and the U.S. Geological Survey to prepare a geological map of Oregon. The field work on the Bend quadrangle and adjacent parts of the Cascade Range was done during part of the summer of 1954 with the assistance of Mr. Philip Lydon, then a graduate student at the University of California, Berkeley. The writer's earlier work on the Newberry volcano, the Three Sisters region, Mount Thielsen, and Crater Lake National Park, references to which are listed in the appended bibliography, has been incorporated in the general reconnaissance map of the central portion of the High Cascades. He is grateful to Francis G. Wells and Dallas Peck of the U.S. Geological Survey for helpful discussion, and particularly to Mr. Peck for locating the boundary between the High Cascade and Western Cascade volcanic rocks on the Diamond Lake and Waldo Lake quadrangles. He takes pleasure also in expressing thanks to Phil Brogan of Bend for valued assistance in many ways and over many years.

John Day formation (Tjd)

The oldest rocks within the Bend quadrangle are part of the John Day formation which ranges in age from late Oligocene to early Miocene. They consist principally of flows and domes of rhyolite, welded rhyolite tuffs laid down by glowing avalanches, bedded rhyolite tuffs formed by airborne showers of ash, and varicolored, fluviatile and lacustrine tuffaceous sediments. Flows of andesite and basalt are quite subordinate.

The largest inlier of these rocks is in the northeast corner of the quadrangle; other inliers form Cline, Forked Horn, and Powell buttes, and a group of hills adjoining the canyon of the Deschutes River near where it is crossed by the Deschutes-Jefferson county line. Cline Buttes are composed almost entirely of dense, pale-gray rhyolite lightly stippled with small phenocrysts of quartz and feldspar, and characterized by closely spaced, platy joints. Locally the lava is somewhat pumiceous; elsewhere it is spherulitic. The flow bands generally trend northeastward and either stand vertically or dip eastward at high angles, though some bands dip in the opposite direction. These attitudes are not the result of deformation but are primary features, and they indicate that the Cline Buttes are remnants of elongate domes of Pelean type, comparable in their manner of growth to the large dome clusters forming the Powell Buttes and those forming the Mutton Mountains in the Madras quadrangle.

The inlier of John Day rocks about 8 miles north of the Cline Buttes also appears to represent a group of denuded Pelean domes and stumpy flows of gray and pink, glassy and spherulitic rhyolite, and so do the Powell Buttes. Forked Horn Butte consists in part of Quaternary basaltic cinders, extensively quarried for road metal, and in part of massive, porphyritic lava, either andesite or dacite, but exposures are insufficient to show whether the lava is part of another Pelean dome or of a flow. Juniper Butte, immediately west of The Dalles-California Highway near the northern edge of the quadrangle, closely resembles the Powell Buttes, a central dome-cluster being surrounded in part by short, outward-dipping flows of rhyolite. Several mesas and cuestas on the opposite side of the Highway, including Haystack Butte, have caps of gray and pinkish rhyolitic lava that rest on rhyolitic lapillituffs and tuffs interbedded with platy and papery tuffaceous shales, and locally these lie in turn on brown-crusted flows of amygdaloidal andesite. Farther south, in the country between Gray Butte and the Crooked River, where the prevailing dips are southeastward at 10° to 30°, the John Day formation consists chiefly of rhyolitic flows and tuffs. Some tuffs are unstratified deposits of glowing avalanches, but most of them are well-bedded products of ash falls. Here and there these rhyolitic rocks are separated by small flows of drab green, vesicular andesite and amygdaloidal basalt. Tuffaceous sediments are undoubtedly more abundant than their natural outcrops suggest, as may be judged by the thick section revealed in artificial cuts along the canal between Trail Crossing and Smith Rock where beautifully varicolored tuffaceous silts, sands, and clays are interstratified with tuffs and lapillituffs.

The maximum thickness of the John Day formation is revealed in the area extending south from near Gray Butte. It does not exceed 5,000 feet, and may be considerably less owing to the presence of unconfirmed strike faults. Nowhere, however, is the base of the formation exposed within the quadrangle.

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Columbia River basalt (Tcr)

The southern edge of the vast Columbia River basalt plateau passes through the northeast corner of the Bend quadrangle, where thin, scattered outliers rest conformably or with only slight disconformity on the John Day formation. None of the outliers are more than 300 feet thick, and most of them are much thinner. The basalt is characteristically black, with a very dense, partly glassy matrix relieved by occasional readily visible crystals of plagioclase and pyroxene and still fewer minute crystals of olivine. Generally the lava is not vesicular, but amygdules of opal and chalcedony are not uncommon. Scoriaceous tops and bottoms of flows, abundant elsewhere within the Columbia River basalt, were not observed here, nor were any fragmental interbeds or feeding dikes detected. Here and there the basalt exhibits crude columnar structure, but normally it has an irregular, blocky jointing that results in the development of angular, flat-faced talus blocks. Near O'Neil, close to the Crooked River, the gently undulating crust of the topmost flow has been reddened to a depth of a few feet by an overlying sheet of Quaternary olivine basalt. The middle Miocene age assigned to the lavas of the Columbia River basalt in this area is based on evidence from other regions.

Glaciated Lavas of the High Cascade Volcanoes (QTba)

The volcanoes that form the crowning peaks of the Cascade Range were developed mostly within Pliocene and Pleistocene time by quiet effusions of olivine basalt and olivine-bearing basaltic andesite, and all of them have been modified by glacial erosion. The Bend quadrangle, however, lies entirely beyond the limits of glaciation save for a small area in the extreme southwest corner, above an elevation of approximately 4,500 feet. Here are to be seen glaciated basic lavas erupted by the Broken Top and Tumalo Mountain volcanoes.

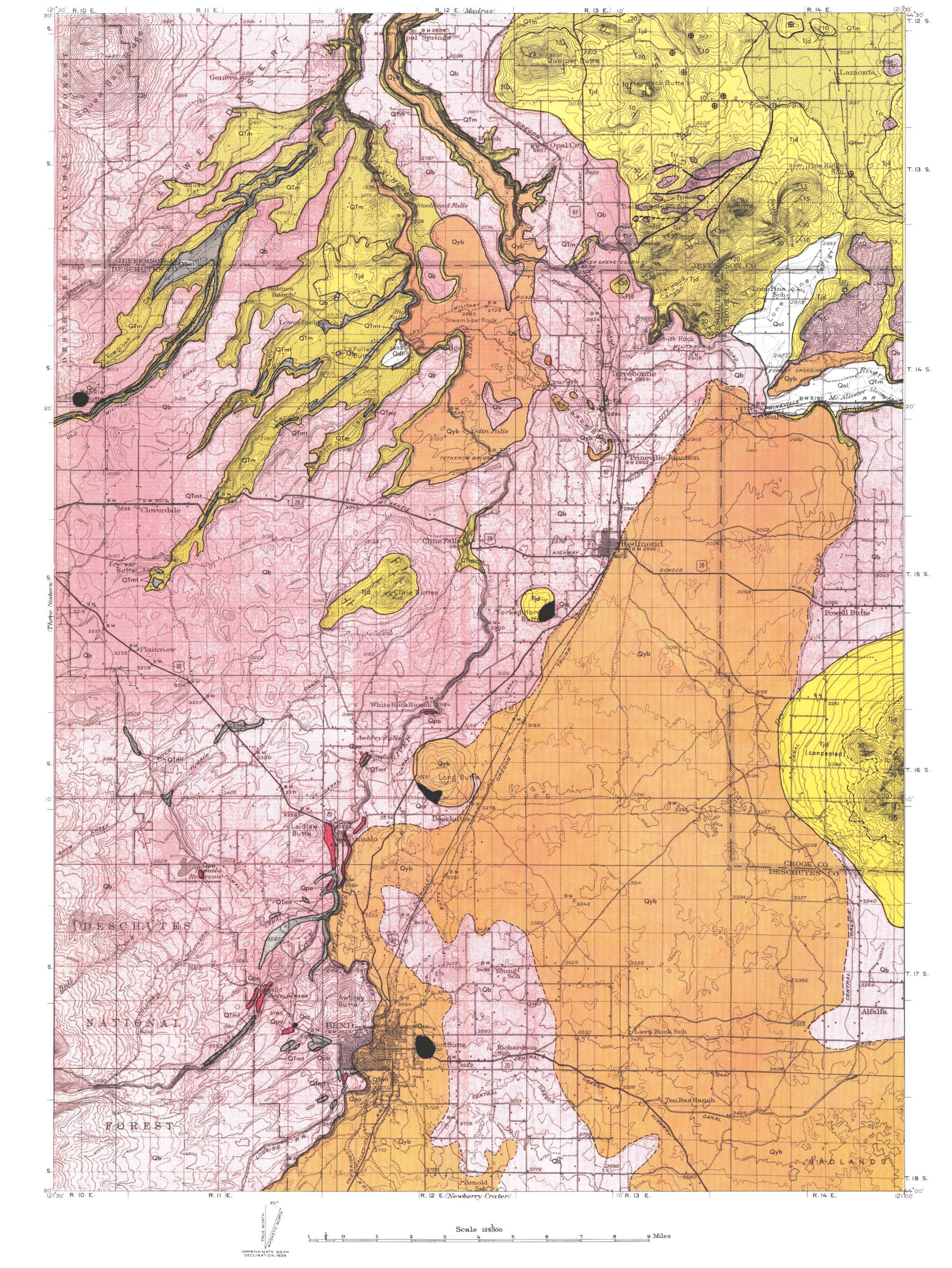
Madras formation (QTm - QTmt)

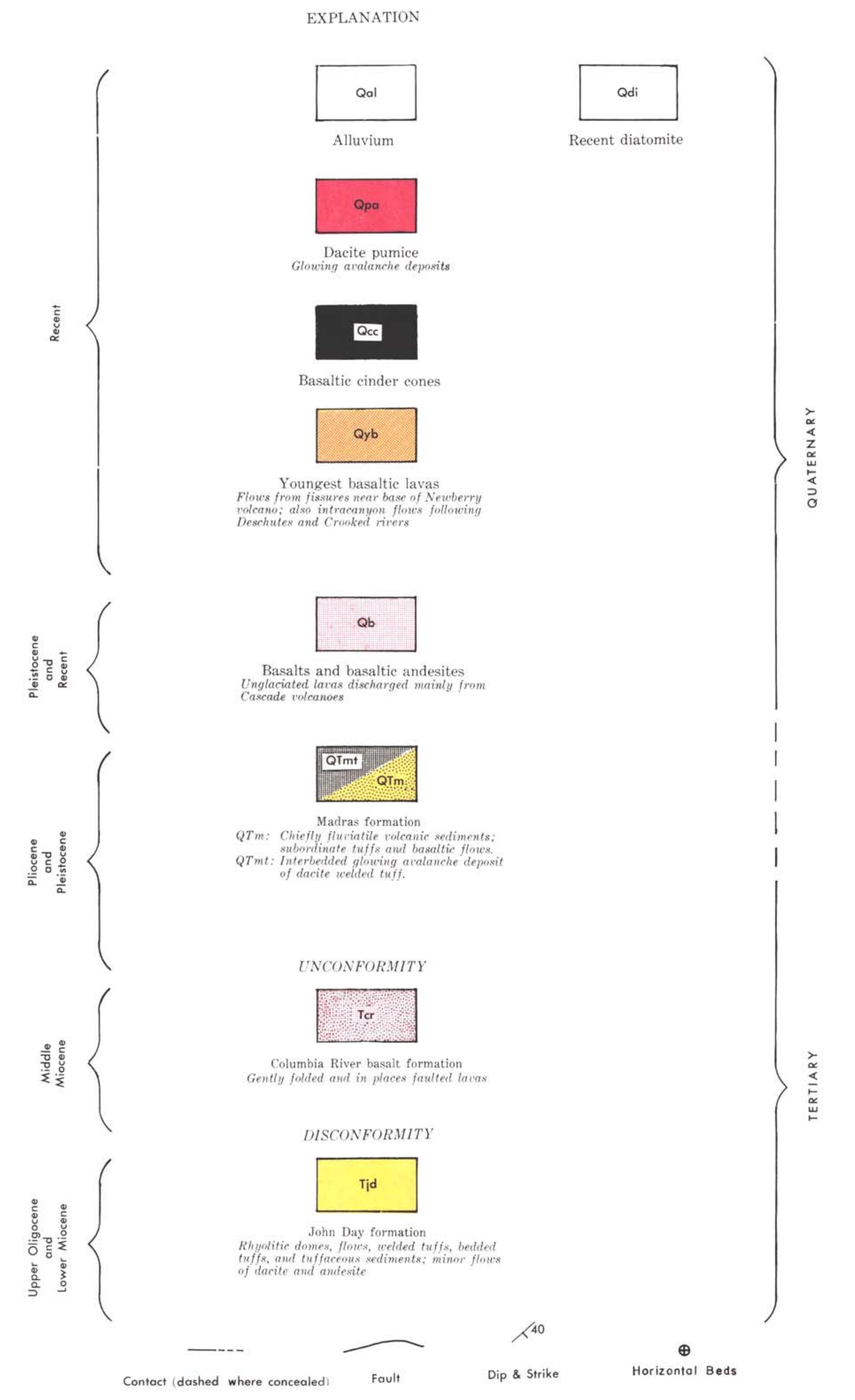
There seem to be no visible records of late Miocene deposition within the Bend quadrangle, and it may be that early and middle Pliocene deposits are also unexposed. But while the High Cascade volcanoes were growing, thick piedmont deposits were being laid down chiefly by rivers but also in lakes to the east. These deposits constitute the Madras formation. In the Bend quadrangle, the formation is best exposed on the walls of the canyons traversing the northwest corner, but to the north, in the Madras quadrangle, where many of the canyons are much deeper, the formation is more widely revealed and is considerably thicker. Fossil plants studied by Chaney (1938) from exposures along the Warm Springs cutoff road between Madras and Portland indicate that part of the formation thereabouts is of early to middle Pliocene age. In the Bend quadrangle, however, only the upper part of the formation is exposed, and though fossils are lacking, physiographic and other indirect evidence suggests that this part ranges in age from late Pliocene to late Pleistocene. The formation thus represents a long span of time, and everywhere, in contrast to the older formations, it is completely undeformed. The maximum exposed thickness in the Bend quadrangle approximates 600 feet, and in general the thickness diminishes mountainward, that is, toward the source of the sediments, lavas, and tuffs.

The formation is composed for the most part of unconsolidated and commonly cross-bedded, fluviatile silts, sands, and gravels consisting of andesitic and basaltic debris. Locally there are coarser layers of similar composition, laid down by torrential volcanic mud flows (lahars), lenses of white, granular pumice and pumiceous tuff of andesitic and dacitic composition, in part waterlaid and in part airborne, and a few thin layers of diatomaceous clay. These deposits are interbedded with a flow or elsewhere two flows of dark olivine basalt more or less charged with opal-chalcedony amygdules, and everywhere they are capped by extensive sheets of similar basalt that form the so-called 'rim rocks' of the canyon walls. But perhaps the most interesting, and certainly the most widespread unit in the Madras formation is a welded dacite tuff (QTmt). This was laid down by glowing avalanches discharged from a parasitic vent high on the northeast flank of the Broken Top volcano, about a mile and a half west of Three Creek Lake. Some avalanches swept eastward from this source to pour down the canyon of Tumalo Creek and then overflow its banks to empty into the valley of the Deschutes River about a mile and a half south of Bend. But most of the avalanches raced northeastward to inundate almost the whole of the Bend quadrangle west of the Deschutes River, and their deposits also underlie much of the flat country around the Sisters, on the adjacent Three Sisters quadrangle. Indeed, the limits of the avalanche deposits encompass an area of more than 200 square miles, and the thickness of the deposits ranges generally between 20 and 50 feet. Near their source they are overlain directly by flows of olivine basalt or are separated therefrom only by thin fluviatile beds, but farther away the thickness of the fluviatile beds between the avalanche deposits and the basaltic 'rim rocks' increases to a maximum of about 200 feet. Around the eruptive vent, the welded and banded pumiceous tuff is overlain by a sheet of streaky, varicolored obsidian. Within the main deposit there are the usual lithological variations to be seen in welded tuffs elsewhere. At the top and bottom of the deposit, where cooling was most rapid, the tuff is only weakly to moderately welded, though still compact enough to form cliffs, and generally the upper part has a pinkish tint owing to the presence of finely disseminated fumarolic hematite. The central parts of the deposit, on the other hand, are usually grayish and firmly welded, and they show a streaky banding due to the presence of abundant flattened lapilli and bombs of black obsidian and whitish pumice. Particularly good exposures can be seen on the canyon walls near the confluence of Tumalo Creek and the Deschutes River, and in McKenzie, Deep, Fremont, and Squaw canyons. Only a few remnants of waterlaid, reworked pinkish tuff are preserved on the walls of Deschutes Canyon between Tumalo and Lower Bridge; it is clear, however, that many avalanches tumbled into the canyon farther down and perhaps some swept onward to enter the Madras quadrangle. It is probable also that some avalanches overflowed from the Deschutes Canyon to empty into the Crooked River, for there are patches of fluviatile, pinkish tuff on its walls, about 2 miles below Peter Skene Ogden Park. Because the vent from which the avalanches issued is a glaciated parasite formed during the concluding stages of growth of the Broken Top volcano, it seems likely that the eruption took place during late Pleistocene time.

Quaternary Basalts (Qb) and Cinder Cones (Qcc)

The boundary between the High Cascade lavas and those shown on the map as Quaternary basalts is drawn along the approximate limits of glaciation. Some of the unglaciated basalts near the western edge of the quadrangle may well be of late Pleistocene age, but probably all of the others, and certainly all those east of the Deschutes River are Recent in age. Many of the glaciated and unglaciated lavas are indistinguishable under the microscope; usually, however, the former are pale gray whereas the latter are generally black owing to a higher content of interstitial glass, and are often more vesicular. In addition, many of the Recent basalts preserve such original features as pressure mounds and ridges, ropy crusts, and lava tubes. Most of the Recent basalts east of the Deschutes River issued from concealed fissures on the northern slopes of the Newberry volcano. Other basalts issued from vents capped by cinder cones, such as Pilot and Henkle buttes, while the basalts forming the 'rim rocks' in the northwest corner of the quadrangle were poured from a northwest-trending fissure marked by a chain of cinder cones that passes through Garrison Butte on the Three Sisters quadrangle. Other vents are marked by large, craterless lava and lava-scoria mounds, such as Long, Awbrey, and Tetherow buttes, or small mounds such as Laidlaw and Fryrear buttes. Two fairly symmetrical shield volcanoes of pale gray olivine basalt, one of them called Squaw Back Ridge, are juxtaposed in the northwest corner of the quadrangle.





Youngest Basalts (Qyb)

The youngest lavas are almost wholly restricted to the country east of the Deschutes River. Some of them were erupted from vents near the northern base of the Newberry volcano. Among these are flows near the town of Bend and those that extend northward along the Deschutes River to Tumalo. These were discharged after the Recent glowing avalanches referred to below, and presumably they are only a few thousand years old. Other youthful basalts poured from vents close to the Tetherow Buttes. These emptied into the canyons of the Deschutes and Crooked rivers which were then as deep as they are now; Their dismembered remnants form benches on the canyon walls.

Recent Pumice Avalanche Deposits (Qpa)

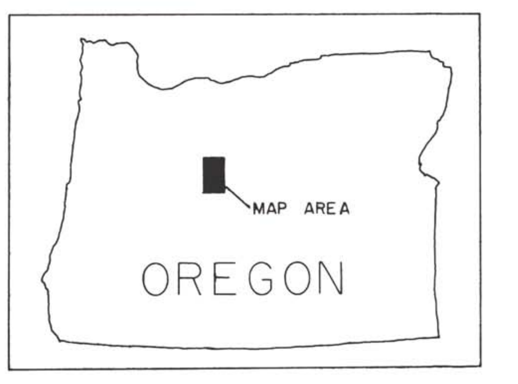
Exposures of unconsolidated white and pink dacite pumice are to be seen at intervals along Tumalo Creek below an elevation of about 3,800 feet, and along the walls of the Deschutes River from a point 6 miles above Bend to White Rock Ranch, some 14 miles downstream. It is clear from the nature and distribution of these deposits that they were laid down by swiftly moving, glowing avalanches. Unfortunately, however, it has not been determined whether the avalanches issued from vents on the flanks of the Broken Top volcano or from others occupied by the domes that form the McKay Buttes on the western flank of the Newberry volcano, though the former seem more likely. In any event, the eruptions took place in Recent time, for the welded tuff in the Madras formation had been deeply eroded and buried beneath fluviatile sediments, and these in turn had been dissected and partly buried by intracanyon basalts before the avalanches descended. The first ones left deposits, locally as much as 30 feet thick, of unbedded and faintly bedded, white, granular pumice containing sporadic bombs as much as 18 inches across, abundant smaller lumps and lapilli of pumice, and small, angular, lithic chips of andesite and basalt. These initial deposits are covered in places by a bed, generally between a foot and two feet thick, composed mostly of almost flourlike, white pumice dust with lenses of small pumice lumps. This bed seems to represent reworked avalanche debris that settled slowly from the choked waters of the Deschutes River. Above it lie pink avalanche deposits as much as 15 feet thick. These, unlike the white deposits, must have been laid down on dry land and have remained hot for a long time, because their pink color results from sublimation of hematite from fumarolic vapors, the passageways of some of which are still marked by vertical and irregular cracks bordered by slightly altered pumice. The pink avalanche deposits are traceable down the canyon of the Deschutes River as far as Twin Bridges, and washed remnants are to be seen near Cline Falls as well as in a quarry adjoining the west side of The Dalles-California Highway near Terrebonne. Locally the avalanche deposits were weathered to a thin soil before being buried by fluviatile basaltic sands and gravels, and in places channels cut in these sediments were partly filled by Recent flows of olivine basalt.

Recent Diatomite (Qdi) and Alluvium (Qal)

Near Lower Bridge, a tributary of the Deschutes River was dammed by a Recent flow of olivine basalt to form a temporary lake about half a square mile in extent. Beds of diatomite and pumiceous, tuffaceous silts and clays accumulated in the lake, the diatomites having an aggregate thickness of approximately 50 feet, one bed reaching a maximum thickness of about 20 feet. The lake beds were subsequently buried by cross-bedded, fluviatile basaltic sand and gravel. At an earlier time, the Crooked River was dammed near O'Neil by flows of basalt so that a lake was produced upstream, and one of its tributaries was impounded to form another lake in what is now Lone Pine Flat. Well-bedded pumiceous and cindery sediments are accompanied by thin beds of diatomite in the resultant lacustrine deposits.

Structure

The late Pliocene and younger rocks of the Bend quadrangle seem to be undeformed; on the other hand, the Columbia River basalt and the underlying John Day formation were deformed together, either during early Pliocene or late Miocene time. Reference to the map will show that in the northeast corner of the quadrangle several small outliers of Columbia River basalt are preserved along and near the crest of a broad, southwest-trending anticline. South of the crest the prevailing dips of the beds of the John Day formation are southward and southeastward at angles as steep as 30°; north of the crest the dips are much more variable though mainly to the north and west. Several unmapped faults are undoubtedly present south of the crest, as along Sherwood Canyon and Lone Pine Flat, and most of the mesas and cuestas north of the crest are horsts separated by faults of irregular trend. Whether the inliers of John Day rocks close to the Deschutes River are on a southwestward extension of the same structural high or owe their exposure to the fact that they were original volcanic eminences is uncertain. As far as can be judged, all of the observed dips shown by the lavas of the John Day formation outside the northeast corner of the quadrangle are primary rather than the result of deformation.



cone composed of andesitic and dacitic lavas, whereas its upper part is composed of two Recent lava-scoria cones of olivine basalt, the younger of which has a well-preserved crater that may have been active during the present millennium. The Middle Sister likewise consists largely of glaciated andesite and dacite flows, one of which forms the well-known Obsidian Cliffs, though the top of the mountain and most of the southern side consist of Recent basalts. Other glaciated andesites and dacites were erupted from vents south of the South Sister, at Devil's Hill and near Todd Lake.

The largest Pleistocene andesite-dacite volcano was undoubtedly Mount Mazama, the ancestral mountain in the collapsed summit of which lies Crater Lake. This volcano, and its parasitic cone, Mount Scott, grew to full height by eruption of pyroxene andesites; then, in late Pleistocene time, more siliceous andesites and dacites were discharged from vents on a semicircular fissure on the northern slopes of the volcano, while a cluster of dacite domes rose near its eastern base and many basaltic cinder cones were formed elsewhere on the mountainsides (Williams, 1941, 1942).

Intracanyon Basalts (Qib)

During Pleistocene time, long flows of massive, pale-gray olivine basalt poured down the ancestral canyons of several of the principal rivers that now traverse the Western Cascades, such as the North Santiam, North Umpqua, and Rogue rivers, and the North Fork of the Willamette River. These flows did not issue from the central vents of the High Cascade volcanoes, but from fissures near the feet of these volcanoes and others farther west. They accumulated to a thickness of 1,600 feet in the ancestral canyon of the North Santiam, to about 1,000 feet in the North Umpqua, and to lesser thicknesses in other canyons. No doubt their eruption took place intermittently over a long span of time. Those in the North Santiam canyon, according to Thayer (1939), must be older than middle Pleistocene because Wisconsin moraines lie on their eroded surface, and probably those that poured down the North Fork of the Willamette River to the vicinity of Oakridge are of about the same age. Those farther south, however, are much less eroded; indeed, the youngest flows that descended the upper reaches of the Rogue River canyon are so little dissected and their surface features are so well preserved that they cannot be older than very late Pleistocene. They may in fact be of Recent age, though they are partly covered by glowing avalanche deposits of pumice derived from Mount Mazama about 7,600 years ago. Intracanyon basalts are also plentiful on the eastern side of the Cascade Range, and some of those in the canyons of the Deschutes and Crooked rivers on the Bend quadrangle are also of Recent age.

Late Pleistocene and Recent Basalts, Basaltic Andesites, and Cinder Cones (Qb)

Whereas the principal eruptions of Pliocene and early Pleistocene time took place from vents close to the present crest of the Cascade Range, later eruptions took place from vents on the eastern flank of the range and on the plateau still farther east. It must be emphasized, however, that the boundaries shown on the map between the Pliocene and Pleistocene lavas and those now under discussion are only approximate because they are based primarily on degrees of erosion. Nevertheless the younger lavas, although olivine basalts and olivine-bearing basaltic andesites essentially like the glaciated, older lavas, are often distinguishable because they are darker, richer in interstitial glass, and more vesicular, and because many of them exhibit such original features as pressure ridges, lava tubes, and ropy crusts. Some of these younger flows form extensive flats along the east base of the Cascade Range and around the base of the Newberry volcano where they are partly covered by fluviatile sediments and partly by a mantle of cinders and pumice. No doubt some of these lavas issued from concealed fissures. Elsewhere the lavas accumulated during the long-continued activity of central vents so that they built fairly steep-sided shield volcanoes of Icelandic type, devoid of summit cinder cones. Examples of such volcanoes are Hamner, Ringo, and Gilchrist buttes, and Cultus, Maklaks, Royce, Lookout, Browns, and Davis mountains on the Maiden Peak quadrangle, and Trout Creek Butte on the Three Sisters quadrangle. The Timber Crater volcano within Crater Lake National Park is a beautifully symmetrical shield volcano capped by scoria cones; its final eruptions, although post-Pleistocene, occurred before the climactic explosions of Mount Mazama, 7,600 years ago. Examples of much smaller lava cones surmounted by cinder cones are the cluster in the northeast corner of the Maiden Peak quadrangle and the cluster at the east base of Mount Washington. Generally these lava-cinder cones show no definite alinement, the most notable exceptions being Garrison Butte and six adjacent cones that lie on a northwest-trending fissure approximately 7 miles north of the Sisters which may well extend as far as Henkle Butte on the Bend quadrangle. Long flows from these alined vents spread across the sediments and tuffs of the Madras formation in this quadrangle. While these volcanoes were active close to the base of the Cascade Range, similar lavas were being discharged from vents marked by cinder cones on the flanks of the Newberry volcano.

The range in age of the basaltic cinder cones is wide. Many of those close to the crest of the Cascade Range, which are parasites on the flanks of the shield volcanoes, have been glaciated, and it may be that some of those close to the foot of the range, although not glaciated, date back to Pleistocene time. It is likely, however, that most of those shown on the accompanying map are of Recent age, and many of them were certainly active during the past few thousand years.

Youngest Basaltic Flows and Related Cinder Cones (Qyb)

Nowhere in Oregon has there been so much recent volcanism as within the area shown on the accompanying map. All of the lavas and cones now to be mentioned were formed during the past few thousand years. Those in the Cascade Range will be mentioned first, from north to south, and then those to the east.

Long narrow tongues of olivine basalt poured down the canyons of Jefferson and Cabot creeks, southeast of Mount Jefferson, some of them from the base of North Cinder Peak after its explosive activity had ended. Far more widespread are the three coalescing fields of almost barren, black basalt along and near the crest of the Cascade Range between the Santiam and McKenzie highways. The eruptions that produced these must have taken place in rapid succession, perhaps not more than 1,000 years ago. The youngest flows issued from Nash Crater and three subsidiary cinder cones on a fissure trending north-northwest, and they dammed the drainage to form Fish and Lava lakes. Similar lavas were erupted from Sand Mountain and four subsidiary cones on a north-south fissure; these dammed the headwaters of the McKenzie River to form Clear Lake on the bottom of which the stumps of drowned trees are still to be seen. Next to the south is an almost treeless wilderness of basalt, more than 70 square miles in extent, adjoining the McKenzie Highway. This must surely be counted among the most impressive fields of recent lava in the United States. The principal vents were Belknap Crater and Little Belknap, and the latter continued to pour out lava after the explosions of the former had come to an end.

Slightly older than the Belknap flows, but definitely belonging to the same brief volcanic episode, are the many almost barren basalt flows discharged from the cluster of cinder cones on the northern slopes of the North Sister. One of these flows spread 13 miles westward, damming Linton Creek to form Linton Lake, and excellent exposures of it are to be seen along the McKenzie Highway. At about the same time, other olivine basalts were erupted from the foot of the beautifully preserved Le Conte Crater, at the southern base of the South Sister, one tongue reaching into Devil's Lake on Century Drive. Approximately coeval flows from the nearby Cayuse Cone descended to the edge of Sparks Lake.

The most voluminous Recent lavas in the Cascades are those erupted from a fissure system 14 miles long that extends directly south from Bachelor Butte through Sheridan Mountain to Lookout Mountain. More than 15 cinder cones and lava-scoria cones lie on this fissure system, and although the lava flows are considerably older than those just described, being largely forested, they exhibit well-preserved ropy crusts, pressure ridges, and lava tubes (e.g., Edison Ice Cave). Some flows from Bachelor Butte may have been erupted during the last millennium or two, but most of the others are older than the dacite pumice blown from Mount Mazama 7,600 years ago, as also are the cinder cones and lavas immediately east of Crane Prairie Reservoir. Most of the flat country bordering the Wickiup Reservoir and The Dalles-California Highway around Lapine consists of either late Pleistocene or Recent basalts blanketed by Mazama pumice.

Three small, post-Mazama fields of barren, quartz-bearing olivine basalt capped by cinder cones lie on a north-south fissure extending from the outlet of Davis Lake to Black Rock Butte. These, like the Wizard Island cinder cone and andesitic flows inside Crater Lake, are probably not much more than 1,000 years old.

While these Recent eruptions were going on in the High Cascades and on the eastern flank of the range, similar cinder cones were being built and basaltic lavas were being discharged around the lower slopes and base of the Newberry volcano. The youngest of these are almost surely less than 1,000 years old; among them are the flows that poured from Lava Butte on The Dalles-California Highway to the Deschutes River, and those that poured through forests on the northwest flank of the Newberry volcano leaving in their wake abundant molds of demolished trees.

Quaternary Lavas of the Newberry Volcano (Qbu and Qyr)

The Newberry volcano is an approximately circular shield volcano about 20 miles in basal diameter which rises 4,000 feet above the surrounding plateau (Williams, 1935). On top there is a caldera, 5 miles long and 4 miles wide. The oldest visible lavas of the volcano are rhyolites exposed on the walls of the caldera. The rhyolites are overlain by basaltic flows and fragmental ejecta and by subordinate flows of andesite, and these in turn are capped by rhyolite flows that aggregate 1,000 feet in thickness, forming Paulina Peak. Presumably the volcano grew to its full height during the Pleistocene epoch; then its summit collapsed along ring fractures, probably in consequence of drainage of the underlying reservoir either by subterranean migration of magma or, more likely, by copious eruptions of basalt from flank fissures. Thereafter eruptions took place within and outside the caldera. No basaltic flows and only a few basaltic cinder cones occur within the caldera, where most of the eruptions involved discharge of rhyolite. Outside the caldera on the flanks of the Newberry shield no less than 150 basaltic cinder cones were built and innumerable basaltic flows issued from them, only the youngest of which are shown separately on the accompanying map.

Recent Rhyolites Within and Near the Newberry Caldera (Qyr)

The top of the Newberry volcano collapsed at about the close of the Pleistocene epoch. Then, as mentioned already, eruptions of basaltic cinders and lavas and of rhyolitic pumice and obsidian flows took place both within the caldera and on the outer slopes of the volcano. The first rhyolitic lava escaped from a fissure high on the north wall of the caldera whence it cascaded to the shore of East Lake. Then, after two domes of rhyolitic obsidian had risen on the edge of Paulina Lake, north-south fissures opened across the middle of the caldera floor, between the lakes. Eruptions from these fissures produced a series of rhyolitic pumice cones, and domes and flows of almost barren, rhyolitic obsidian. They began about 9,000 years ago when showers of pumice from one of the vents fell in a cave near Fort Rock, scorching sandals left by Indians in their flight for safety. But the last explosions did not take place until 2,000 years ago, as shown by radiocarbon dating of charred wood found beneath the topmost layer of pumice in road cuts between East and Paulina lakes. The bare fields of glistening, black obsidian in the southern part of the caldera must have been formed immediately after these last explosions of pumice.

China Hat and East Butte, not far beyond the eastern base of the Newberry volcano, are also pumice cones, whereas McKay Butte and two adjacent buttes on the opposite side of the volcano are rhyolite domes. All of these grew during the intra-caldera stage of activity.

Basaltic Cinder Cones (Qcc)

(See Bend quadrangle text for discussion)

Recent Pyroxene Andesites (Qa)

Two conspicuous, steep-sided, almost symmetrical, craterless cones rise approximately 2,500 feet above the eastern base of the Cascade Range. One of them, Odell Butte, about 8 miles southeast of Odell Lake, is mostly mantled with pumice blown from Mount Mazama, solid exposures of pyroxene andesite, locally rich in cristobalite, being virtually confined to the summit region. Steep to vertical flow banding suggests that this part of the butte, at least, was formed by a viscous protrusion of Pelean type. The other cone, Black Butte, which measures 4 miles across the base, consists of vesicular, pale-gray, olivine-bearing basaltic andesite lavas, the final effusions being so viscous as to form a dome obliterating the summit vent. Apparently the conduit of this volcano lies on a north-south fault that passes through Metolius Springs and along the upper part of the canyon of the Metolius River.

Dacite Pumice Erupted by Mount Mazama (Qpf and Qpa)

The climactic explosions that led to the collapse of the top of Mount Mazama and the formation of Crater Lake took place about 7,600 years ago, by which time all the glaciers on the volcano had retreated above the elevation of the present rim of Crater Lake, except in three canyons on the south side. The initial outbursts after a long period of calm were of Vulcanian type, the pumice being hurled high into the air to be drifted by winds and fall in showers over a vast area, chiefly to the east and northeast. The deposits of this pumice fall (Qpf) approximate $3\frac{1}{2}$ cubic miles in volume. Immediately afterwards, glowing avalanches swept down from the summit of Mount Mazama at hurricane speeds. They raced down the canyon of the Rogue River for a distance of 17 miles, and down all the other deep glacial canyons on the mountainsides, inundating vast areas of flat ground below (Qpa). Most of the avalanche deposits are composed of dacite pumice, mineralogically and chemically similar to the dacite of the earlier pumice fall, but the final avalanches deposited dark, hornblende-rich basaltic scoria. All told, the avalanche deposits total between 6 and 8 cubic miles in volume. It was the rapid drainage of the reservoir beneath Mount Mazama brought about by these colossal eruptions, coupled with underground drainage of magma, that caused the mountaintop to founder and so produce Crater Lake. The discovery of artifacts beneath the deposits of the pumice fall shows that Man already inhabited this part of Oregon when these dramatic events took place.

Recent Dacites (Qd)

There has been more volcanic activity in the Three Sisters region during the past few thousand years than in any other part of the entire Cascade Range. This activity has produced basaltic cinder cones and flows on the one hand, and domes and flows of dacite and beds of dacite pumice on the other. The latest dacitic outbursts took place close to the South Sister. They formed an extensive sheet of almost barren obsidian at Rock Mesa, and a spectacular chain of obsidian domes and flows that extends for about 3 miles northward from Century Drive. Discharge of a few of these thick masses of blocky lava was preceded by explosions of dacite pumice. All of these obsidians are younger than the adjacent cinder cones, but whether or not they are also younger than the Recent basalts bordering McKenzie Pass is uncertain. In any event, the obsidians are younger than the dacite pumice blown from Mount Mazama, and perhaps they are no more than about 1,000 years old.

Two much older, but still Recent domes of pale-gray pumiceous dacite are present near the northeast base of the Broken Top volcano, namely Melvin and Three Creek buttes. These seem to lie on a northwest-trending fissure that continues in one direction to the vent of Trout Creek Butte volcano and in the other along the base of a pronounced break in slope of the Broken Top volcano.

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VOLCANISM IN THE CENTRAL PART OF THE HIGH CASCADE RANGE OF OREGON AND ON THE PLATEAU TO THE EAST

By
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Volcanic Rocks of the Western Cascades (Twc)

The Cascade Range is divisible into two belts, namely the Western and High Cascades. The former belt consists of gently folded volcanic rocks ranging in age from late Eocene to late Miocene. Most of the topography here is mature and there are no traces of original volcanic forms. The High Cascades, on the other hand, consist of younger volcanic rocks that are virtually undeformed; most of the topography there is constructional and the original forms of the volcanoes, even though modified by glaciation, are easy to visualize. Other important contrasts distinguish the two belts. The thick volcanic accumulations of the Western Cascades are mainly products of fissure eruptions that produced extensive plateaus. Hence there are few eroded plugs marking the conduits of large volcanoes; instead, eruptive fissures are marked by narrow dikes of irregular trend. The High Cascades, on the contrary, were built almost wholly by eruptions from central craters so that clusters of large, coalescing cones were formed, many of which have been dissected by glaciers so as to reveal their feeding pipes. Finally, whereas the High Cascade volcanoes grew almost entirely by effusions of basalt and basaltic andesite, the rocks of the Western Cascades were produced by much more varied eruptions. Moreover these older rocks range in composition from rhyolite to basalt, and the lavas are intercalated with heterogeneous sheets of explosion debris, ranging from coarse agglomerates to fine tuffs, as well as with layers of tuffaceous sediment.

The Western Cascade belt averages approximately 50 miles in width, and the volcanic rocks are as much as 13,000 feet thick. Beneath the High Cascades, these rocks must interfinger with equivalents of the Clarno, John Day, Columbia River, and Mascall formations, which are exposed on the plateau to the east.

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Only the upper part of the volcanic sequence of the Western Cascades is represented on the accompanying map. Thayer (1939) distinguished two principal groups within the basin of the North Santiam River. The older group, which he called the Breitenbush tuffs, approximates 7,500 feet in thickness east of Detroit. It consists chiefly of greenish crystal tuffs, lapillituffs and tuff breccias, fine whitish tuffs, rare beds of agglomerate, fluviatile tuffaceous sediments, ranging from finely bedded silts to coarse laharic conglomerates, and occasional lava flows. Some beds contain a late Miocene flora, but some may date back to the Oligocene or even to the Eocene epoch. Near Detroit the beds dip westward beneath a younger group which Thayer called the Sardine lavas. These extend to the vicinity of Mill City. Their thickness approximates 6,000 feet, and they consist mainly of massive flows of andesite and fewer flows of basalt and rhyolite interbedded with layers of tuff and breccia. Near Halls (now covered by Detroit Reservoir), in the canyon of the North Santiam River, these rocks are intruded by a small stock of diorite porphyry. In the vicinity of the intrusion, the Sardine lavas, which are normally grayish or brownish, have a distinctive green color due to the presence of epidote and chlorite. Small mines and prospects are restricted to this belt, which runs southward to the vicinity of Blue River and Upper Soda on the McKenzie Bridge quadrangle.

Throughout most of the McKenzie Bridge quadrangle the rocks of the Western Cascades lie flat or dip at angles of less than 10°. The youngest rocks adjoining the South Santiam canyon east of Iron Mountain are dark flows of andesite and basalt interbedded with minor lenses of agglomerate, lapillituff, and greenish rhyolitic or dacitic tuffs, and cut by several narrow, vertical dikes of andesite or basalt. Westward to the vicinity of Upper Soda, the underlying rocks include more pyroclastic debris, ranging from whitish rhyolite tuffs to darker, varicolored andesitic lapillituffs and tuff breccias. Between Upper Soda and Cascadia dark flows of andesite and/or basalt again predominate. In the southeast corner of the quadrangle, gently dipping and flat-lying flows of brown-crusted dark andesites form the bulk of the sequence, but tuffs and breccias, though not well exposed, are plentiful.

Pre-Pliocene Volcanic Rocks East of the Cascade Crest (Tab)

In the northeast corner of the Maiden Peak quadrangle, there is a ridge that culminates in Wake Butte. It consists of well-bedded basaltic tuffs and lapillituffs, in part palagonitic, marked by a fine, buff matrix and in places by abundant angular blocks and lapilli of black basalt. The prevailing dips are toward the north, northeast, and east at angles of an much as 30°, but locally they are in opposite directions. These dips are primary features, though the ridge itself seems to be an eroded fault block. The age of the rocks is uncertain, although almost certainly pre-Pliocene, and no similar deposits have been observed within or close to the Cascade Range.

Where the Metolius River crosses the Mount Jefferson quadrangle, the canyon walls consist chiefly of andesitic lavas, lapillituffs, tuffs, and laharic deposits cut by occasional dikes. Pyroxene andesites predominate but hornblende-rich varieties are common. Within the big bend of the canyon, the dips are variable, though generally westward at angles of 10° or less; higher up the canyon, on the Green Ridge scarp, the dips are eastward at angles of 10° to 30°. The age of these rocks is also uncertain. They were eroded to a gently undulating surface before being buried by Pliocene and Pleistocene basalts. No doubt, however, the rocks are coeval with some members of the volcanic sequence in the Western Cascades.

Finally, there is a fault block approximately 10 miles south-southeast of the Newberry caldera. This consists mainly of porphyritic pyroxene andesite and andesitic basalt flows that strike N. 10° - 15° W. and dip both to the west and east.

John Day formation (Tjd)

(See Bend quadrangle text for discussion)

Columbia River basalt (Tcr)

(See Bend quadrangle text for discussion)

Pliocene and Pleistocene Volcanoes of the High Cascades (QTba-QTv)

The High Cascade volcanoes probably began to erupt about the beginning of the Pliocene epoch, and almost all of them were broad shield volcanoes built by quiet outpourings of gray olivine basalt and subordinate flows of olivine-bearing basaltic andesite. Explosive activity contributed little to their growth until the final stages when the summit craters of many shields were capped by steeper cones of fragmental ejecta. Glacial erosion has modified the shapes of all these volcanoes; indeed, most of them have been reduced to radiating ridges separated by glacial cirques. The parasitic cones on their flanks have been all but demolished. The fragmental cones on their summits have been denuded until the more resistant fillings of their central pipes have been left standing as gigantic monoliths, like miniature Matterhorns. Especially vivid examples of such deeply dissected volcanoes include Three Fingered Jack, Mount Washington, North Sister, Husband, Mount Yoran, Lakeview, Cowhorn, Sawtooth and Howlock mountains, Mount Thielsen, and Union Peak. Glacial erosion has also revealed, though less conspicuously, the central pipes of the Wife, Sphinx, Broken Top, and Diamond Peak volcanoes.

Detailed accounts of several of these denuded High Cascade volcanoes have already been published (Williams, 1933, 1942, 1944); it must suffice therefore to describe a few additional examples. Probably nowhere in the Cascades, except at Crater Lake, is the inner structure of a volcano more clearly displayed than on Three Fingered Jack. After the main shield volcano had been formed by discharge of massive flows of gray olivine basalt, strong explosions took place from the summit crater building a cone of ejecta more than a mile in diameter. The fragmental materials of this summit cone are magnificently exposed on the walls of the cirques adjacent to the highest pinnacles. They consist of buff, brown, red, orange, and gray tuffs, lapillituffs, tuff breccias, and agglomerates. Some layers contain scoriaceous bombs; others are crowded with angular, lithic fragments of dense black basalt. Presumably, therefore, Strombolian eruptions alternated with eruptions of Vulcanian and Ultra-Vulcanian type. The ejecta generally dips away from the central pipe at angles of less than 30°, and it is cut by a maze of vertical and steeply dipping dikes most of which are also radial with respect to the central pipe. Some dikes measure about 10 feet across, but most are between 3 and 6 feet wide. Only a few of them extend beyond the fragmental cone to cut the encircling lavas of the old crater walls.

Toward the close of the explosive phase, thin flows of vesicular black basalt issued from fissures on the flanks of the summit cone, spreading on to the older flows of gray olivine basalt, just as similar flows did on such other High Cascade volcanoes as Mount Thielsen and North Sister.

The vertical plug filling the central pipe of the Three Fingered Jack volcano is to be seen northeast of the summit. It measures approximately 400 by 100 yards across, its major axis trending north-northwest. Like all other central plugs of High Cascade volcanoes, it consists of olivine-bearing micronorite more or less charged with tridymite and cristobalite. Pale-gray, slightly coarser-grained micronorite and dark-gray, almost aphanitic micronorite cut each other irregularly, and each contains angular fragments of the other, indicating repeated autobrecciation and successive intrusions. Generally, there is neither banding nor vesicularity, and steeply dipping joints become more widely spaced inwards.

The central plugs of some High Cascade volcanoes are considerably larger than that of Three Fingered Jack, and some volcanoes have two plugs instead on only one. For example, the Husband volcano has two plugs, one of which is the largest in the range, measuring three-quarters of a mile long and 300 yards wide. The plugs of the Union Peak, Howlock Mountain, and Mount Thielsen volcanoes each measure approximately half a mile by a third of a mile. The Lakeview plug measures 500 by 300 yards, but the twin plugs of the Diamond Peak and Broken Top volcanoes are much smaller. Around some plugs, e. g., the Union Peak, Mount Thielsen, and Cowhorn Mountain plugs, the surrounding fragmental deposits are strongly upturned; round others there is no deflection. And although most plugs intrude pyroclastic cones, some, such as the Lakeview and Diamond Peak plugs, do not. Almost all are elongated in a north-south direction, that is to say, parallel to the length of the Cascade Range.

Many High Cascade volcanoes have been much less modified by glacial erosion, although these also have lost their summit craters. Some of these volcanoes may have begun to grow at the same time as those that now reveal their central plugs, but, if so, they certainly continued to be active to a later date. Among these less denuded volcanoes are Fuji Mountain, Mount Bailey, and Maiden Peak, each of which consists of an eroded summit cone of fragmental ejecta capping a basaltic lava shield. Other craterless volcanoes are composed entirely of basaltic flows.

Although gray olivine basalts and olivine-bearing basaltic andesites constitute by far the bulk of the lavas of the Pliocene and Pleistocene High Cascade shield volcanoes, and although some volcanoes discharged darker and more glassy flows of the same composition during their declining stages of growth, the Miller Mountain volcano in the Chemult quadrangle also erupted more siliceous lavas from parasitic vents far down its northeast flank. Thus, on the canyon walls of Big Marsh Creek and the Little Deschutes River, the normal mafic lavas are overlain by extensive, glaciated flows of glassy pyroxene dacite through which protrude such domes of dacite as those forming Cappy Mountain, and Burnt and Hemlock buttes.

The earliest High Cascade lavas were erupted from a north-south chain of volcanoes close to the present edge of the Western Cascades. It seems moreover, that these volcanoes lay on or near the base of an eastward-facing erosion scarp cut in the rocks of the Western Cascade sequence. In places, this buried scarp was between 1,500 and 3,000 feet high, and where it was steepest and straightest it was almost certainly the result of faulting. As the volcanoes gained in height and the crest of the scarp was lowered by erosion, more and more of the High Cascade lavas were able to flow westward, inundating the scarp and spreading beyond on to a surface of low to moderate relief cut in the older volcanic rocks. Especially was this the case in the Waldo Lake quadrangle, where High Cascade basalts spread far to the west over a gently undulating surface mostly between elevations of 3,000 to 4,000 feet. Some basalts poured westward down the ancestral valleys of the present major rivers, but it is apparent that most of the present canyons that cross the Western Cascades were incised after the High Cascade volcanoes had ceased to discharge their lavas in that direction.

Madras formation (QTm-QTmt)

(See Bend quadrangle text for discussion)

Pleistocene Andesite and Dacite Cones (Qad)

The bulk of the High Cascades, as noted already, consists of Pliocene and Pleistocene olivine basalts and olivine-bearing basaltic andesites erupted from flattish shield volcanoes, and in places discharge of similar lavas continued until very recent times. But during the Pleistocene epoch several large, steep-sided, composite cones of andesite and dacite were built either on the tops of the older shields or in the depressions between them. The South Sister, for example, is made up of three parts. Its lower part is an eroded basaltic shield volcano capped by a steeper