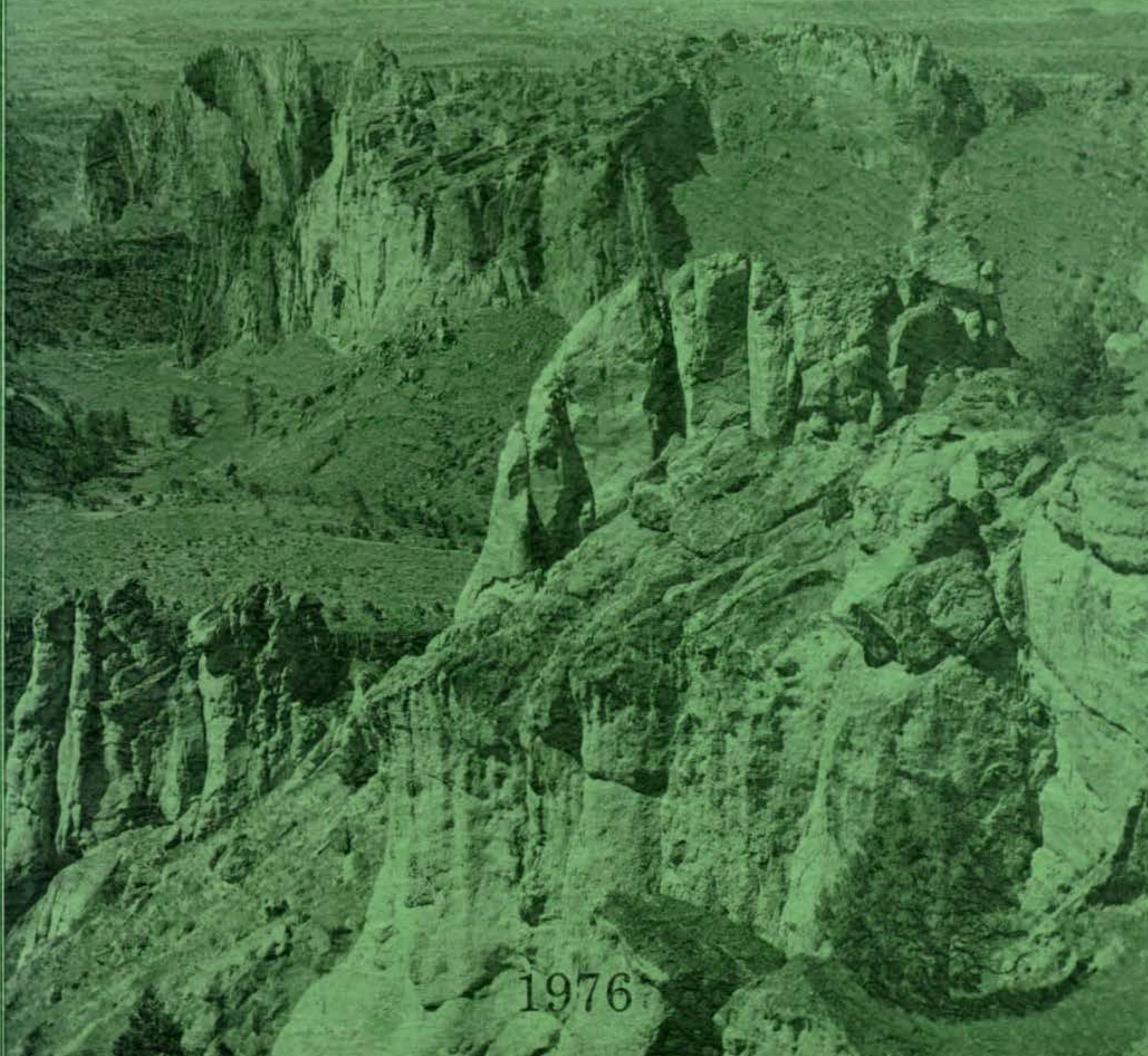
BULLETIN 89 TEXT

GEOLOGY AND MINERAL RESOURCES

OF

DESCHUTES COUNTY, OREGON



1976

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1069 State Office Building, Portland, Oregon 97201

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GEOLOGY AND MINERAL RESOURCES OF DESCHUTES COUNTY OREGON

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1976

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GEOLOGY AND MINERAL RESOURCES OF DESCHUTES COUNTY, OREGON

INTRODUCTION

Purpose and Scope of Report

The importance of low-cost industrial minerals, such as sand, gravel, and building stone, close to growing communities is generally overlooked. As a result, urban encroachment on land underlain by these materials is a growing problem. Recognition of this problem by Deschutes County planners and other concerned persons in the County led to the request that the Oregon Department of Geology and Mineral Industries prepare a survey and evaluation of the County's industrial mineral resources. The following report is the outcome of that request.

Industrial mineral deposits are natural concentrations of useful and economically valuable rock materials. Because such deposits are directly related to the geologic history of an area, any in-depth discussion of them should include information on their origin, distribution, and relationship to rock units. Such information is of particular value to those charged with the responsibility of land use planning. For this reason we have described the geology of Deschutes County in some detail.

Three geologic maps illustrate the distribution of the rock units with which the mineral resources are associated. A colored geologic map shows the geology of Deschutes County at a scale of 3 miles to the inch. Two maps in black and white show, on a larger scale, the geology of the urban areas of Bend and Redmond, where land use planning is most critical. A mineral resources map shows the location of pits and quarries where industrial minerals are mined. Pertinent data for each site are given in the Appendix.

The field work and mapping for this project were done during the field season of 1974 and all available geologic maps and texts on the region were used in preparing this report. The geologic map of the Redmond area was modified from Stensland (1970 [revised in 1974]). The areas of previously published mapping are outlined on the County geologic map, and known available published references used in preparing the maps and writing the report are listed alphabetically in the Bibliography at the end of the text. Except for the chapter on geothermal resources, which was written by E. A. Groh, the text is the responsibility of N. V. Peterson. E. M. Taylor is responsible for much of the mapping in the northwest part of the County.

Acknowledgements

The authors are grateful to the many people, agencies, and organizations who provided information, technical assistance, and helped in other ways to make this report possible.

Mr. Lorin Morgan, Deschutes County Planning Director representing Deschutes County, helped to plan the project, and provided base maps and other information. Dennis Larson and Larry Chitwood, resource geologists of the Deschutes National Forest, provided information about industrial mineral deposits and were helpful in discussions of geologic problems. Roland VanCleve of the Oregon State Highway Department, and Charles Plummer and Don Scholes of the Deschutes County Road Department also furnished information about the production and source of road-building materials in the County. Bill Miller, formerly a member of the Governing Board of the Oregon Department of Geology and Mineral Industries, was helpful in planning the project and provided information about mineral resources. Robert Coates, Jim Curl, Chuck Clark, and Robert Johnnie also provided information about the production, location, and reserves of their industrial mineral resources.

Harry Metke of the Bend Water Department furnished well logs. Don Anderson, Jim McNeely, and Leroy Fox provided historical information and photographs of early-day mineral production in the County. Norman MacLeod of the U. S. Geological Survey provided preliminary age dates of rock units and freely discussed geologic problems of the area. We also benefited from field conferences with Bruce Nolf of Central Oregon College and "Mr. Central Oregon Geology" himself, Phil Brogan. Peggy Sawyer and the others at the Bend Chamber of Commerce as usual always cheerfully took care of our unusual requests.

Finally, the entire staff of the Oregon Department of Geology and Mineral Industries provided the moral support, editing, cartography, and other myriad details to make this a finished product.

Location, Accessibility, and Culture

Deschutes County lies just west of the center of Oregon (Figure 1); its interesting shape is like a giant ski boot with the toe pointing eastward and the heel at the west, outlined by the crest of the Cascade Mountains. Deschutes County, established in 1916, contains about 3,060 square miles (7925 km^2). Bend is the County Seat.

The County is crossed from northwest to southeast by U. S. Highway 20 and from north to south by U. S. Highway 97, which connects the Columbia River area on the north with Klamath Falls on the south. State Highway 126 and 242 cross the north part of the County and in summer furnish access to the Willamette Valley. A network of County, U. S. Forest Service, and private logging roads gives access to most other parts of the County. Among these is Century Drive, a paved loop road that provides a winter route to the popular ski area at Bachelor Butte and a summer route to numerous lakes and recreation areas in the southwest part of the County.

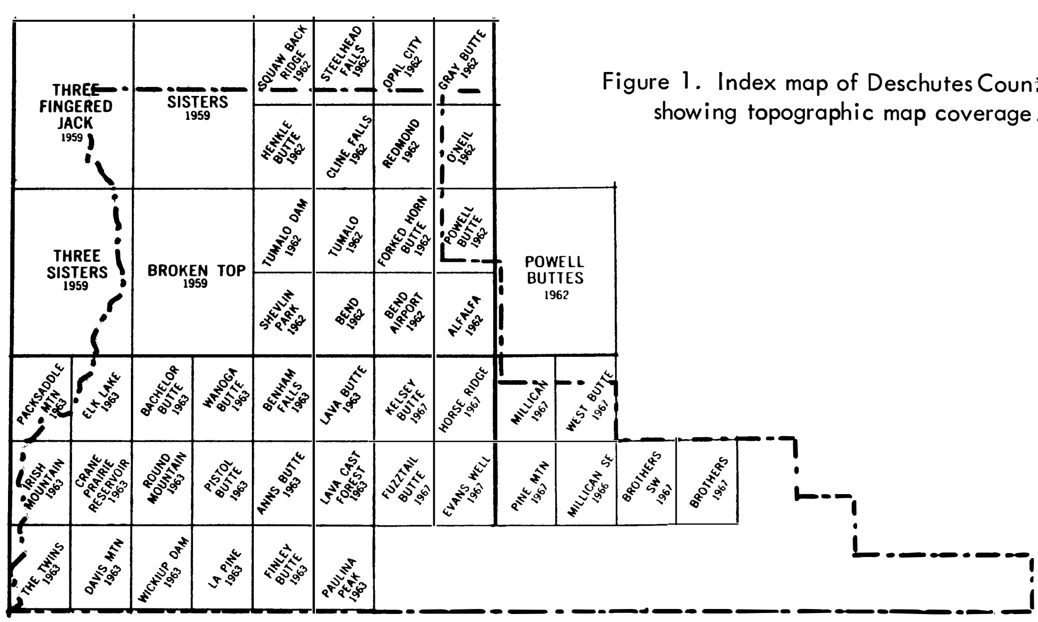


Figure 1. Index map of Deschutes County showing topographic map coverage.

Burlington Northern and Union Pacific rail lines provide daily service to the County, and the City of Prineville owns and operates a railroad that connects Redmond with Prineville. Roberts Field (Bend-Redmond Airport) at Redmond, provides scheduled airline service, and the Bend Municipal Airport serves small aircraft.

Pacific Power and Light Co. furnishes the area's electricity, and Cascade Natural Gas Co. brings in natural gas from a pipeline paralleling U. S. Highway 97.

Urban areas obtain domestic water from Tumalo Creek and the Deschutes River, and outlying areas tap the ground-water supply by means of wells. Most of the available surface-water supplies south of Redmond have been appropriated, so any new water supplies will have to be developed from the ground water.

Population density of the County as a whole is about 12 persons per square mile (2.6 persons per km^2). Total population and estimated future growth trends are shown in Figure 2. Most of the residents live in the north part of the County in and around the population centers of Bend (16,000), Redmond (5,000), and Sisters (600). From 1960 to 1970 Deschutes County was the fifth fastest growing county in Oregon, and since 1970 this rate of growth has increased even more, mainly in the suburban and outlying areas.

The Bend Chamber of Commerce reports, "The recreation development has been most dramatic in Deschutes County, where between 1960 and 1970 the rural population increased by 66 percent, while Bend grew by 10 percent. Developments are springing up all along the Deschutes River, ranging from simple plots of land in the woods (Figure 3) to large planned developments like Sunriver and Black Butte Ranch. Continued growth appears certain; some 15,000 lots are presently sold but unoccupied, and sales continue at a rapid rate."

A diversified economy is typical of Deschutes County, and even though timber, agriculture, and livestock raising continue to be the most important industries, forest product remanufacturing and recreation are rapidly expanding. The County has some of the most popular year-round recreation areas in the Pacific Northwest. The ski area at Mt. Bachelor is nationally known and is the center for a variety of winter recreation activities. In the summer, fishing in the numerous lakes and streams is very popular and the overall scenic beauty of the western half of the County attracts campers and hikers.

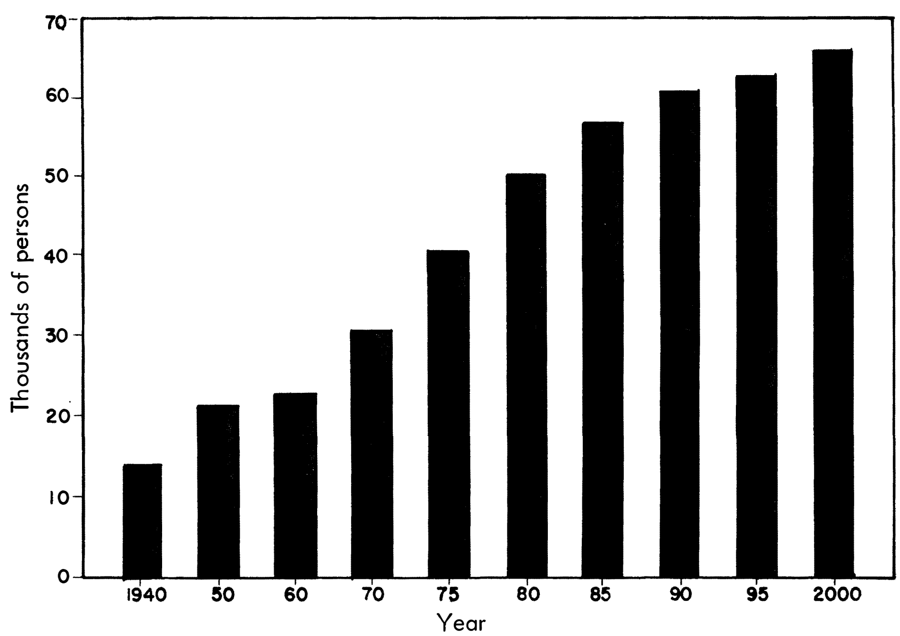


Figure 2. Population trends and projected population growth in Deschutes County. Projections for the years 1980 through 2000 from Center for Population Research and Census, Portland State University.

Figure 3. The juniper-rimrock landscape of central Oregon is changing rapidly as houses, such as these along the Deschutes River north of Tumalo, become more numerous.

Climate and Topography

The High Cascades form a definite weather barrier. Precipitation reaches 100 inches (250 cm) in the High Cascades and gradually decreases eastward to less than 10 inches (25 cm) in the High Lava Plains east of Bend. Most of the precipitation is winter snow; in summer there is only an occasional thunder shower. The temperature at Bend averages 47.5° F (8.6° C), but ranges as high as 105° F (40.5° C) in summer and as low as -25° F (-59° C) in winter. The short summer season (only about 120 frost-free days) limits agricultural crops to the hardiest varieties, such as alfalfa, grain, and potatoes.

The topography of Deschutes County ranges from over 10,000 feet (3,050 m) in the majestic peaks of the High Cascades to a general elevation of about 4,000 feet (1,200 m) in the broad area of the High Lava Plains extending eastward beyond the County boundaries. This wide variation in altitude, as well as in precipitation, results in great diversity of vegetation. The foothills and lower elevations of the High Cascades are thickly timbered with fir, hemlock, and pine (Douglas fir, Western white fir, Lodgepole pine, and Ponderosa pine). By contrast, the vegetation in the High Lava Plains in the eastern part of the County changes eastward from Ponderosa pine and Lodgepole pine to Juniper, sagebrush, and rabbit brush. Bunchgrass and planted grasses, such as crested wheat grass, give this part of the High Lava Plains some value for cattle grazing.

The northward flowing Deschutes River divides the County into distinct physiographic provinces. West of the river are the foothills and towering peaks of the High Cascade Mountain Range. East of the river is the gently undulating lava-covered plain, where no distinctive drainage pattern has yet been developed. The northern part of the High Lava Plains slopes gently northward; and here the Deschutes River and its tributaries have steep-walled canyons in the flat-lying lavas and sedimentary materials. Crooked River, one of the largest of the Deschutes tributaries, crosses the extreme northeast corner of the County. South of Bend the High Lava Plains are dominated by the massive Newberry Volcano (8,010 feet) (2,440 m) which has had a complex eruptive history and now holds two large lakes within its summit caldera.

In the area between the Cascade Crest and Newberry Volcano, volcanic activity has greatly altered the course and activity of the Deschutes and Little Deschutes Rivers. From Benham Falls southward the streams meander and flow sluggishly because of numerous lava dams in that vicinity. The youngest dam of this kind was formed relatively recently by lava flows from Lava Butte. From Benham Falls northward the Deschutes channel is somewhat straighter, and the canyons are more deeply incised; but even here older ash flows and lava flows have filled ancestral canyons and have forced the river to cut new channels.

Deschutes County could perhaps be called "the land of a thousand volcanoes." More than 500 large volcanoes, cinder cones, or volcanic vents can be counted on the geologic map, and probably that many or more are obscured by erosion and later sedimentary and volcanic cover. It is likely that Deschutes County contains a greater abundance and variety of volcanic landforms than any other area of similar size in the United States. For anyone interested in volcanoes and their products, Deschutes County is an outdoor classroom.

SUMMARY OF GEOLOGIC HISTORY

Origin of the Rocks

The geologic history of Deschutes County is one of recurrent episodes of volcanism that can be traced back nearly 40 million years to early Tertiary time (see time chart on County geologic map). Rocks of early Tertiary age occur in small outcrops along the eastern and northern borders of the County and more extensively in counties to the north and east. To the south, in Deschutes County, early Tertiary rocks may lie at depth beneath younger volcanic and sedimentary materials.

The oldest of the Tertiary rocks, which originated during a period of intense volcanism in late Eocene to early Oligocene time, are part of the Clarno Formation. They consist of weathered reddish brown andesite and basalt flows with interbedded layers of tuff and breccia. Vents for the volcanic eruptions have been obscured by erosion and subsequent tectonism.

The next episode of Tertiary volcanism, which occurred in late Oligocene to early Miocene time, produced the more siliceous explosive and effusive materials of the John Day Formation. The flow-banded rhyolite and ash-flow tuff that make up the spectacular erosional spires and pinnacles at Smith Rocks and Coyote Butte are thought to be remnants of these violent eruptions, with Gray Butte to the northeast as a possible volcanic vent. Cline Buttes near Redmond is also assumed to be a John Day volcano.

Later, during the Miocene epoch, large volumes of basaltic lava, known as the Columbia River Group, covered much of northeastern Oregon, reaching the northeastern edge of Deschutes County. Here, along Bear Creek, a few of the Miocene lava flows overlie the eroded massive layers of varicolored tuffs of the John Day Formation. Late Miocene sediments overlying the gently deformed basalt of the Columbia River Group may represent the Mascall Formation.

Gradual regional subsidence began in central Oregon in early Pliocene time and was accompanied by widespread and varied volcanic activity which produced a heterogeneous assortment of thin basaltic lava flows, ash-flow tuffs, ash falls, and volcanic detritus. Pliocene-age materials were distributed widely in the central and northern part of the County, where they accumulated as a flat-lying unit hundreds of feet thick, known as the Deschutes Formation. Sedimentation and minor sporadic volcanism continued into the Pleistocene.

The latest period of intensive volcanic activity in Deschutes County began along the north-south alignment of the Cascade Range, also at Newberry Volcano, and at isolated locations like Grassy Butte in the east part of the County. Earlier workers believed that the broad High Cascades platform with its crowning peaks began to build in Pliocene time, but Taylor (1968) now suggests that the High Cascades are entirely of Pleistocene and Holocene age. McBirney (1969) and McBirney and others (1974) have confirmed that even the largest central Cascade volcanoes, including the Three Sisters, Bachelor Butte, Broken Top, and the adjacent Newberry Volcano, were built within the last million years. Basalt was the most common material erupted during this latest volcanic episode, but numerous ash falls and ash flows erupted from silicic centers near Broken Top, South Sister, and also from Newberry Volcano. Obsidian domes within Newberry Volcano are as young as 1,200 years; and the most recent basaltic lava flows from vents on the north flank of North Sister are only a few thousand years old. In view of this recent activity it is surprising that no historic volcanic eruptions have occurred, and it is interesting to speculate where the next eruption might take place.

The High Cascade peaks and their flanks have been deeply scarred by the erosive forces of Pleistocene glaciers. A few small remnants of the former large glaciers and ice fields are still present (Figure 4). Prominent terminal moraines mark their latest advance and retreat. Outwash sand and gravel from their meltwaters fill ancient channels and form broad fan-shaped deposits at lower elevations.

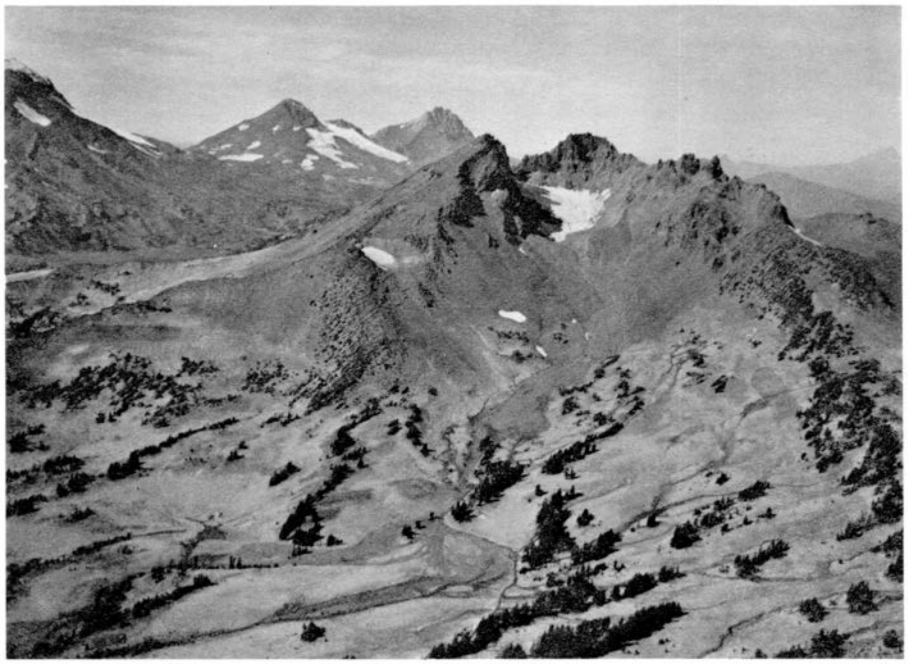


Figure 4. This late summer view of Broken Top and the Three Sisters shows the remnants of the once extensive glaciers that eroded the High Cascade peaks during the Pleistocene.

Structural Events

Evidence from rocks exposed in Deschutes County and in surrounding areas indicates moderate folding and faulting of the Clarno Formation in Oligocene time, minor folding of the John Day Formation and Columbia River Basalt in Miocene time, and, finally, erosion of the region to one of moderate relief. The general horizontal attitude of the Deschutes Formation and other post-Miocene units shows that folding had ceased by late Cenozoic time.

In early Pleistocene, Deschutes County began to be the focal point for three major styles of crustal activity, some of which continued on into Holocene time.

One of these was a northwest-trending zone of en echelon faults that extended across the entire County. This feature, the Brothers fault zone, is interpreted to be part of a regional zone of crustal weakness along which minor faulting has offset all units older than late Pleistocene.

A second kind of Pleistocene activity was the construction and destruction of Newberry Volcano, which grew into a huge shield-shaped mass and then collapsed along large concentric fractures, forming a caldera as magma drained away. In Holocene time, fractures on the flanks of the volcano provided escape for the extensive lava extrusions such as the "Lava Badlands" and the pyroclastic eruptions such as Lava Butte. Fractures within the caldera were the locales for the eruption of silicic domes and flows of obsidian.

A third type of crustal activity was the development of a north-trending deep-seated structural lineament and the eruption along it of the High Cascade volcanoes previously described.

In historic time, Deschutes County has been relatively quiet in a geologic sense, indicating that crustal movement and volcanism are dormant.

DESCRIPTION OF GEOLOGIC UNITS

The geologic units described in this section of the report are presented in chronological order in so far as this is feasible. Many of the younger units overlap in time because they represent nearly simultaneous volcanic eruptions and accumulations in different places. Even though similar in age, the units are sufficiently distinctive in composition to be given lithologic names and be mapped. Letter symbols following the name of each unit appear on the geologic maps as an aid to reading the maps.

Following the description of each unit is a brief summary of the associated mineral resources; fuller discussion can be found in the section titled "Mineral Resources."

Pre-Pliocene Rocks (Tpp)

The pre-Pliocene rock unit in this report includes all rocks of Eocene, Oligocene, and Miocene age. This unit is exposed in several small isolated areas of Deschutes County as follows:

In the northeast corner of T. 20 S., R. 19 E., about 10 miles north of Hwy 20 northwest of Hampton Buttes, the rocks are mainly andesite flows, breccias, and interbedded tuffaceous sedimentary rocks that were correlated by Walker and others (1967) with the Clarno Formation of Eocene-Oligocene age. The original andesite flows are now altered to greenish-gray amygdaloidal rocks which typically weather to irregular fragments with coating of red-brown in a reddish-brown soil. Agate, jasper, and fossil wood occur in similar rocks to the east on the flanks of Hampton Buttes.

In the northeast corner of T. 14 S., R. 13 E., at Smith Rocks, Coyote Butte, and a small isolated outcrop south of Terrebonne, there are erosional remnants of thick ash flows, rhyolite flows, and silicious pyroclastic rocks of the John Day Formation. The dominant rocks in the Smith Rocks State Park are platy, mottled tan to red rhyolite flows and ash-flow tuffs. Differential weathering of variably silicified tuffs and devitrified rhyolite flows partially accounts for the curious erosional land forms (Figure 5). The Crooked River has also had a part in undercutting and eroding the spires and pinnacles as it was dammed and forced northward by encroaching basaltic lava flows from the south.

In the northeast corner of T. 19 S., R. 16 E., northeast of Millican in the upper reaches of Bear Creek, the pre-Pliocene rocks include basalt flows of the Columbia River Group (Walker, 1967). In this area several flow units of the typical thick columnar jointed dense black basalt flows that weather to a reddish-brown color and litter the slopes with thick talus, are present. Walker correlates this part of the Columbia River Group flows with the Picture Gorge Basalt and these exposures may be the southernmost of the typical Columbia River Group in central Oregon. Above the basalt flows in this area are tuffaceous sedimentary rocks, "Tts" of Walker and others (1967), that are light colored, poorly bedded tuffaceous sediments of flood plain or shallow lake origin. These are believed to be correlative with the Mascall Formation, a part of the Columbia River Group of late Miocene age.

Two other notable occurrences of pre-Pliocene rocks are in the north part of the County. Their age is speculative. Stearns (1931) described a large mass of eroded andesite covering several square miles and straddling the border between Deschutes and Jefferson County on the west bank of the Deschutes River. Forked Horn Butte southwest of Redmond is also composed of this characteristic porphyritic andesite vitrophyre. Stearns suggested that this rock type originated with the older andesites of the Cascades and he assigned it a Miocene (?) or Pliocene (?) age. Stensland (1970) correlates the andesite vitrophyre with rocks of Clarno age. As Stearns noted, the age of the andesite remains unknown, but it is separated from the overlying horizontal beds of the Pliocene Deschutes Formation by a steep erosional unconformity.

The pre-Pliocene rocks generally do not appear to contain any notable mineral resources. However, small quantities of the silicified tuffs near Terrebonne have been quarried for building-stone. Basalt of the Columbia River Group and the andesite vitrophyre described above could provide crushed rock where sand and gravel are not conveniently available.

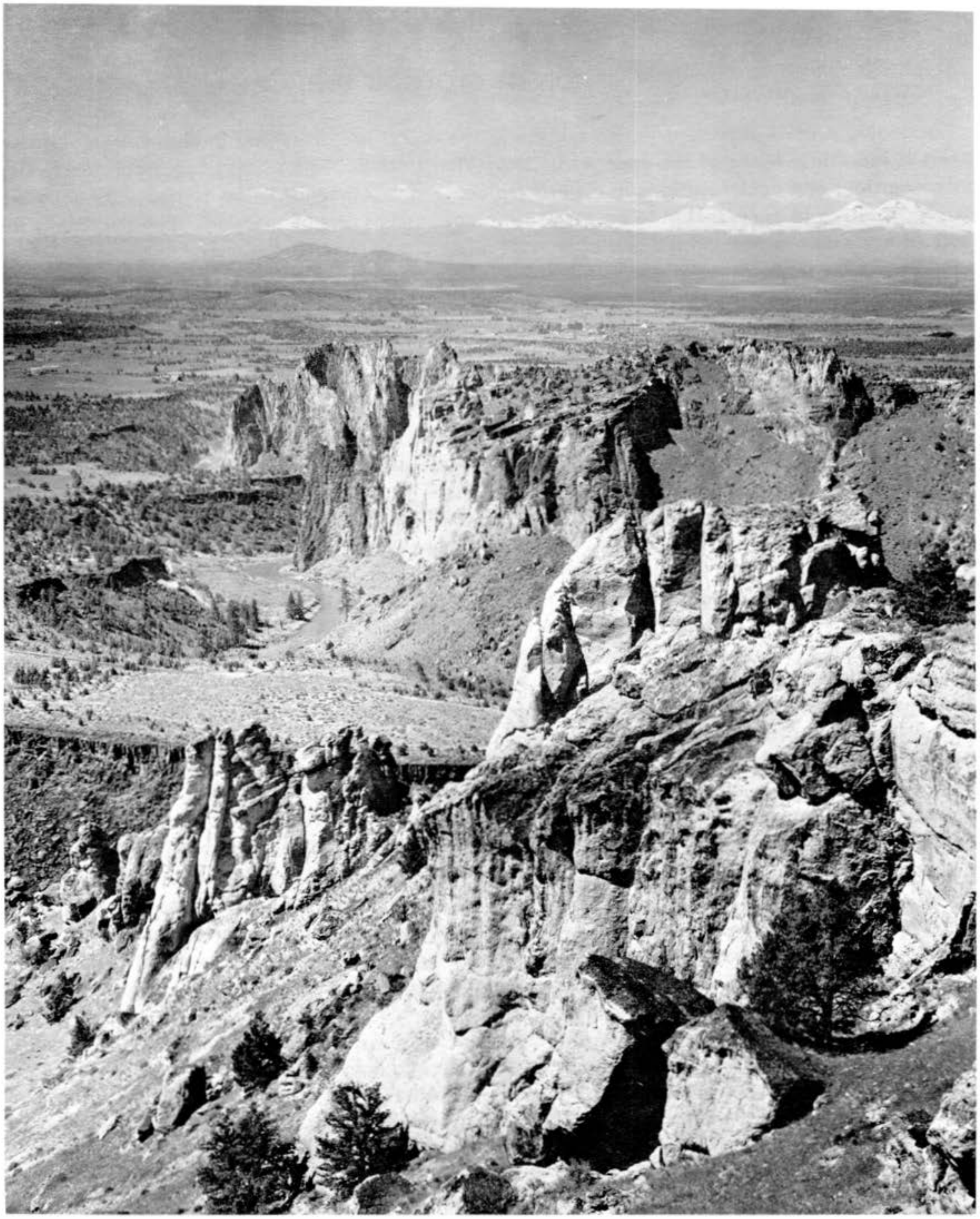


Figure 5. View from Smith Rocks looking southwest across the central Deschutes River basin. Smith Rocks are the erosional remnants of a John Day age (Oligocene) volcanic center composed of rhyolite domes and ash-flow tuffs. Lava at the base of Smith Rocks flowed from the north flank of Newberry Volcano and forced Crooked River against Smith Rocks. Cline Buttes, another rhyolite volcano of John Day age, is in the middle distance. The snow-covered peaks of the High Cascades in the distance mark the western boundary of Deschutes County. (Oreg. Hwy. Div. photo 6068)

Pliocene Rocks

Tuffaceous sandstones (Tst)

Tuffaceous sandstones and siltstones occur in irregular patches along the northeastern boundary of the County. The sediments are thinly layered, partially consolidated, and commonly tan to light brown. They appear to have been deposited in a fluvial, flood plain, or shallow lake environment. Outcrops are scarce and areas underlain by the Tst unit usually exhibit a subdued topography. The unit is believed to be of early to mid-Pliocene age.

Some lenses of sand and gravel occur in the Tst unit. Small amounts have been used for road building and maintenance northeast of Brothers, but the supply appears to be limited.

Ash-flow tuffs (Twt)

Densely welded portions of ash-flow tuffs interfingering with the tuffaceous sandstone (Tst) are preser in irregular patches on the south and west flanks of Hampton Buttes in the eastern part of the County. The ash-flow tuffs are gray to reddish and probably consist of more than one unit. Walker (1970) describes one thin, pumiceous ash-flow tuff that crops out extensively west of Hampton Butte along the Crook-Deschutes County line and states that it has been dated at 3.6 million years (late Pliocene). No mineral resources are known to be associated with the Twt ash-flow tuffs.

Basalt (Tb)

The unit is composed of thin flows of medium to dark-gray olivine basalt, generally with diktytaxitic textures. The basalt is commonly vesicular and has secondary fillings of opaline silica. A thin soil covers the top flow, and no initial surface structures are preserved. South and east of Hampton, fault blocks show multiple thin flows totaling at least 100 feet (30 m) thick (Figure 6).

In the Bear Creek Buttes and on the eastern flank of Pine Mountain, the Tb basalt is the predominant rock type. On the west flank of Bear Creek Butte, in the Highway 20 roadcuts, the flows alternate with agglutinate and cindery debris and are apparently near their source. At the Horse Ridge summit, the steep canyon walls of Dry River and the highway roadcuts expose the numerous thin scoriacious basalt flows and alternating cindery breccia, ash, and agglomerate layers and show the complex buildup of the rounded volcanic landforms of Bear Creek Buttes and Horse Ridge. East of Bear Creek Buttes the Tb basalt overlies the Tst sediments of late Miocene age and is difficult to differentiate from the overlying QTb unit. No known age determinations are available, but the Tb lava flows are generally believed to be Pliocene in age

Small quarries for crushed rock have been opened in the Tb basalts; however, the thinness of the flow and the lack of closely spaced jointing precludes development of large tonnages at any one location.

Pliocene-Pleistocene Volcanic Rocks

There are literally hundreds of eruptive centers in the County ranging in size from small spatter or cinder cones to voluminous volcanic piles such as the majestic High Cascade stratovolcanoes. Many of the large eruptive centers in the east and north, such as Pine Mountain, Frederick Butte, and Cline Buttes, contain rock types ranging from rhyolite to basalt and have a complex eruptive history. The larger peaks in the High Cascades, with the exception of Middle and South Sister, are predominantly basaltic. Middle and South Sister are two of those that exhibit an especially complex volcanic history involving both flow and pyroclastic rocks that range from rhyolite to basalt. The shield volcanoes and smaller vents, including the cinder cones, have a simpler volcanic history and usually contain only a single rock type.

Silicic vent rocks (QTsv)

Predominantly rhyolite to dacite lavas make up Pine Mountain, Frederick Butte, and Cline Buttes.

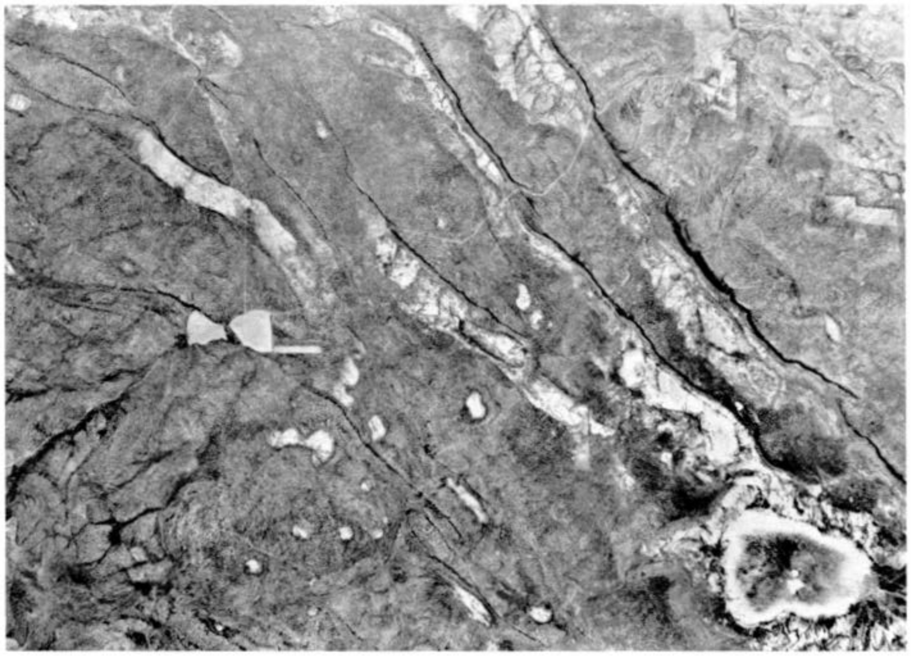


Figure 6. High elevation aerial view of parts of T. 22 S., Rs. 20 and 21 E. in eastern Deschutes County. The Brothers fault zone offsets lava flows of the Tb and Qtb units, forming northwest-trending fault blocks and intervening valleys with interior drainage.

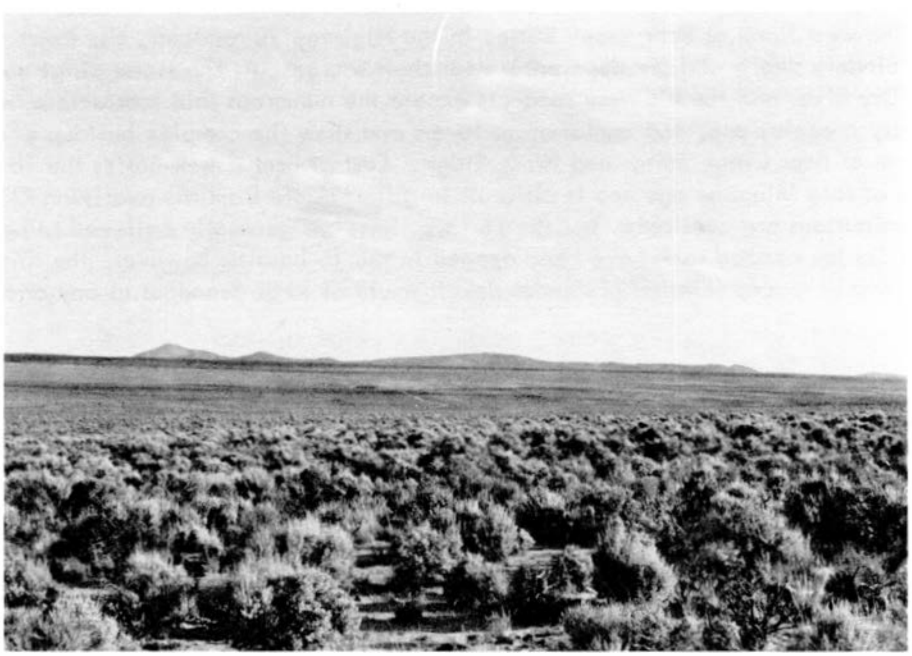


Figure 7. Frederick Butte, about 10 miles south of U.S. 20. The outcrops form a semicircular volcanic feature interpreted to be a large caldera-like structure.

We are not aware of any absolute dates for Pine Mountain or Cline Buttes, but both show considerable erosion and are covered with thick soil zones. The light-gray, flow-banded rhyolites and rhyolite breccias suggest that Cline Buttes is part of a formerly larger complex of intrusive-extrusive domes; Williams (1957) suggests that Cline Buttes is of John Day age, and its composition and position not far from outcrops of known John Day rocks to the northeast makes this a reasonable suggestion. Pine Mountain is predominantly rhyolite and dacite vitrophyre, both massive and flow banded. It also contains thick basaltic flows on its northeast flanks and obviously has a complex eruptive history. Its soil cover and state of erosion indicate that it also may be of John Day age; however, Walker and others (1967) consider it of Pliocene age.

The outcrop pattern at Frederick Butte suggests that it could be the north half of a fairly large caldera (Figure 7). This roughly ring-shaped mass is predominantly flow-banded rhyolite-dacite with a few dikes and minor flows of basalt. A potassium-argon age date by Walker (1974) gives a 3.9 ± 0.4 million year age for rhyodacite from Frederick Butte, indicating volcanic activity in late Pliocene time. Since its last volcanic activity, Frederick Butte has been eroded, faulted, and all but inundated by Plio-Pleistocene basaltic lava flows which now surround it.

Another east-west trending ridge or dome complex of medium gray flow-banded dacite of uncertain age is situated at Benham Falls south of Bend. This resistant rock forms Benham Falls and forces the Deschutes River to make a wide loop around it. Ash-flow tuffs (Qwt) lap around this dome complex indicating that it must be at least as old as late Pliocene. A preliminary potassium-argon age date of 2 to $2\frac{1}{2}$ million years has been reported by MacLeod (personal communication, 1976).

A quarry has recently been opened on the east flank of Cline Buttes where flow-banded rhyolite and breccia are being crushed for use in the construction industry. Zones of perlite were also noted in the Cline Buttes complex, but the quality and quantity are not known. There are probably sites on Pine Mountain where large quantities of crushing rock could be developed; however, its remoteness from markets is not encouraging. The geothermal potential near the large silicic vents is still to be determined.

Mafic vent rocks (QTmv)

The basaltic eruptive centers occur generally in two roughly aligned belts which reflect the major structural lineaments in the County. In the eastern part of the County the larger basaltic eruptive centers are roughly aligned northwesterly along the Brothers fault, and prominent vent areas include the Bear Creek Butte and Horse Ridge. Along this same trend in the Bend-Redmond vicinity, Aubrey Butte, Overturf Butte, Tumalo Butte, Long Butte, and Laidlaw Butte are some of the prominent features. At the very north edge of the County the symmetrical Black Butte volcano straddles a prominent fault of the Brothers fault zone, which here veers northward.

Of the spectacular stratovolcanos along the Cascade Crest, Mt. Washington, North Sister, and Broken Top are all predominantly of basaltic composition. Of the many large steep-sided shield type volcanos on the east flank of the Cascades, Davis Mountain, (Figure 8), Brown Mountain, Maiden Peak, Cultus Mountain, and The Twins appear to be randomly distributed while others like Bachelor Butte, Sheridan Mountain, Lookout Mountain, Round Mountain are parts of aligned chains of volcanos that form impressive north-south masses paralleling the High Cascades. Many have been glaciated severely and their central plugs are exposed, while others like Bachelor Butte and Black Butte show only minor glacial scarring and still retain their symmetrical constructional shapes.

The mafic volcanic vent rocks are far from homogenous. They consist of lava flows and a great variety of pyroclastic material, including cinders and scoria. Layered tuffs, breccias, and mud-flow debris are commonly exposed in the large volcanic piles.

Most of the basaltic volcanic vent areas in the eastern part of the County appear to have been considerably eroded and may be as old as Pliocene. Most of those in the triangle between the High Cascades, Newberry Volcano, and the Deschutes Basin retain their original constructional landforms and probably range from Pleistocene to Holocene in age.

Cinders have been quarried from many of the large basaltic centers such as Davis Mountain, Lookout Mountain, and Round Mountain. These vent areas will continue to be sources of cinders and scoria for local road building.

Figure 8. View across Wickiup Reservoir toward Davis Mountain, one of many shield volcanoes in southwestern Deschutes County.

Figure 9. Wake Butte is an elongate erosional remnant of a tuff ring complex of probable Pliocene age. Photo shows the eroded edges of thin layers of palagonite tuff.

Figure 10. View of Lava Butte cinder cone from the south side showing the crater in the top and the vent and gutter at the base from which lava flowed around the cone and westward toward the Deschutes River.

Pyroclastic rocks (QTp)

Cinder-scoria cones and mounds, tuff rings, and basaltic tuff cones are closely associated with the previously described basaltic eruptive centers, and there are hundreds of these smaller explosive volcanic landforms. They range from older eroded tuff-ring deposits of Pliocene age, such as those at Wake Butte (Figure 9), to the symmetrical cratered cones like Lava Butte (Figure 10), which is only a few thousand years old. Many north-south aligned pyroclastic cones are concentrated on the east flank of the Cascades, and heavy concentrations can be seen on the north and south flanks of Newberry Volcano (Figure 11). North and South Twin Lakes, two of the many interesting small volcanic features, are true maars (lake-filled explosion craters).

The tuff ring and maar-type features result when a rising basaltic magma encounters water or water-saturated materials near the surface. The resulting violent eruptions generate fine ash and rock fragments that are thrown high into the air and then settle to form the typical thin layers of basaltic tuff that build up around a broad cone-shaped crater. The tuff ring deposits are composed of a variety of volcanic rock fragments in a matrix of fine frothy basaltic glass. Their colors range from gray to drab yellows and browns. Peterson and Groh (1963) have discussed the maars of south-central Oregon in detail.

Figure 11. View east from Abbot Butte toward the gently sloping north flank of Newberry Volcano showing some of the many Pleistocene and Holocene cinder-scoria cones that dot the surface.

Figure 12. Deschutes Formation exposed in the Deschutes River canyon in sec. 16, T. 16 S., R. 12 E., west of Long Butte. Massive upper layer is tan to light gray pumiceous ash-flow tuff. Lower layers are sand, gravel, and ash. A northwest-trending fault locally controls the direction of the river channel.

The numerous cinder and scoria cones in Deschutes County are also basaltic in composition. Most were built over vents by fire fountaining, a less violent eruption than the maar type. During fire fountaining, molten clots of lava shoot out of the vent to heights of a few hundreds of feet and shower down around the vent in a conical mound of bombs, lumps of scoria, cinders, and ashes. Typical cinder cones such as Lava Butte or Pilot Butte are 400 to 600 feet (120 to 180 m) high and 2,000 to 5,000 feet (600 to 1,500 m) across at their base. Many of the simple cones have well-developed central craters, while others have broad rounded tops. Many of the cones also exhibit breached craters where later eruptions of lava have rafted away parts of the cinder cone or scoria slopes (Figure 10).

The palagonitic material (altered volcanic glass) of the tuff rings has no known economic value, but the cinder cones furnish a major portion of the cinders and scoria for the road building and construction industry in the County. Details about the composition and texture of the cinders and scoria are discussed in the mineral resource section of the study.

Deschutes Formation (QTd)
[(QTds) on Redmond map]

The name Deschutes Formation was first used by Russell in 1905 for fluvial and lacustrine volcaniclastic sediments in the Bend - Madras area; so this name has historical priority, even though later writers have called the unit the Madras Formation and the Dalles Formation.

The Deschutes Formation is a heterogeneous assemblage of basaltic tuffaceous sediments, conglomerate, mudflows, silicic ash-flow tuffs, diatomite, and interbedded basaltic lava flows. The base is not generally exposed in Deschutes County; however, several hundred feet of the middle and upper parts of the formation are exposed in the Deschutes River Canyon, lower Squaw Creek, and Deep Canyon in the north central part of the County. Figure 12 shows a typical section of the thin- to thick-bedded siltstone, sandstone, and conglomerate with minor resistant ash-flow tuff layers.

Stensland (1970) describes the Deschutes Formation in great detail and assigns an early through late Pliocene age to the formation. He restricts the name to the sedimentary sequence beneath the conspicuous "rimrock" basalt (QTdb on Redmond map; QTb on County map) which forms broad plateaus and flat-topped ridges in the central and northern part of the County. Farther south and east in the Deschutes Basin, especially adjacent to the Deschutes River, younger ash-flow tuffs, basaltic lava flows, and interbeds of sand and gravel indicate a generally similar depositional environment and it appears that rocks similar to those of the Deschutes Formation have been accumulating more or less continuously to the present time.

A distinctive mudflow unit interlayered within the Deschutes Formation near Redmond is mapped separately by Stensland (1970) who calls it the "Tetherow mud-flow breccia." The unit has been noted by earlier workers, particularly Stearns (1931). The mudflow unit shown on the Redmond area map as QTdm is at least 100 feet (30 m) thick. It is exposed adjacent to and in the canyon of the Deschutes River near Tetherow Bridge west of Redmond and also just west of Forked Horn Butte. The unit weathers to low rounded hills and, in the canyon walls, to bold cliffs and "hoodoo" landforms (Figure 13). As Stensland indicates, this unit is generally composed of unsorted angular volcanic debris ranging from fine ash to large blocks as much as 10 feet in diameter. Composition of the fragments ranges from basalt to rhyolite with a predominance of the andesite vitrophyre like that which makes up Forked Horn Butte. The matrix is tan to pinkish, is distinctly tuffaceous, and contains small fragments of perlite and black glass. It is also micro-vesicular and somewhat altered to palagonite. The composition and texture indicate an explosive volcanic origin for the mudflow unit.

The upper part of the Deschutes Formation contains a large deposit of commercial-quality diatomite which has been mined from an area of about one square mile at Lower Bridge west of Terrebone. The relatively pure diatomite accumulated to a thickness of about 40 feet (14 m) in a spring-fed lake, probably as a result of a lava-dam of an ancient Deschutes River channel. This deposit is described in more detail in the mineral resource section of this report.

Diatomite and some sand and gravel from the conglomerate interbeds are the main mineral resource potential for the Deschutes Formation. Some of the ash-flow tuff layers may be suitable for use as building stone.

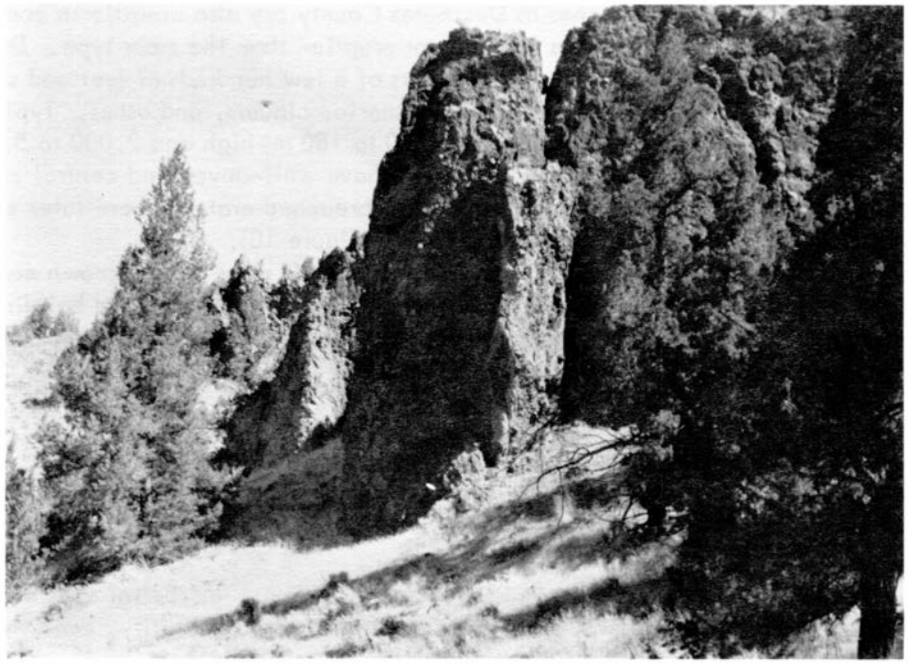


Figure 13. East wall of the Deschutes River canyon above Tethrow Bridge, west of Redmond, is composed of mud-flow breccia of the QTdm unit (Redmond quadrangle map) eroded to steep cliffs and small hoodoos.

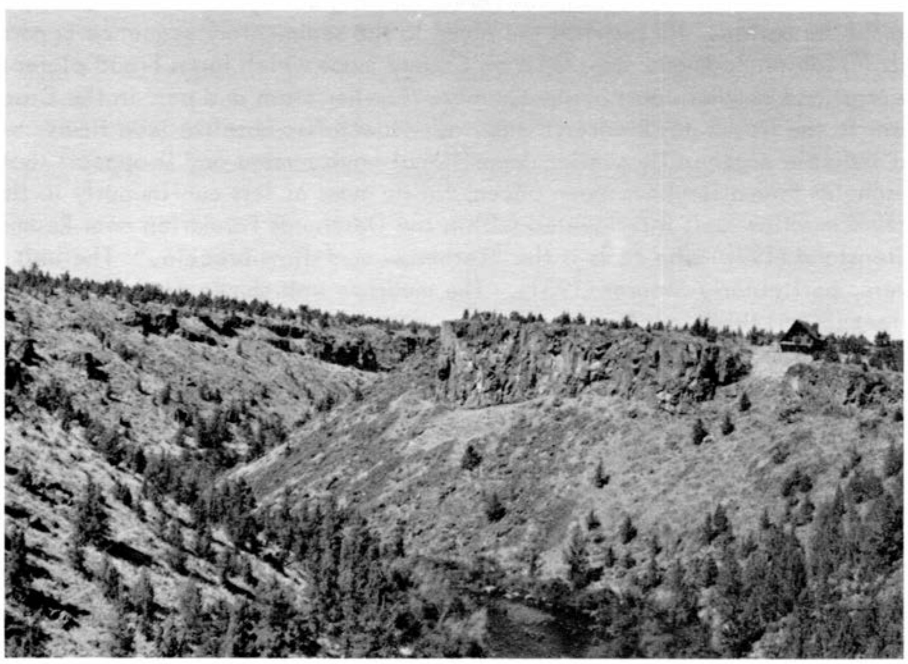


Figure 14. Deschutes River canyon west of Canyon Drive. "Rimrock" lava of the QTb unit overlies and fills shallow erosional channels in layered sediments and ash-flow tuffs of the Deschutes Formation.

A study of liquid waste disposal in wells Sceva (1968) shows the Deschutes Formation to extend south and east of Bend beneath the cover of the extensive overlying basaltic lava flows. Sceva reports that in much of the County the regional water table is within the Deschutes Formation at a depth of 500 to 600 feet (150 - 180 m) below the surface and serves as a major source of ground water.

Pliocene - Pleistocene Basalt Flows and Dikes

Basalt flows (QTb) (QTdb, Redmond map)

Similar to the previously described Pliocene basalt flows (Tb), these flows are generally medium-gray to black, vesicular, and diktytaxitic. They are the predominant rock type in the eastern third of Deschutes County and also form the conspicuous and widespread "rimrock" basalt at the top of the Deschutes Formation in the northern part of the County (Figure 14). In both places the lavas flowed over areas of moderate relief, and the thicknesses of individual flows varies from 10 to 100 feet (3 to 30 m). Flow breccia is usually present at the base of the flows, and rubbly and vesicular zones occur near the surface. Roughly developed columnar jointing is usually present. Original flow surfaces are sometimes recognizable, usually covered by only a thin layer of wind-blown cindery or pumiceous soil.

In the eastern part of Deschutes County tensional stresses associated with the Brothers fault zone have broken the flows into northwesterly aligned elevated blocks and intervening elongate valleys that usually have internal drainages and small dry lakes (Figure 6). Some blocks are slightly tilted, but most of the flows are horizontal. Nowhere does the displacement on the normal faults appear to be over 100 feet (30 m), and the sharply aligned fault escarpments can be easily seen in air photos of the area, indicating the recency of the faulting. The flows appear to be quite young, although this period of basaltic volcanicity may have persisted for quite a long time. Walker and others (1974) reports a potassium-argon age of 6.6 m.y. for the second flow from the top just east of Millican along U. S. Highway 20. Similar basalt flows lap around Frederick Butte, where rock from a rhyodacite dome is dated at 3.9 m.y. Sources for the basalt flows in eastern Deschutes County are not conspicuous but some flows appear to have originated from small eroded vent complexes such as Watkins Butte and K. O. Butte along the southern border of the County.

In the northwest part of the County, in the Bend-Redmond-Sisters triangle, the QTb "rimrock" basalt, is also faulted along the same northwest trending zone, although not nearly as intensely as in the eastern part of the County. Displacements are small and indicate tensional stresses with normal fault movement. The age range of these flows is perhaps not as great at that of the eastern flows, and individual flows appear to be generally thicker. Scoriaceous, rubbly zones are present at the bottoms and tops of the flows, and freshly broken surfaces show the light-to dark-gray diktytaxitic texture that is typical of so many of the Pliocene-Pleistocene basalt flows east of the Cascades. The typical irregular columnar jointing is poorly to well developed. Many of the vents for the "rimrock" basalt flows have probably been obscured by later volcanism, but it appears that early activity at mafic volcanoes such as Aubrey Butte, Overturf Butte, Laidlaw Butte and the faulted basaltic hills along U. S. Highway 20 between Tumalo and Sisters may have been their source.

The only mineral resource potential for the QTb basalt flows is for common crushed rock. The thinness of the flows, the presence of cindery interflow zones, and the lack of closely spaced jointing make crushing difficult, and sites for large quarries with sufficient tonnages are scarce.

Dikes

Only in a few places has erosion exposed narrow dikes and intrusive spines that mark the vents for lava flows or cinder-scoria mounds. The few that are shown on the County geologic map and the Redmond geologic map are long, narrow ridges of dense, fine-grained to porphyritic basalt which appear to be sources for the lava flows mapped as QTb in the northwest part of the County. Near Lower Bridge, northwest of Redmond, a relatively narrow ridge 80 feet (25 m) high is interpreted as a dike. It extends N. 10° W. for about half a mile (.8 km) from the Lower Bridge Market Road. A similar long, narrow basalt ridge is present in sec. 10, T. 17 S., R. 11 E., northwest of Bend. Another smaller elongate ridge about 2 miles (3.2 km) southeast of Sisters is probably a dike but is shown on the geologic map as a basaltic vent QTmv. The largest intrusive body is a wide mass or dike, exposed by erosion of Tumalo Creek, between Aubrey Butte and Tumalo Butte.

ZONE	IDENTIFYING CHARACTERISTICS
Black ash flow 0 - 20' thick 0 - 6 m	Prominently exposed in east wall of Tumalo Creek Canyon at Shevlin Park. Surface usually removed by erosion; in some places has a thin to thick layer of dark-gray ash with large black breadcrust bombs scattered through it. Upper to mid-parts are punky; dark gray, dark brown, to black, with scattered rock fragments of various colors. Lower part often intensely welded to glassy with elongate blebs of black glass common. Appears to be the youngest ash flow of the Qwt.
	Lenses of cindery sand and gravel at base of this ash flow.
Gray pumice ash flow 0 - 30' 0 - 9 m	Prominently exposed at Meadow Campground south of Bend in Deschutes River Canyon. Also occurs south and west of Bend. Generally is a gray to pinkish pumice-charged ash flow. Pumice fragments are altered to a reddish brown and are devitrified. Groundmass also shows some alteration, with small brownish specks disseminated throughout. Like the other ash flows, appears to have filled in low topography and in some areas is missing.
Zone of irregular induration	Where it can be recognized, this contact is concordant and thin with only a fine layer of pinkish ash.
Pink ash flow Tumalo 0 - 30' 0 - 9 m	Appears to be one of the most widespread. Can be seen in roadcuts surrounding Tumalo Park and is prominently exposed south of Bend. Groundmass pinkish to tan; distinctive tan to brown pumice fragments abundantly disseminated. Upper part of flow is irregularly hardened, and the thickness of the partly welded zone varies greatly over short distances. Where not welded and in the lower part it is punky to loosely indurated. Lower parts contain abundant large pinkish pumice fragments. In some areas erosion has removed nearly all of this ash flow.
	Contact easily recognized and marked by a thin layer of pink to grayish ash.
White pumice deposit 0 - 40' 0 - 12 m	Widespread in the area just south and west of Bend; also occurs in thick deposits near Tumalo and Laidlaw Butte. White to light-gray lump pumice. Minor amounts of ash and scattered small angular basalt and andesite fragments. Occurs as an essentially unsorted, compacted but non-indurated massive deposit; airlain, probably a glowing avalanche type deposit. Contains occasional charred wood fragments. Pumice fragments are unaltered and range in size up to 6 inches (15 cm) but average closer to 1/2 inch (1 cm). This is the marketable pumice of the Bend area.
	A few inches to a few feet of layered dark-gray to gray ash and rounded pumice fragments or dark-gray to black bombs usually present at this contact.
Brown to red-brown ash flow 0 - 40' 0 - 12 m	Perhaps the most widespread ash-flow tuff unit. Occurs prominently low in Deschutes River Canyon at Tumalo Park, along Highway 20 at Innes Market Road Junction, also low in west wall of Tumalo Creek Canyon in Shevlin Park. Usually tan to dark brown or reddish, with abundant volcanic rock fragments. Contains characteristic large lumps of black, porphyritic pumice.
	Base usually not exposed, but underlying units are assumed to be basaltic-andesite lava flows or sediments of the Deschutes Formation.

Figure 15. Stratigraphy and identifying physical characteristics of the Qwt ash-flow tuff. Oldest flow at bottom of column; youngest at top.

Pleistocene Ash-flow Tuffs and Pumice (Qwt)

Williams (1957) mapped and described a widespread welded dacite tuff of late Pleistocene age west and north of Bend, and also describeda glowing avalanche deposit of unconsolidated white and pink dacite pumice in the Tumalo Creek and Deschutes River canyons. Our field work in the area west and north of Bend shows that there are at least five distinctive ash-flow tuff units, including the thick deposit of unconsolidated white pumice. The age of the ash flows is not definitely known; the earliest unit may be as old as latest Pliocene, with the latest unit early to mid-Pleistocene. All appear to have been erupted during an episode of explosive volcanic activity in the Broken Top - South Sister area. Even though this explosive activity was relatively brief, there was enough time between eruptions for erosion channels and thin sedimentary deposits to develop on most of the ash-flow units. It was not the intent of this study to map the extent of each ash-flow unit, so they are all included under the symbol Qwt on both the County geologic map and the Bend map. Figure 15 is a generalized stratigraphic column showing the sequence of ash-flow tuffs with their identifying characteristics. A separate study of the ash-flow tuffs west of Bend is being completed by E. M. Taylor of Oregon State University. Taylor's study will show the areal extent of the individual flows and describe them in detail.

Newberry Volcano has also been a source of ash-flow tuffs and has two distinctive dark-colored andesitic (?) ash-flow units on its flanks. On the northeast flank a dark-brown to reddish-orange, punky to partially welded ash-flow tuff can be traced over several square miles. Excellent exposures as much as 25 feet (8 m) thick can be seen in the SW$\frac{1}{4}$ sec. 26, T. 20 S., R. 14 E., where Teepee Draw and other northeast trending drainages cut through the ash-flow unit (Figure 16).

Although the Qb flows from the north flanks of Newberry Volcano have not been mapped separately in this study, three ages can be recognized in the field by slight differences in vegetation, weathered surfaces, and soil cover; the oldest flows are slightly offset by faulting.

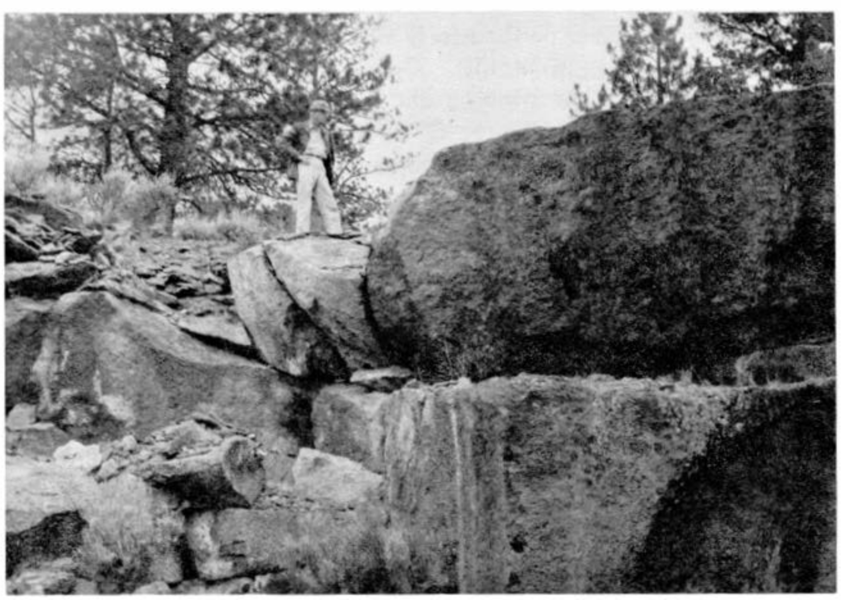


Figure 16. Outcrop of ash-flow tuff of the Qwt unit along Teepee Draw. The partly welded ash flow grades from dark brown near the base to reddish orange at the top. Newberry Volcano is believed to be the source.

This is probably the same ash flow reported by MacLeod and others (1975) to be 0.7 $\pm$ 0.7 m.y. old.

On the west flank of Newberry, near the surface, a thin layer of dark brown to black tuff breccia of probable ash-flow origin covers several square miles. Much of the matrix and most of the rock fragments are pumiceous to cindery with iridescent coatings. Gray to tan, rounded rhyolite fragments are common. Feldspar crystals are abundant in both groundmass and fragments. It is not known whether this deposit was erupted from within the caldera or from one of the numerous volcanic vents on the upper west flank of the volcano.

The ash-flow tuff units Qwt on both the County and Bend quadrangle geologic maps contain important mineral resources. Pumice in the vicinity of Bend and Tumalo has been mined from pits and marketed throughout the Pacific Northwest since the mid-1940's. The present production of nearly 500,000 cubic yards (382,000 m^3) annually has a value of over a million dollars. Building stone from the partially welded parts of the ash flow tuffs has been quarried for use locally since the early 1900's. Production of building stone is less steady and is only a fraction of that of the pumice industry; however, even though only a few hundred to a few thousand tons are quarried annually, the price averages much higher per ton than pumice. A more detailed discussion of both the pumice and building stone potential is contained in the Industrial Minerals section.

Pleistocene and Holocene Basalt Flows

Basalt flows (Qb)

Pleistocene basaltic lava flows of both pahoehoe and aa types are the most widespread and voluminous of the surface rocks in the County. They underlie much of the area on the east flanks of the Cascade Range, as well as the area surrounding Newberry Volcano, extending northward to the Crooked River north and east of Redmond.

The oldest of the Qb Pleistocene basalt flows are exposed west of the Deschutes River. These lavas came from vents on the flanks of the High Cascade volcanoes and occur as linear bodies as thick as 100 feet (30 m) that flowed over a slightly eroded northeasterly sloping surface. Chemical composition, texture, and structure of separate flows vary considerably. Generally the flows are dark gray to black and dense, but porphyritic. Some show flow banding and a platy jointing resulting from flowage as they cooled. Most are moderately vesicular. Like the QTb rim-capping lavas in the north part of the County, some of the Qb lavas are clearly channel fillings of former streams that flowed northeastward from the High Cascades. Where the contact can be seen, the underlying rocks are usually stream gravels that directly overlie the widespread Qwt ash-flow tuff deposits. With more detailed work, most individual flows might be traced to their source. Vents for the Qb flows are either lava cones and shields mapped as QTmv or cinder cones mapped as QTp.

The most conspicuous and widespread of the Pleistocene Qb flows are the relatively thin sheets of pahoehoe basalt associated with fissure eruptions on the flanks of Newberry Volcano. The flows occupy the large area bounded on the west by U. S. Highway 97, on the north by Redmond and the Crooked River, on the east by Horse Ridge and Powell Buttes, and on the south by the north flank of Newberry Volcano. Figures 17 and 18 are views of the hummocky topography of these pahoehoe flows. Fresh ropy surfaces, tumuli, and collapse depressions are typical of this lava terrain, locally called the "Badlands" or the "Lava Badlands." Newly broken surfaces show the basalt to be light to medium gray, medium grained, with characteristic diktytaxitic texture (open arrangement of the intergrown crystals of feldspar, pyroxene, and olivine). Sceva (1968) determined that in much of the area the lava flows extend from land surface to depths of 50 to 100 feet (15 to 30 m).

Within the "Badlands" field are individual lava tubes and extensive lava-tube systems through which the pahoehoe lava flows advanced and spread laterally. Greeley (1971) describes in detail most of the known lava tubes in the Bend area. An interesting lava-tube system not studied by Greeley is called the Redmond Caves, on the southeast edge of the city in sec. 21, T. 15 S., R. 13 E. These lava tubes distributed the Qb lavas northwesterly into a large dry canyon that trends northward along the west edge of Redmond (Redmond geologic map and Figures 19 and 20). The confined lava was then funneled northward to spread over a wide area west of Terrebonne and farther north beyond the boundary of Deschutes County.

Figure 17. Typical topography and vegetation along U.S. 97 both north and south of Bend, where "Badlands" lavas form an uneven surface thinly covered with wind-blown ash, cinders, and pumice.

Figure 18. Roadcut north of Bend shows thinness of soil zone and structure of one of the low, rounded tumuli in lavas of the Qb unit and the typical joint pattern in the basalt. Most excavations for streets and utilities in Bend and Redmond encounter this lava.

The youngest of the three Qb "Badlands" lava flows covers a roughly circular area of about 30 square miles (80 km^2) north and east of Horse Ridge and were erupted from a slightly elevated fissure vent just north of Highway 20. Figure 21 shows the relatively small vent area with its distributary lava tubes.

Vents higher on the north and east flanks of Newberry Volcano erupted flows of a more viscous basalt, which is typically dark gray to black, dense, and porphyritic and has blocky hummocks on its surfaces. These flows now appear as thick tongue-shaped northeast-trending landforms extending into Millican Valley just east of Horse Ridge.

A distinctive porphyritic diktytaxitic basalt flow extends northward from the base of Pilot Butte, an interesting cinder-cone vent of Pleistocene age on the eastern edge of Bend. Future studies could easily delineate this and similar individual flows, which could help unravel the events in this spectacular local volcanic landscape.

Large quantities of vesicular basalt rubble have been removed from the surface of the Qb lava flows for use as building stone in walls, fireplaces, and other building construction. No estimates are available for the amount used or the annual value. The large area covered by the Qb lavas represents an apparent inexhaustible supply; however, only the top few feet of the flows are jointed so that they break into usable stone. The Qb lavas represent only marginal quality crushed rock because of this vesicularity, and the thinness of the individual flows and the lack of closely spaced jointing makes crushing difficult, so the supply from any one source is small.

Holocene basalt flows (Qhb)

Within the last 10,000 years, both aa and pahoehoe basalt flows have erupted at several places in the High Cascades and on and around Newberry Volcano. Ages for some of the flows have been determined by dating charcoal from trees that were inundated by the lavas. Lobes of spiny black aa lava extend eastward from the McKenzie Pass area into Deschutes County from Belknap Crater, Little Belknap, and from Yapoah Cone on the north flank of the North Sister. Taylor (1965, 1968) described these lava flows in detail and, from C-14 dating, determined that they range in age from 2,500 to 3,000 years. Farther south on the lower south slopes of South Sister, lava flows believed to be of Holocene age were erupted from LeConte Crater, from Cayuse Crater, and from a small unnamed vent about 2½ miles (4 km) south of Broken Top. Lava flows assumed to be of Holocene age erupted from cinder cone vents on the north side of Bachelor Butte and flowed westward to dam a broad drainage, forming Sparks Lake.

In the extreme southwest corner of the County a viscous, black basaltic lava welled up and spread outward from a series of small, closely spaced vents near the northwest base of Davis Mountain. This flow, which is about 3 miles (5 km) long, 1 mile (1.5 km) wide, and 70 feet (20 m) thick, dammed the channel of Odell Creek and formed Davis Lake (see Figure 22). How long ago the eruption took place is not known. The freshmess of the blocky lavas is deceiving, however, for Davis Lake has accumulations of diatomite as much as 4 feet (1+ m) thick that must have required at least a few thousand years to accumulate.

As reported by Peterson and Groh (1969), several episodes of Holocene volcanism are well recorded within and around Newberry Volcano. Of particular interest is a northwest-trending rift zone, traceable from within the caldera to and beyond Lava Butte, from which eight separate basaltic aa flows have been erupted (Figure 23). The flows vary in size from less than 1/2 square mile (1 km^2) in extent and a few feet (meters) thick to the largest and thickest of the flows at Lava Butte, covering 10 square miles (25 km^2) and ranging in thickness from 30 to 100 feet (10 - 30 m). Tree molds containing carbonized wood are present in most of the flows, and C-14 dating shows that the volcanic activity that produced the molds occurred in a relatively short period of time about 6,000 years ago. A similar aa flow (Surveyor Flow) on the south flank of Newberry also has tree molds and is the same age as the more extensive flows on the north flank.

A large basaltic pahoehoe lava flow of questionable Holocene age has been mapped in the area east of China Hat and East Butte. The flow, thickly covered with pumice from Holocene explosive eruptions from within Newberry Volcano, covers about 30 square miles (80 km^2). It flowed northwestward around the south and west base of Pine Mountain from an inconspicuous vent near Firestone Butte. The pumice cover on this flow supports a pine forest; however, the ropy surfaces, tumuli, and other initial flow surfaces are preserved and are especially conspicuous at its northern terminus (Figures 24 and 25).

Figure 19. Redmond Caves, in sec. 21, T. 15 S., R. 13 E., are in the collapsed part of a lava tube system that distributed lavas of the Qb unit into Dry Canyon extending northward through Redmond.

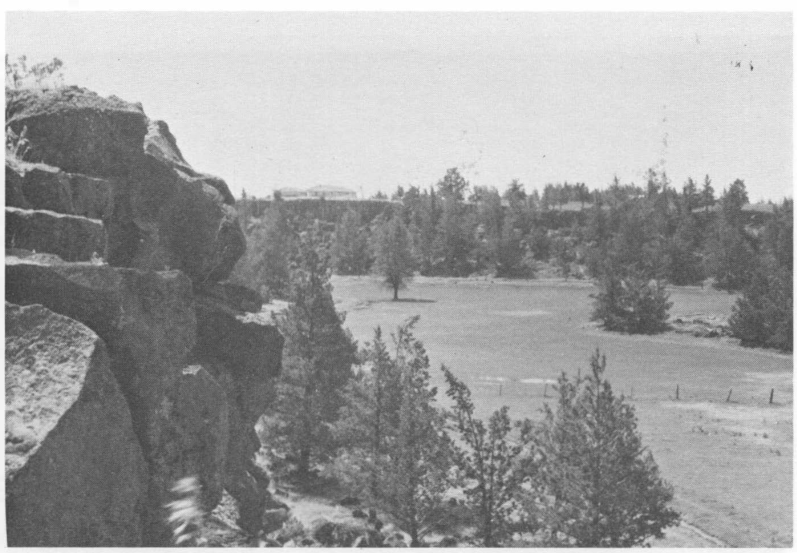


Figure 20. View across Dry Canyon at north edge of Redmond. Grass-covered floor is alluvium underlain by "Badlands" pahoehoe lava from lava tube shown in Fig. 19.

Figure 21. Collapse depression and partly filled lava tube near Horse Ridge north of U.S. 20 marks the vent for the latest "Badlands" lava eruptions. Highway cuts expose fresh, gray, diktytaxic olivine basalt.

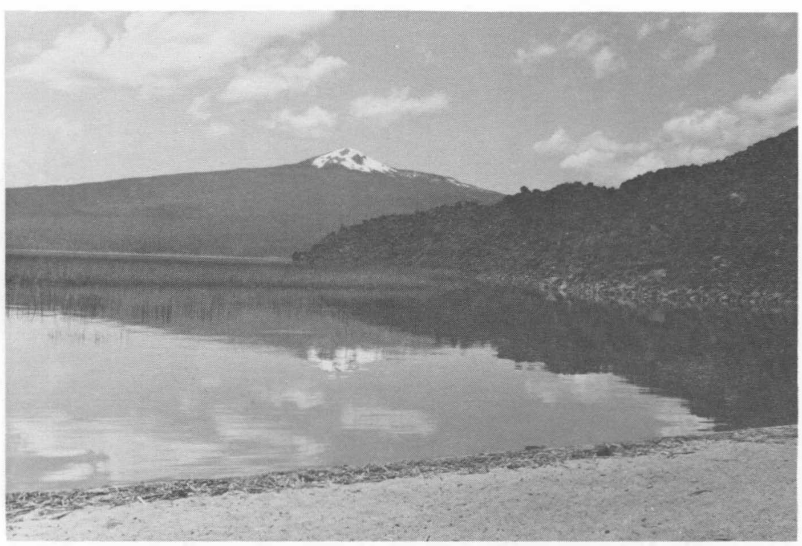


Figure 22. View across Davis Lake. Maiden Peak in distance is a broad shield volcano (QTmv). Black, blocky lava flow at right of photo impounds the lake.

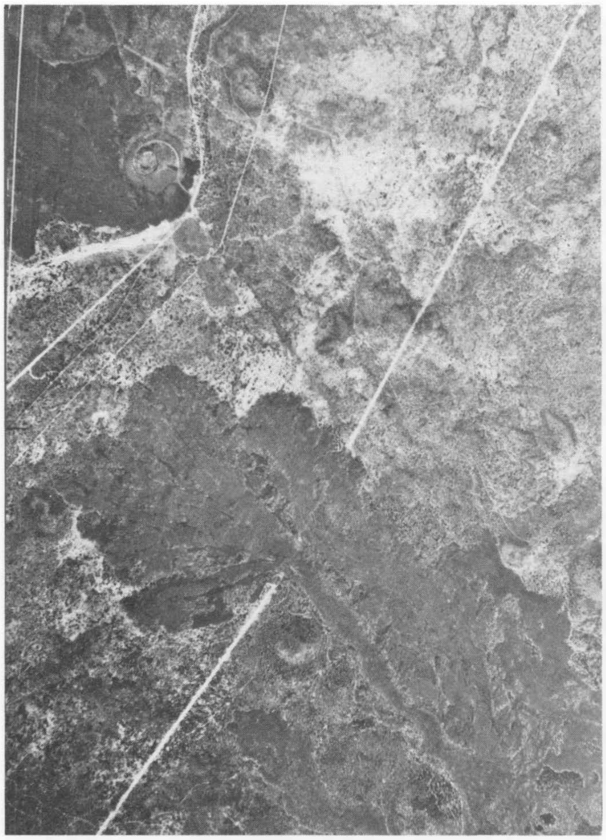


Figure 23. High-altitude aerial view of Lava Butte (upper left corner of photo) and one of the Qhb lava flows on the northwest rift zone. Mazama pumice masks older cones and flows. White diagonal line is the natural gas pipeline.

During the field checks for this report a very small Holocene volcanic vent and associated lava flow was discovered about halfway up the east flank of Sitkum Butte, which is a palagonite tuff cone (Figure 26). The vent area is a north-south fissure, about 1,000 feet (350 m) long, over which several small spatter cones have developed. Lava flowed eastward from this fissure and covered an area of less than 1/4 square mile (1 km^2).

Most of the Holocene basalt flows are of the aa or block type with extremely rubbly surfaces. Much of the surface rubble is scoriaceous to highly vesicular, with only minor economic potential for building stone and construction use.

Pleistocene and Holocene Silicic Domes and Flows

Pleistocene and Holocene dacite and rhyolite intrusive-extrusive rocks are restricted, with a few exceptions, to the Middle Sister-South Sister area in the Cascades and to the flanks and summit caldera of Newberry Volcano. These rocks represent two main episodes of silicic volcanism: Pleistocene, mapped as Qrd, and Holocene, mapped as Qhr.

Pleistocene silicic domes and flows (Qrd)

Dacite and rhyolite domes and flows mapped as Qrd in the Cascades have been glaciated and partly devitrified. The largest areas of such rocks are on the east flank of South Sister and in the area of Tam McArthur Rim near Broken Top. Two smaller but thicker dacite flows make up Devils Hill and Kaleetan Butte. To the east of the Cascades, Melvin Butte and Three Creek Butte are isolated dome-shaped masses of fragmental rhyolite resembling cinder cones. The rhyolite is light gray to white, finely crystalline, and slightly iron-stained from oxidation of iron-bearing minerals.

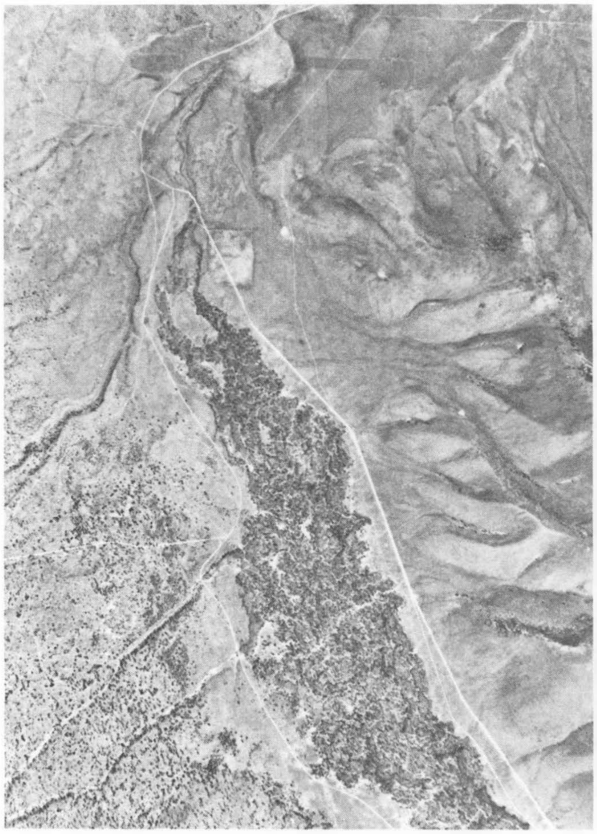
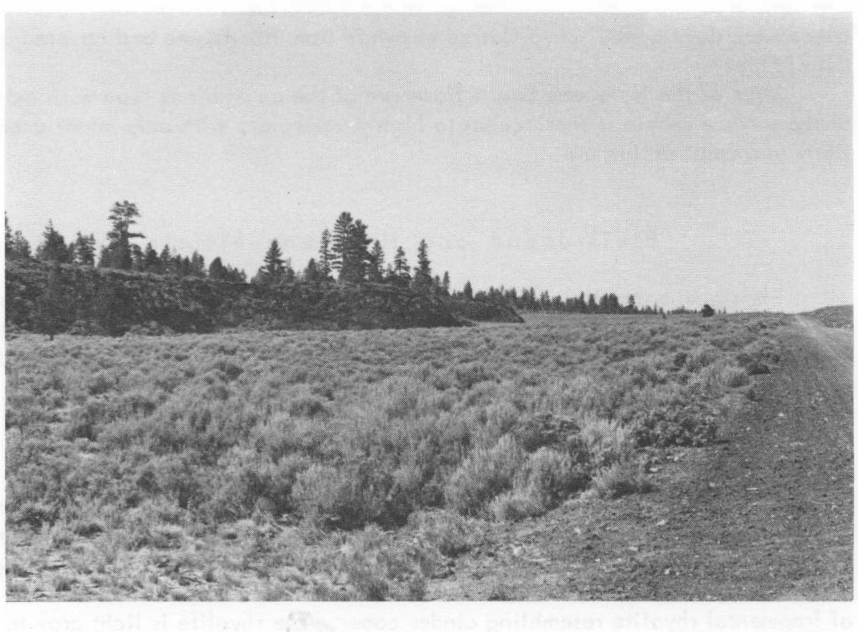


Figure 24. High-altitude aerial view of the Holocene pahoehoe lava that skirts the southwest side of Pine Mountain. The lava flowed down a shallow valley, spreading in toes and protuberances as it advanced.

Figure 25. View of margin of the above lava flow showing steep edges and protuberances.



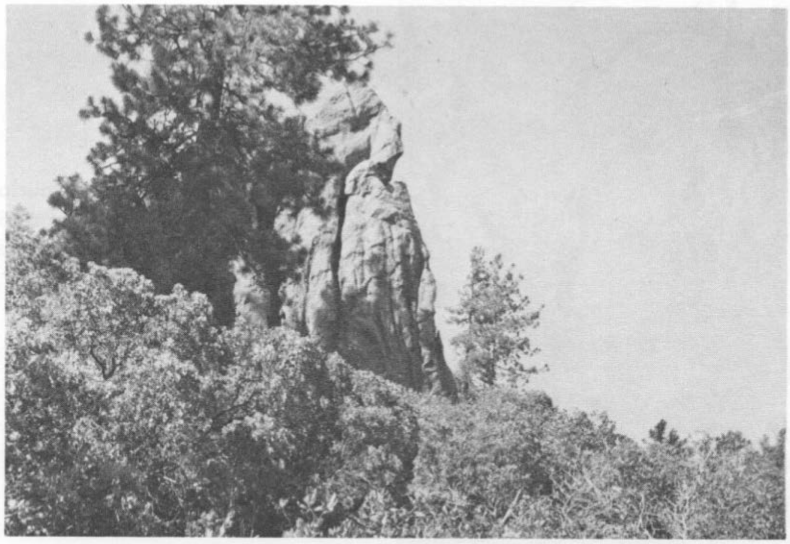


Figure 26. The erosional remnant of a palagonite tuff cone on Sitkum Butte resembles an Indian chief in silhouette. The name is assumed to be of Indian origin - was there a Chief Sitkum?

Bench Mark Butte, just north of Crone Prairie Reservoir, is o brood, dome-shaped moss of dense block andesite-dacite vitrophyre that built up over o centrolly located vent. It covers almost 3 square miles (8 km^2), overages 200 feet (60 m) thick, and has concentric ridges and bulbous toes of large blocks that outline its initial structure.

Rhyolite-dacite domes at Newberry Volcano hove been described in detail by Williams (1935), Higgins and Waters (1967), ond Higgins (1973). The older group of silicic rocks (Qrd) ore exposed in the caldera of Newberry Volcano on the lower northeast wall, at Paulino Peak, in ports of the south wall, and in two dome-shaped mosses on the south shore of Paulino Lake.

Satellite domes and flows of light-gray flow-bonded rhyolite, breccia, and block streaky obsidian occur at McKoy Butte on the northwest flank of Newberry Volcano and at Chino Hot and East Butte on the lower east flank.

Quartz Mountain, a slightly older dome complex of obsidian, lies southeast of Newberry on the south edge of the County. MacLeod, Walker, and McKee (1975) list K/Ar radiometric dotes for some of the domes on the flanks: Quartz Mountain 1.11 ± .05 m.y.; East Butte 0.85 ± .05 m.y.; Chino Hot 0.78 ± 0.20 m.y.; and East McKoy Butte 0.58 ± 0.10 m.y.

Holocene silicic domes and flows (Qhr)

The Holocene rhyolite and dacite domes and flows (Qhr) occur on the south flank of South Sister and at Newberry Volcano. Beginning at an elevation of about 7,900 feet (2,600 m) and extending almost due south to Century Drive is a string of nine or ten spectacular dacite obsidian domes and flows (Figures 27, 28, and 29). As described by Williams (1944), "No doubt the extrusions occurred in rapid succession, possibly within o few days or weeks, and by analogy with fissure eruptions in other regions it is likely that activity began at the upper end of the chain and moved progressively downward." Minor eruptions of pumice preceded this latest upwelling of obsidian in the South Sister area.

The largest single obsidian dome and flow, covering about two square miles (5 km^2), occurs at Rock Mesa on the Cascade divide, partly in Lane County and partly in Deschutes County and within the Three Sisters Wilderness area. Rock Mesa has recently had notional publicity because of litigation over the

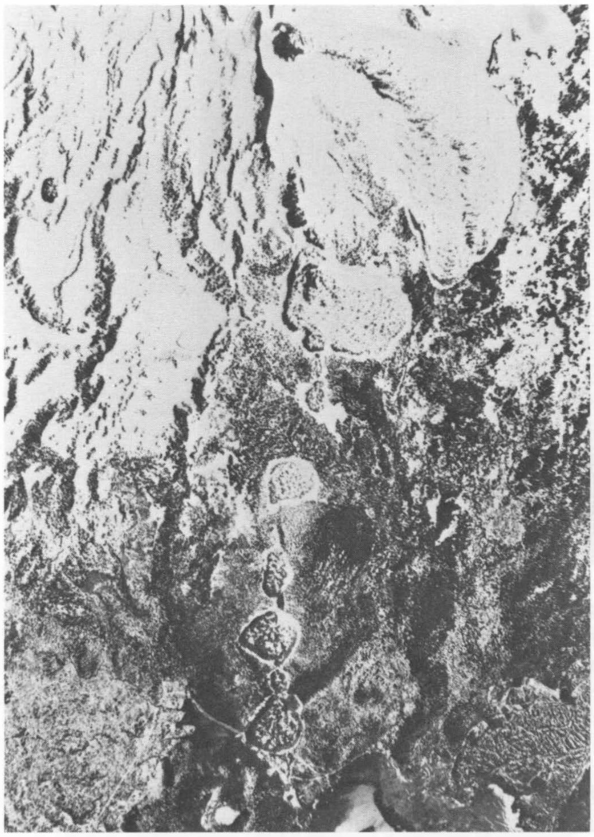


Figure 27. High-altitude aerial view of the chain of Holocene obsidian domes which were built over a fissure on the south flank of South Sister.

Figure 28. Two generations of glassy rhyolite-dacite domes. Upper left is glaciated Devils Hill. Uneroded domal surface to the right is the southernmost in the chain of obsidian domes.

Figure 29. Mid-winter view of Rock Mesa on the south flank of South Sister. Snow cover accentuates concentric ridges of spiny obsidian that welled up over a now-concealed vent. Broken Top is in left background. (Oreg. Hwy. Div. photo 6175)

validity of mining claims for block pumice that occurs with the obsidian. The age of Rock Mesa has recently been determined to be 2,300 $\pm$ 150 years before the present.

At Newberry Volcano, all of the Holocene silicic activity took place within the caldera, with the exception of one small rhyolite obsidian dome discovered on the southwest flank. At least five spectacular obsidian flows (Qhr) have been described in detail by many authors. Williams (1935), Higgins and Waters (1967, 1968) recognized that these flows were some of the youngest of Newberry's volcanic features. Charcoal from beneath the Big Obsidian Flow (Figure 30) has been determined from C-14 dating to 1,270 $\pm$ 60 years old. The ages of several other obsidian flows within the caldera have been determined by the thickness of their hydration rinds, a dating technique developed by Friedman (1968, 1971). The ages vary from 1,350 to 5,000 years B.P., confirming their Holocene origin (Peterson and Groh, 1969).

Block pumice has been selectively mined from the surface of the Newberry Volcano Holocene obsidian domes for years. The economic potential of block pumice within Newberry caldera and in the South Sisters area will have to be weighed against the scenic and recreational value of these areas.

Figure 30. Snow on Big Obsidian flow in Newberry caldera accentuates flow lines and pressure ridges that developed as the pasty magma spread outward from its vent close to the south rim of the caldera approximately 1,270 years ago.

Surficial Deposits

The unconsolidated surficial deposits fall into two general categories: l) the glacial and glaciofluvial deposits (Qgm), which includes lateral and terminal moraines, glacial drift, and outwash gravels; and 2) alluvium (Qal), comprising all the other stream-deposited gravel, sand, silt, the air-laid ash and pumice, slope wash deposits, alluvial fans, and sand dunes.

The surficial deposits provide most of the sand and gravel for Deschutes County and are an important industrial mineral resource. The sand and gravel chapter discusses their impact in more detail.

Glacial and glaciofluvial deposits (Qgm)

Taylor (1968) has recognized three episodes of glaciation in the High Cascades during Pleistocene time as follows:

> "The great extent and depth of glacial ice which lay upon the High Cascades of Oregon during the Pleistocene have not been stressed in geologic literature. In the central Cascades, three episodes of glaciation are easily recognized. The most recent episode is represented by fresh moraine and outwash between 7000 and 9000 feet elevation on high peaks. Radiocarbon ages of associated lavas and ash deposits indicate that these moraines were formed less than 2,500 years ago and should be referred to the Neoglacial 'Little Ice Age.' A minor glacial advance near the end of the last century slightly reworked some of the 'Little Ice Age' moraines.
>
> "The next oldest glacial stage ended 10,000 to 12,000 years ago and is here referred to the latest Wisconsin. During this time, a broad ice field accumulated in the High Cascades. It surrounded the major peaks, buried all but the highest summit ridges, and fed numerous glaciers, some of which were 19 miles long. Neither the ice field nor its satellite glaciers extended beyond the High Cascade platform; in the central Cascades few of these glaciers existed below 3600 feet elevation.
>
> "The oldest glacial events are collectively referred to as 'pre-latest Wisconsin.' They are recorded in deeply weathered and poorly preserved lateral and ground moraines, far removed from the Cascade Crest. These deposits lack the andesitic and rhyolitic rock types which are common in the summit peaks and in the latest Wisconsin moraines."

The glacial moraine material is a heterogeneous assemblage of volcanic rock types. It contains large blocks, boulders, and pebbles, ranging from angular to well rounded, in a finer sand and silt matrix.

A good example of "Little Ice Age" glaciation is shown by a well-preserved terminal and lateral moraine on the northeast flank of Bachelor Butte at the 7,800- to 8,000-foot (2375 - 2440 m) elevation (Figure 31). The moraines can be easily seen and interpreted from the Cascade Lakes Highway.

Moraines and outwash deposited by Wisconsin-age glaciers are more prominent in the northern part of the County, where they occur as a discontinuous belt on the east flanks of Mount Washington and on North and Middle Sister. Another broad belt of glacial detritus is present in the southwest part of the County, especially around Cultus Mountain and in the area between the The Twins, Maiden Peak, and Davis Mountain. Remnants of once larger lateral moraines are present in the upper parts of Trout, Squaw, and Tumalo Creeks. The broad flat north and west of Sister, Black Butte Swamp, and the flats surrounding Crane Prairie and Wickiup Reservoirs are probably underlain by glacially derived sediments, but for convenience they are mapped as alluvium (Qal).

Alluvium (Qal)

The largest alluviated area is the broad flat between Newberry Volcano and the High Cascades in the southern part of the County. This wide valley extends on both sides of the Little Deschutes and the Deschutes River from south of Lapine northward to Benham Falls. It also extends westward and northward to the headwaters of the Deschutes River and surrounds Crane Prairie and Wickiup Reservoirs. Although most of the detritus came from the High Cascades, large quantities of alluvium have been spread into the Lapine area from the west flank of Newberry Volcano.

Figure 31. Bachelor Butte from Century Drive. Lateral and terminal moraines deposited by a glacier extend halfway down the northeast flank.

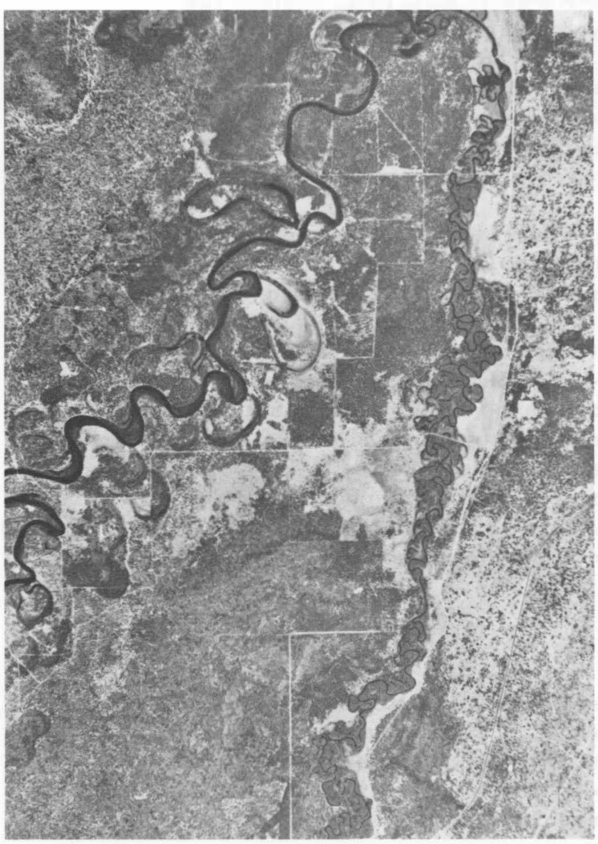


Figure 32. High altitude aerial view showing the meandering pattern of the Deschutes and Little Deschutes Rivers. Oxbow lakes and cutoff meanders indicate that the streams have reached base level in this area.

The extensive alluviation of this broad area has resulted from almost continuous constrictions of the Deschutes River by basaltic lava flows and glowing avalanche deposits. Lava flows from Newberry Volcano dammed the river countless times and forced it westward, while both basaltic lava flows and ash-flow tuffs from Cascade vents resisted this change and pushed the channel toward the east. The extreme meandering of the Deschutes and Little Deschutes River above Benham Falls indicates that base level has existed for a long time. Cut-off meanders, small oxbow lakes, and swampy ground are indicative of an old-age stream (Figure 32). The near-surface alluvium consists of a few feet of soil containing a mixture of pumice from Mount Mazama and reddish-black ash and cinders from the Holocene eruptions on Newberry's flanks; the underlying sediments are a crudely layered sand, silt, and gravel sequence that typically contains large percentages of a fine brownish pumice-cinder matrix with rounded pebbles of scoria and volcanic rocks. Well logs show a highly variable thickness of the alluvial materials ranging from a few tens of feet (meters) thick at Wickiup and Crane Prairie Reservoirs to 400 or as much as 500 feet (120-150 m) thick near the Little Deschutes River just north of Lapine. Much more detailed study will be needed to decipher the glacial, volcanic, and sedimentary history of this part of the Deschutes Basin. Chitwood (1974) has compiled a preliminary map showing the pattern of glacial outwash on Deschutes National Forest lands and included the area described above.

In the eastern part of the County, lake sediments and windblown sand have accumulated in Millican Valley from Horse Ridge eastward for about 15 miles (40 km). This broad, high-desert valley was the site of a sizeable lake for at least part of Pleistocene time. Layered sand, gravel, and silt exposed in roadcuts, borrow pits, and lake terraces along Highway 20 near Millican are as much as 50 feet (15 m) thick.

Dry River, a conspicuous meandering stream course cutting through the lake sediments, extends from the Brothers area to the west end of Millican Valley. Here, Dry River enters a narrow steep-walled canyon and within a distance of 3 miles (8 km) drops 500 feet (150 m) into the east part of the Deschutes Basin. At the viewpoint along Highway 20, near the Horse Ridge summit, the dry canyon is 300 feet (90 m) deep, and its steep walls reveal the many layers of lavas and pyroclastic materials of the Tb unit. It is apparent that the stream that carved this canyon drained the lake which once occupied Millican Valley. Whether the lake drained suddenly and catastrophically or gradually over a long period of time is not known.

A large gravel fan was built where the now-dry stream entered the Deschutes basin. Finer debris was distributed extensively to the north and west, but it is now mostly covered by the latest of the Badlands lava flows. In the vicinity of Alfalfa, where the sediments were not covered by basalt flows, the sand and gravel is at least 10 feet (3 m) thick and some has been mined for local road building. In the southwest part of the Millican Valley, large sand and gravel fans were derived from the somewhat eroded northeast flanks of Newberry Volcano. Tepee Draw and two unnamed dry stream canyons near Evans Well have distributed large quantities of sand and gravel into Millican Valley and to the area on the south side of Horse Ridge.

A less extensive high-desert valley extends along the southwest slopes of Hampton Buttes in the vicinity of Hampton. Shallow deposits of layered silt, sand, and gravel overlie and surround basaltic lava flows that floor the valley.

South of Pine Mountain, in the southeast part of T. 21 S., R. 15 E., one small area of airfall pumice, completely masking the underlying rocks, has been mapped as alluvium. The Kotsman Basin, at the southeast base of Pine Mountain is a small area of interior drainage that has been alluviated, and the surface there is also covered with pumiceous soil.

Minor amounts of alluvium are being deposited at the present time. Some glacial debris continues to be carried to lower elevations by meltwater from snow and ice fields, and occasionally a large quantity of debris is flushed down a choked stream canyon. Nolf (1966), reported such an event in October, 1966 when about 50 million gallons of water from a glacial lake on the east side of Broken Top Volcano was suddenly released into the drainage of Soda Creek.

The Deschutes River, Tumalo Creek, and Squaw Creek are continually reworking and slowly moving sand, silt, and gravel downstream, and the many lakes and reservoirs are receiving small amounts of fine-grained sediment. Minor amounts of wind-deposited sand is accumulating in dunes and ridges at the west end of Millican Valley.

No attempt has been made to map all the smaller patches of alluvium.

GEOLOGIC STRUCTURE

Because of the very limited extent of rocks older than Pliocene age in Deschutes County, the structure of these older units is obscure. The dips of the small outcrop areas of siliceous tuffs of the John Day Formation in the northeast part of the County at Coyote Butte and Smith Rocks indicate that a southwest plunging anticline passes beneath the essentially horizontal Deschutes Formation and younger lava flows.

Three major tectonic features are evident in Deschutes County. They are the Brothers fault zone, the High Cascades lineament, and Newberry Volcano. These three features roughly define a triangular area (Figure 33, sketch map) where Quaternary volcanism has been concentrated.

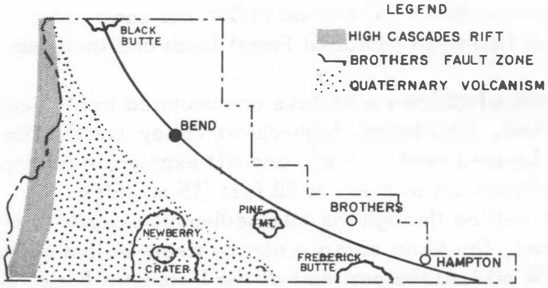


Figure 33. Sketch map of Deschutes County showing the three major tectonic features.

Brothers Fault Zone

The Brothers fault zone is a northwest-trending belt of closely spaced en echelon normal faults (Figure 34). It has been described by Higgins and Waters (1967), Walker and others (1967), and Walker (1969). Stewart, Walker, and Kleinhampl (1975) consider it to be part of the northwesterly portion of the "Oregon-Nevada lineament." which extends from Mount Jefferson in Oregon southeastward into north-central Nevada. Walker (1969, p. 79) suggests that the "Normal faults of the zone and the many volcanic vents along the zone represent only the surface manifestations of deformation on a large deeply buried structure, the exact nature of which is not known. The pattern of normal faults within and near

Figure 34. The small community of Brothers, on U.S. Highway 20, is situated on the Brothers fault zone.

Figure 35. The recency of some of the faulting in eastern part of County is shown by this slickensided fault plane exposed in a rock quarry in sec. 22, T. 21 S., R. 20 E., near Hampton Butte.

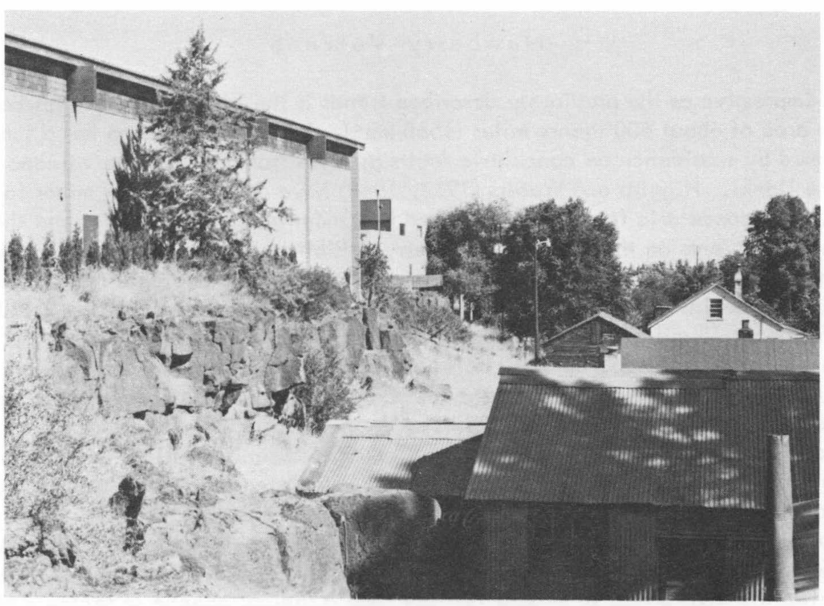


Figure 36. Faulting has created vertical offsets in Pleistocene Qb "Badlands" lava flows. In Bend, between 3rd and 4th Streets, a large commercial building is on upthrown side of fault and smaller residence on down side.

the Brothers fault zone and the relation of many small monoclinal folds to the faults suggest, however, that the zone overlies a deeply buried fault with lateral displacement; the normal faults denote only adjustment of surface and near-surface volcanic and tuffaceous sedimentary rocks." (Figure 35.)

The northwest-trending faults of the Brothers fault zone have displaced all the rocks in the area except the latest Pleistocene "Badlands lavas." The latest displacements of the lava flows are relatively small, in most cases only ten to a few tens of feet (Figure 36). Some of the slightly older shield volcanoes and mafic vents, such as Bear Creek Buttes and Horse Ridge, show displacements on the faults of as much as a few hundred feet (100 m). Horse Ridge has been faulted into a horst and graben structure.

High Cascades Lineament

The structural weaknesses along the High Cascades lineament generally trend north-south and are marked by aligned cinder cones, explosion craters, and in some cases by large composite volcanoes. Visible faulting is only minor, but young volcanic activity has been concentrated on a grand scale.

The Bachelor Butte, Kwolh Butte, Sheridan Mountain chain is typical of the larger aligned vents. Another interesting north-south alignment is marked by four small explosion craters (maars) now occupied by South Twin Lake and North Twin Lake, with two unnamed craters between. The alignment continues northward into Shukash and Palanush Buttes which are small cinder cones. An older alignment, parallel to the High Cascades, but trending slightly northeast, is marked by Gilchrist Butte, Haner, Wright, Wampus, and Pringle Buttes. Gilchrist Butte, a steep-sided shield volcano with several periods of volcanism, has been faulted by a N. 15° E. normal fault that extends for about 10 miles northeastward to the north end of Pringle Butte. This is the only faulting in the High Cascades zone where vertical displacement is conspicuous.

Another distinctive zone of weakness is marked by the north-south string of Holocene obsidian domes on the southeast flank of South Sister. Many other examples can be easily seen on the geologic map.

Newberry Volcano

Almost as impressive as the previously described trends is the large shield of Newberry Volcano, which covers an area of about 600 square miles (1560 km^2). Newberry Volcano has a summit caldera (Figure 37), formed by subsidence on concentric faults as lavas from beneath the volcano were erupted from vents on the flanks. Higgins and Waters (1967, 1968) have described other minor faults within the summit caldera. The concentric fractures are marked by cinder and spatter cones, and the 150 or more cinder cones and small vents on the flanks of Newberry exhibit a general N. 25° W. trend, with concentrations on the southeast and northwest flanks. Most are shown on the geologic map. The strongest and latest structural trend begins within the caldera at the "Fissure" on the north wall of East Lake and extends northwestward for about 15 miles (24 km) to just north of Lava Butte (Figure 38).

Newberry Volcano lies about midway between the High Cascades and the Brothers fault zone. Although Higgins and Waters (1967) considered the Newberry shield to be located on the Brothers fault zone, more recent studies show that the fault zone passes to the northeast. The divergent rock types erupted from Newberry Volcano suggest an association with High Cascade volcanism. More detailed work will be necessary, however, to show whether the volcano is directly associated with either the Brothers fault zone or the High Cascades.

Most certainly these large-scale geologic features have plate-tectonic implications. Beaulieu (1972b) has reviewed the tectonic history of Oregon, using the concepts of plate tectonics as they are presently known. It is definitely known that in middle Tertiary time a radical change in tectonic behavior occurred. Prior compressional forces (plate subduction) with accompanying andesitic volcanism and thrust faulting were replaced by tensional forces with flood basalts and block faulting. The reason for the concentration of late Tertiary and Holocene volcanism in the Three Sisters and Newberry Volcano area is not yet well understood and, as Beaulieu suggests, "A plate tectonic model consistent with all the data is yet to be formulated."

Figure 37. Aerial view across Newberry caldera. Former shield volcano collapsed along concentric fractures, marked by south rim in this photo.

Figure 38. East Lake and north rim showing the "fissure," a fracture marking the beginning of the northwest rift zone which extends to or beyond Lava Butte.

GEOTHERMAL RESOURCES

Recent interest in Oregon for geothermal resources is high and our studies show a favorable geologic environment for parts of Deschutes County. The potential for the future development of this type of earth energy appears to be considerable.

Known geothermal resources of the world occur mainly in regions of recent volcanism and tectonism. The productive steam fields of The Geysers in California, Lardarello in Italy, and Matsukawa in Japan, and the very hot water reservoirs such as those of New Zealand, Iceland, Cerro Prieto in Mexico, and the Imperial Valley area of California are known to be associated with volcanism, tectonism, or both. Most lower temperature geothermal resources also have this association.

Natural steam and hot waters with temperatures above 392°F (200°C) can be used to generate electric power. Waters of lower temperature may be useful to generate electric power through the application of a heat exchanger and high-vapor pressure working fluid, but the main uses lie in the field of multi-purpose heat. Major uses for the lower temperature waters include residential and building space heating, greenhouse heating, agricultural product drying, and food process heating and drying. Iceland, New Zealand, Hungary, and Klamath Falls, Oregon are places well known for the multi-purpose application of geothermal energy.

Intense volcanic and tectonic activity has been the geologic history of Deschutes County. Volcanic activity in the Quaternary ($2\frac{1}{2}$ million years to the present time) has been especially pronounced within the County. This is shown in the building of the great Newberry Volcano, a shield complex, and the continuation of volcanic activity of this feature essentially to the present time. It is also evident in the Quaternary volcanism of the High Cascades, particularly the Three Sisters-Broken Top area, the Mount Bachelor-Sheridan Mountain chain, and the Kiwa Butte area.

Tectonic activity within Deschutes County is evident from the presence of the Brothers fault zone passing through the County. In general, the older rocks along this zone are the most intensely faulted, with faulting dimishing but still present in all but youngest (late Pleistocene) lava flows of the "Badlands." Faults along the northwest rift zone on Newberry Volcano (Peterson and Groh, 1965) seem to be the most recently active.

In the light of this strong volcanism and tectonism within the County it is surprising that only two surface thermal displays are known. Both exist within Newberry Caldera (Newberry Crater). One series of hot springs is present along the northeast shore of Paulina Lake and extends into the lake. Maximum measured temperature is 135°F (57.3°C), and gas, mainly of CO_2, is emitted. The other display is located along the south shore of East Lake. It also extends into the lake and has a maximum measured temperature of 150°F (65.6°C), and gas, including hydrogen sulfide, is emitted. Temperatures of these springs are no doubt affected by dilution with cool lake waters.

Subsurface-temperature data from wells in the County are scarce; but available information indicates a temperature gradient below normal. Two holes southwest of Bend were measured to a depth of about 400 feet (122 meters). The gradients were essentially isothermal with bottom-hole temperatures of 9.5°C (49°F). The below-normal geothermal gradient and probable lower-than-normal terrestrial heat flow may be the result of ground-water migration,since the regional heat flow pattern for this part of Oregon is expected to be in the normal to above-normal range. Sceva (1968) suggests a northward migration of ground water in the Deschutes River basin with cooler waters in the Bend area and increasing temperatures toward the north.

Walker (1974) and MacLeod and others (1975) have reported on the progressive decrease in the age of silicic volcanic eruptions from east to west along the Brothers fault zone in Oregon. Silicic volcanism near Glass Buttes, just south of the eastern end of Deschutes County, has an age of about 5 million years. Westward are scattered younger silicic eruptions, and in Newberry Caldera the youngest silicic rock dated so far is about 1,300 years (Peterson and Groh, 1969). Still farther to the west, young silicic eruptions in the South Sister-Broken Top area are only a few thousand years in age. MacLeod and others (1975), reporting on the significance of geothermal potential in southeast Oregon, state: "Most electric-power-producing geothermal fields in the world occur in or proximal to areas of young silicic volcanic rocks.

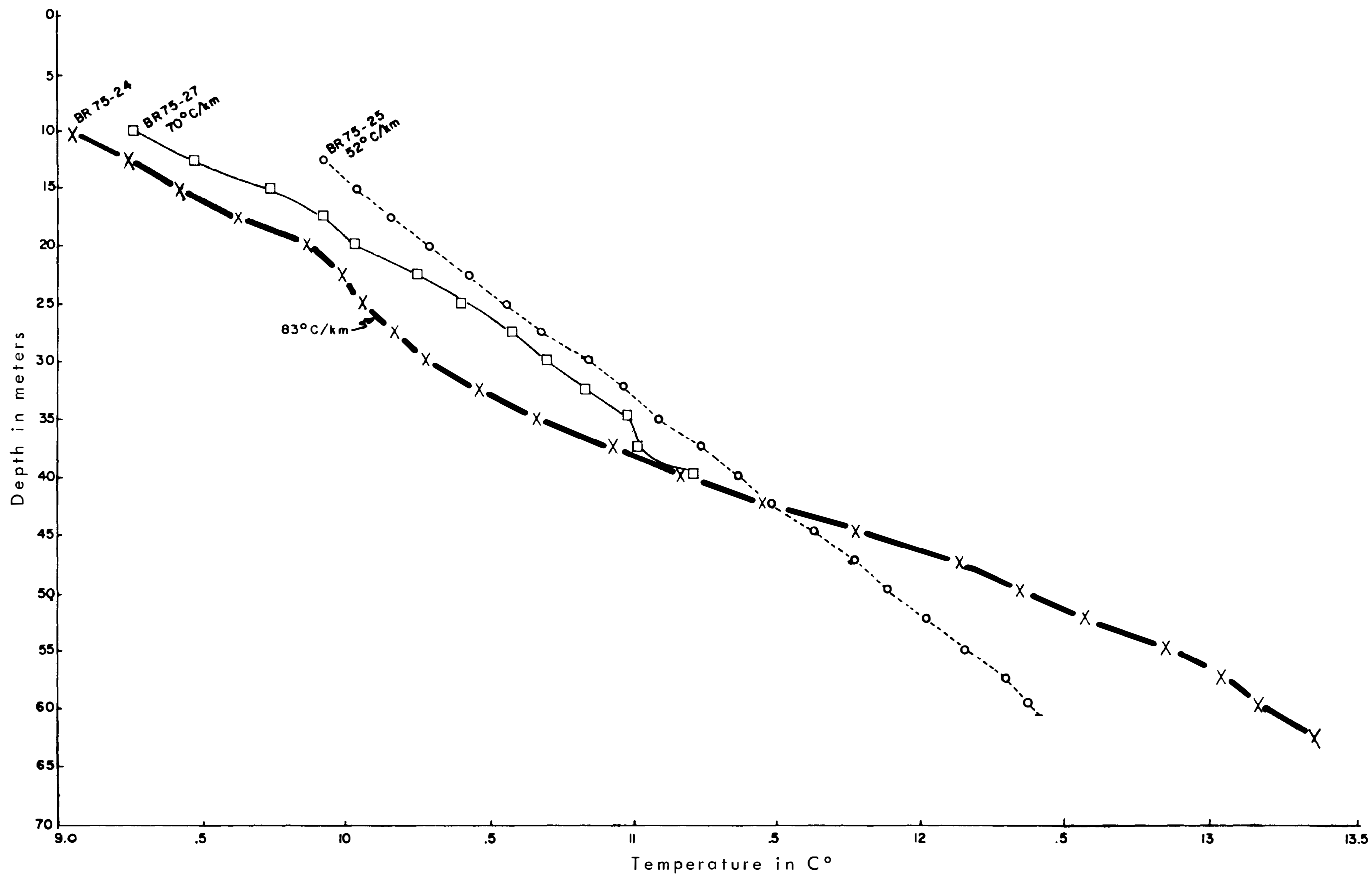


Figure 39. Diagram showing geothermal gradients for three wells, BR75-24, BR75-27, and BR75-25, drilled on a traverse across the Brothers fault zone between Hampton Butte and Frederick Butte.

On the basis of the well-defined age progression of rhyolitic domes in Southeastern Oregon, silicic bodies sufficiently young to be heat sources for geothermal systems are likely only in the vicinity of Newberry Volcano at the west end of the northern belt of domes."

Insufficient data about geothermal gradients, heat-flow, and lack of surface thermal displays does not necessarily preclude the possibility of a large geothermal potential for the County. Prospective areas with good potential include the Brothers fault zone, Newberry Volcano, and the High Cascade Range.

The Brothers fault zone and associated young silicic volcanism, as Walker (1974) says, deserve further study because of their poorly defined potential for geothermal energy. The Oregon Department of Geology is currently studying the Brothers fault zone to determine geothermal gradients across its strike. One traverse in Deschutes County, where 200-foot (60-meter) holes have been drilled for temperature measurements extends from Hampton Buttes to the area just south of Frederick Butte. Preliminary measurements (Bowen and others, 1976) show a slightly higher than normal gradient across the Brothers fault zone in the eastern part of Deschutes County (Figure 39). A more refined interpretation of the area heat flow will be made when more gradient measurements have been taken and when rock heat conductivities are determined. The Department's project includes a series of holes to be drilled for temperature measurement farther west, extending from Bear Creek Buttes to Quartz Mountain and at additional sites around Newberry Volcano.

Private companies are already showing interest in the Glass Butte area. A large number of applications for Federal geothermal leases have been filed. Environmental and other problems should be minimal for this relatively uninhabited prospective area.

As MacLeod and others (1975) suggest, Newberry Volcano and its caldera is a prime prospect because of the indications of a large probable heat source at a shallow depth within the crust. This aspect is apparently the reason that several major oil companies, other corporations, and numerous individuals have applied for Federal geothermal leases. Most of the more than 300,000 acres of Federal geothermal leases applied for in the County are on Newberry Volcano or in its caldera. The geological uniqueness, developed recreational facilities, and scenic aspects of the caldera seem to preclude any geothermal development within the caldera for the foreseeable future. A 1975 Oregon legislative resolution (H.J.R. 31) directed the State Energy Facility Siting Council to forbid thermal power plants in a 39,000-acre area which includes the Newberry caldera and the Lava Cast Forest geologic area. Subsequently, on November 12, 1975, the Energy Facility Siting Council took action to forbid thermal power plants in the designated 39,000 acres but to allow geothermal exploration outside the approximately 11,000 acres of the caldera and the 6,270-acre Lava Cast Forest geologic area.

The flanks of Newberry Volcano, although less favorable, may offer prospects for geothermal development with minimal environmental effects.

At the present time, geothermal prospects for the High Cascade range must be considered as speculative. Geologically the volcanicity of the area suggests large sources of heat brought to shallow levels of the crust; however, a great deal of preliminary exploration will be required to assess the geothermal resource potential. Here again, exploration and development of geothermal resources must be compatible with the environmental aspects.

NON-METALLIC MINERALS

Significance of Deschutes County Resources

The known mineral resources of Deschutes County are the non-metallic types called "industrial minerals." They include pumice, scoria, cinders, and building stone (products of volcanic activity) and diatomite, clay, and sand and gravel (deposits in lakes or river basins).

These materials represent an important asset to the economy of Deschutes County. Besides being available for local needs, they can satisfy export demand; fairly large quantities of pumice, scoria, and cinders and some building stone are shipped to other parts of the Pacific Northwest.

The industrial minerals are in adequate supply for the present time in Deschutes County; but certain mineral commodities, particularly sand and gravel, essential ingredients for concrete and economic only if near the place of use, could be zoned out of existence by expansion of urban developments across the surfaces of the deposits.

A review of mineral production statistics by the U. S. Bureau of Mines (Figure 40) shows that from 1950 to 1961 diatomite production from the Terrebonne deposit was the leading mineral industry activity in the County. Closure of the Terrebonne mine in 1961 is reflected by a sharp drop in the total mineral production for 1961. Since 1961, pumice (including scoria and cinders), sand and gravel, and stone, in that order of value, have been the significant mineral commodities produced in the County. The U. S. Bureau of Mines' dollar values are for raw products and in most cases represent only a fraction of the market value of the products.

The industrial mineral commodities are described below in alphabetical order, and the location of the individual mineral deposits and occurrences is shown on the Mineral Location Map and listed in the Appendix.

Building Stone

The surface and near-surface volcanic rocks in Deschutes County provide an almost unlimited supply of material suitable for use as rubble or rough construction stone. One large source is the vesicular basalt of the Pleistocene lava flows ("Badlands" lava), shown as Qb on the geologic map, which form the extensive plain from Bend to Redmond. The basalt has a characteristic jointing parallel to the surface that allows the near-surface part of the flows to break into relatively uniform rectangular blocks of varying thickness. The highly vesicular nature of the top part of the flows also presents a pleasing appearance when used in walls, facing for walls, fireplaces, monuments, or other construction uses (Figures 41 and 42).

Blocks of ash-flow tuff, mainly from the area west and south of Bend and near Tumalo, have been quarried, shaped, and used for building construction since the early 1900's (Figure 43). The material is still being used locally to make attractive walls and buildings (Figure 44), and small tonnages are marketed in the Willamette Valley and Portland areas.

Evidence of quarrying on a small scale can be seen at many places. The near-surface occurrences, ease of quarrying, and short haul make it possible for individual operators or small companies to produce stone with a minimum of capital investment when a market exists (Figure 45).

Clays

Characteristics and uses

Clay is technically defined as "a loose, earthy, extremely fine-grained, natural sediment or soft rock composed primarily of clay-size or colloidal particles, and characterized by high plasticity, and by containing a considerable amount of clay minerals (hydrous aluminum silicate) derived from feldspathic

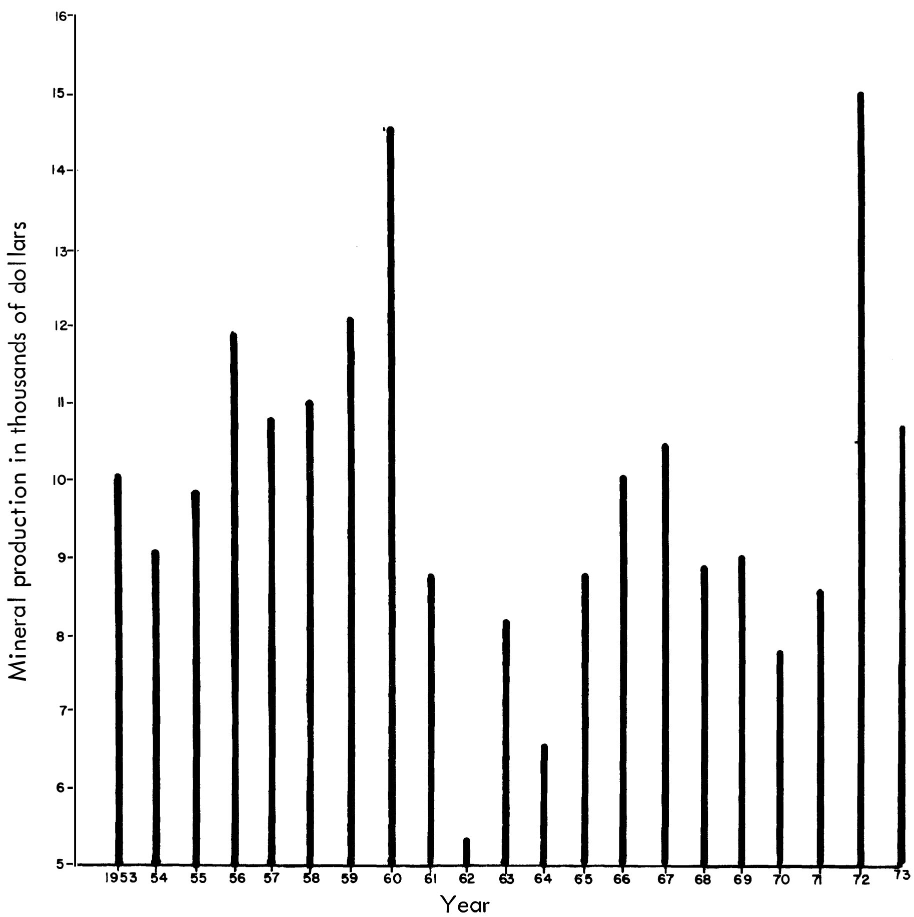


Figure 40. Deschutes County mineral production as reported by the U.S. Bureau of Mines. The high-value commodity up to 1962 was diatomite from the Terrebonne deposit. The low in 1962 marks the end of production at Terrebonne. From 1962 to the present, pumice (including cinders and scoria), sand and gravel, and crushed stone have been the significant commodities produced. The steep rise in production values of the early 1970's reflects the rapid population growth of the County.

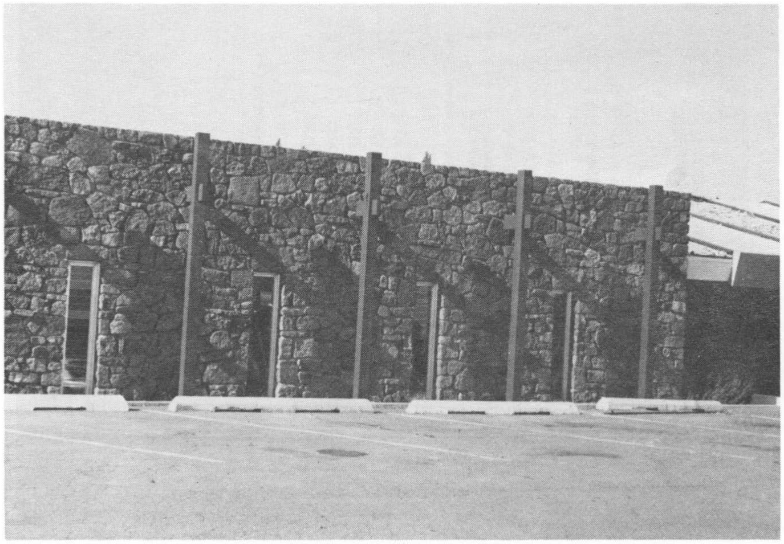


Figure 41. Vesicular basalt from the Pleistocene Qb lava was used to build this handsome rubble stone wall in a restaurant in Bend.

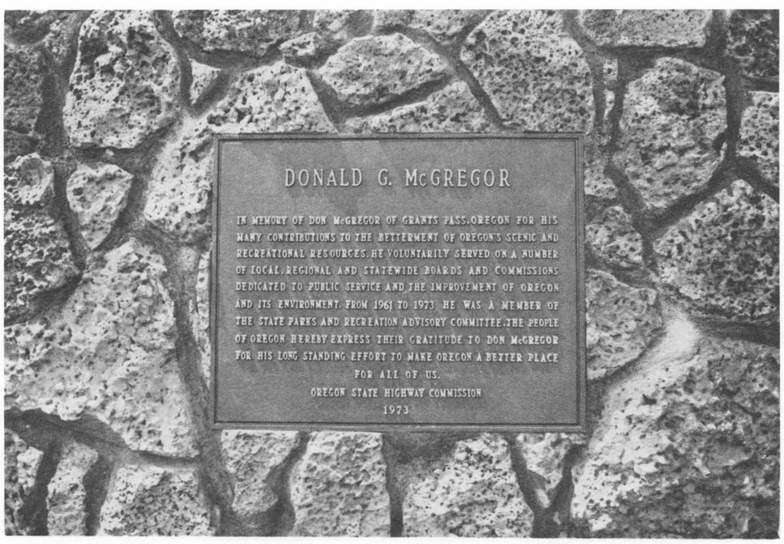


Figure 42. Rubble stone from Qb lava flow was used to face the Don McGregor memorial at Lapine Recreation Area on the Deschutes River.

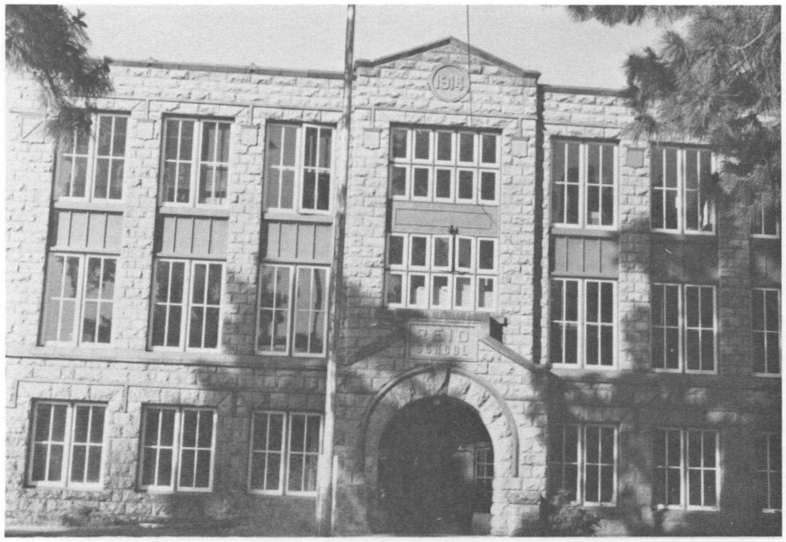


Figure 43. Rough blocks of Tumalo ash-flow tuff were quarried and brought to the site where they were individually shaped and used to build the Reid School in Bend.

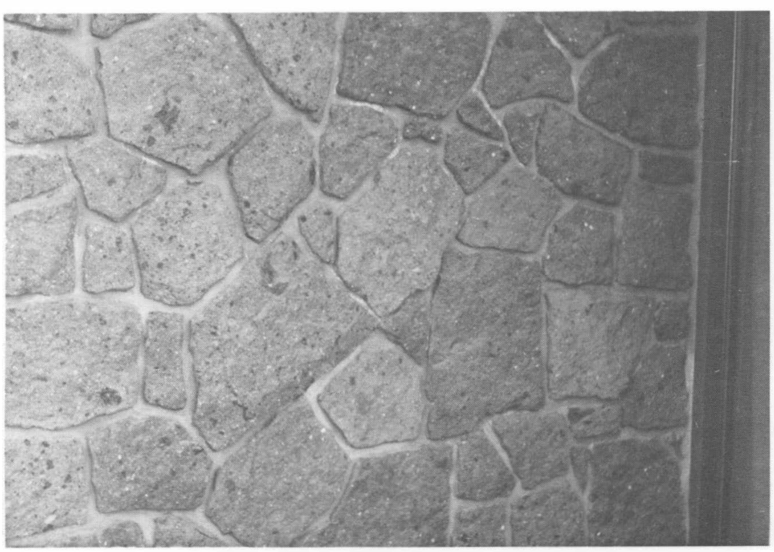


Figure 44. The welded portion of the black ash-flow tuff readily splits into roughly rectangular slabs of rubble stone. Here it has been used as wall veneer for a bank in Bend.

rocks by weathering (primarily decomposition) or by precipitation, and subordinate amounts of finely divided quartz, decomposed feldspar, carbonates, ferruginous matter, and other impurities: it forms a pasty, plastic moldable, impermeable muddy mass when finely ground and mixed with water, retaining its shape on drying, and becoming firm, rocklike, and permanently hard upon heating or firing."

The three groups of clay minerals, kaolin, montmorillonite, and illite, are all complex hydrous aluminum silicates with variable physical properties. Most are dense, flaky, fine-grained particles with the ability to absorb substantial amounts of water or other liquids. Clay minerals most commonly originate from either hydrothermal alteration or from chemical weathering of primary silicate minerals such as feldspar, pyroxenes, and amphiboles.

Most clay deposits contain mixtures of clay minerals, and for uses such as expanded aggregates, cement additives, or brick and tile they can be used untreated after crushing. For more specialized uses, such as making pottery, fillers, drilling mud, and binders, the clay must be ground, sized, and dried. Specialty clays like the kaolins, fire clays, and fuller's earth require more sophisticated processing.

Bentonite is a clay material composed of extremely fine crystalline montmorillonite and colloidal silica. Bentonite can absorb large quantities of water, increasing its volume to about eight times its original size. Its main use is to thicken drilling muds, but it can be used also for lining irrigation canals and ponds to prevent leakage.

Clay deposits in Deschutes County

Two occurrences of impure clay (Nos. 63 and 10) are shown on the Mineral Location Map.

No. 63 is the D. B. Anderson (Van Meter) clay pit, just west of Bend. It was the source of material used in making bricks for many of the buildings in Bend during the early 1900's (Figure 46). The deposit occurs on the downthrown side of a fault in an area underlain by ash-flow tuffs and small basaltic cinder cones. The finer ash from the tuffs accumulated along with cinders in a shallow undrained depression probably created by the fault. The material has been partially weathered to a mixture of clay minerals and clastic particles of pumice and cinders. For making brick, the coarser cinders and pumice were screened. It is reported that an updraft kiln built in about 1900 was fired with slab wood and had a capacity of 32,000 bricks a day. Apparently bricks were produced intermittently until about 1940. Until recently, pit-run material was sold in the Bend area for use as common fill.

No. 10 is the Edgar clay deposit in Sage Flat, about 5 miles north of Sisters. It appears to cover only a few acres and to be less than 10 feet thick. The clay is tan to brown and contains some carbonaceous material. It probably resulted from weathering of fine ash, cinders, pumice, and wind-blown materials confined in a small undrained basin created either by faulting or by a lava flow dam that blocked drainage in the upper part of Stevens Canyon. The heterogeneous fine-grained rock particles are not completely altered to clay. The material is a mixture of clay minerals including bentonite and could possibly have some use as a sealer of water storage ponds or irrigation ditches.

Diatomite

Characteristics and uses

Diatomite, or diatomaceous earth, is a friable, lightweight, light-colored, sedimentary material composed mainly of the microscopic siliceous skeletons of aquatic plants (algae) called diatoms. These plants are abundant in shallow marine or lacustrine waters where temperature, light, nutrients, and dissolved silica are favorable for their growth. The shells or frustules are composed of hydrous silica similar to opal, and each species has a characteristic shape, size, and ornamentation. Thousands of living and fossil species have been identified and described in the literature.

Pure diatomite is white, but inorganic sediment or carbonaceous impurities are usually present, imparting gray to tan colors to massive deposits. Because of the porous nature of the diatom shells (some contain 75 to 80 percent void volume), dry in-place materials are lightweight and range from 25 to 35 pounds per cubic foot. After processing, the dry powders range from 5 to 16 pounds per cubic foot. Most deposits consist of a variety of diatom species. The shape and size of the shells as well as shell fragmentation affect

Figure 54. Pallets of black ash-flow tuff rubble stone ready for transport to a Portland market. Stone from this quarry was used for the building shown in Fig. 44.

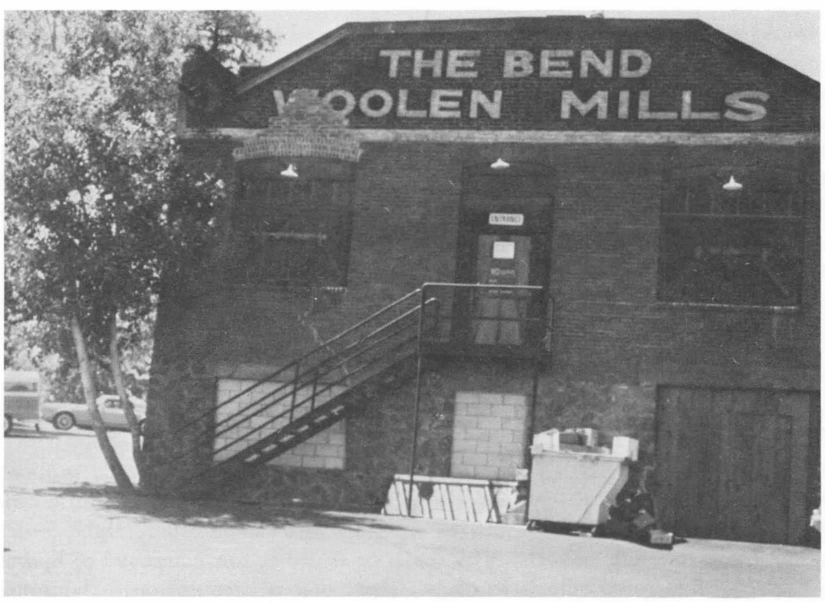


Figure 46. Locally made bricks from the Van Meter clay pit were used in many early buildings in Bend. This building, dating from the 1920's, now houses a tavern and restaurant.

the properties of the diatomite. Diatom shells are inert to most acids but will dissolve in strong alkalies.

Diatomite has a great variety of industrial uses as filters, fillers, insulating materials, absorbents and fluid carriers, aggregate and pozzolan for light-weight cement, abrasives, and ceramic products. Each use requires diatomite of specified purity, particle size, particle shape, and sorting. Since diatomite is a bulk product, a commercial deposit must be relatively pure, easily mined, and economical to process and transport to markets.

Living diatoms flourish in clear, cool, relatively shallow bodies of water with a high dissolved silica content that is regularly replenished. These conditions are most often found in areas of widespread volcanic activity where drainages have been disrupted to form lakes and the volcanic rock products easily contribute silica to ground waters.

Diatomite in Deschutes County

During the past several million years, conditions in Deschutes County have been favorable for the growth and accumulation of diatoms. A particularly noteworthy deposit of Pliocene-Pleistocene age occurs near Terrebonne. Thin beds of diatomite formed in temporary lakes dammed by lava flows across the upper Deschutes drainage. Diatomite is accumulating today in appreciable amounts in Davis Lake and in other lakes east of the crest of the Cascades.

Terrebonne deposit: Diatomite was an important commodity in the Deschutes County mineral industry from the early 1920's until 1961. Diatomite was discovered at Lower Bridge about 6 miles west of Terrebonne, probably by early settlers in the area. Subsequent exploration showed diatomite of good quality as much as 38 feet thick covering several hundred acres. Some diatomite is reported to have been mined and shipped before 1920; however, large-scale production did not begin until 1936. The Great Lakes Carbon Company acquired the property in 1944 and operated it until 1961, when the filter-grade diatomite was mined out. Total production must have been several million tons. The Terrebonne diatomite deposit has been described by Stearns (1931) and Moore (1937). Dyrsmid (1954) described the deposit, processing plant, warehouse, and shipping facilities.

The diatomite occurs within the upper part of the Deschutes Formation. It is underlain by a reddish-tan ash-flow tuff and overlain by a fairly thick layer of sand and gravel and also by the thin Pleistocene Badlands lava flows.

The immediate area around Lower Bridge has not been systematically prospected for similar deposits of diatomite; however, Stensland (1970, Revised 1974) has mapped outcrops of diatomite in sections 13 and 24 several miles east of the Terrebonne deposit. Possibly other tabular-shaped bodies of diatomite are covered by the thin Pleistocene lava flows in this local area.

Davis Lake diatomite: Moore (1937) reported an occurrence of diatomite of recent origin in and around Davis Lake. The relatively impure diatomite has accumulated to a thickness of $3\frac{1}{2}$ feet in a lake that formed when Odell Creek was dammed by a lava flow west of Davis Mountain (Figure 22). Layered pumice beneath the diatomite may have been erupted by Mount Mazama. If so, it indicates how rapidly diatomite can accumulate if conditions for diatom growth are favorable. The associated ash and pumice and the thinness of the deposit make this occurrence of academic interest only.

Gemstones

Brightly colored agate, jasper, and fossil wood are present in minor amounts in Deschutes County. Although they are not technically industrial minerals and are of only minor economic importance, they furnish enjoyment and recreation for the many hobbyists who look for them. The gravelly layered sediments along the northeastern border of the County, unit Tst on the geologic map, contain some agate and jasper derived from the weathering and erosion of the Clarno and John Day Formations. Similar materials have also been brought into Millican Valley by streams entering from the northeast, and agate and jasper can be found in the gravels adjacent to U. S. Highway 20 from Millican to Brothers.

Pumice and Volcanic Cinders

As industrial mineral products, pumice, pumicite, and cinders are generally grouped together. These materials are the result of explosive volcanic eruptions, and the volcanic environment of Deschutes County has provided sizeable good-quality deposits. A thick blanket type deposit of lump pumice underlies at least 20 square miles southwest, west, and northwest of Bend; and block pumice is present as a frothy surface layer associated with obsidian flows both at Newberry Volcano and at Rock Mesa. Cinder-scoria cones and mounds are abundant throughout the County and represent an inexhaustible supply of good-quality material. Pumice, pumicite, scoria, and cinders have produced the greatest dollar value of any mineral commodity in Deschutes County since 1961, when the Terrebonne diatomite mine ceased operation.

Pumice and pumicite

Origin: Pumice is a light-colored, cellular, almost frothy rock made up of glass-walled bubble casts resulting from the violent expansion of gases in a viscous rhyolite or dacite magma. It may occur as coherent, massive blocks composed of highly vesicular glassy lava in either a flow or vent filling or it may be highly fragmented by violent eruption. When the fragments are less than 4 mm in diameter the product is called pumicite, even though it has the same origin, chemical composition, and cellular structure as pumice. Pumice is usually concentrated relatively close to the vent from which it was erupted, while pumicite may be carried by winds for great distances before settling as an accumulation of fine-grained ash.

Uses: The properties that make pumice and pumicite useful in industrial applications include light weight, good heat and sound insulation, and excellent abrasive capability. The main uses for pumice continue to be as a lightweight aggregate for building blocks, lightweight structural concrete, plaster aggregate, and as a soil conditioner. Other uses include polishing glass, metal, leather, wood, and stone. Some scouring powders and soaps contain pumicite, and minor amounts are used as fillers, absorbents, carriers for insecticide, catalyst carrier, and filters. Pumicite is also used in sizeable quantities as a pozzolanic additive in monolithic concrete: it increases the workability, strength, and durability of the concrete and reduces the heat of hydration.

Block pumice is merely a size designation, being the lump or chunk-size pumice. It ranges from 2 inches or more in one dimension to blocks over 5 feet in diameter. The smaller pieces have a variety of uses. They make excellent abrasive blocks for cleaning of restaurant grills, removing callouses, dressing grinding wheels, and polishing belts; pumice blocks are also used for straining vinegar. Larger blocks of rough pumice have a market in landscape architecture: their light weight permits easy transportation and handling.

Pumice and cinder production

Lump pumice, mainly for use as a concrete aggregate in the manufacture of building blocks, has been produced in the Bend-Tumalo area in large quantities since about 1940. Production has generally increased, with an estimated 380,000 cubic yards mined, processed, and sold in 1973. The production is divided between the Central Oregon Pumice Company, which has several active pits west of and within a few miles of Bend (Figure 47) and the Cascade Pumice Company, which mines from large open pits just southwest of Tumalo. Both companies utilize inexpensive open-pit mining methods, using large front-end loaders to excavate pit-run material, which is trucked to nearby screening and loading facilities (Figure 48). The Central Oregon Pumice plant is in Bend, and the Cascade Pumice plant is at Deschutes Junction, about halfway between Bend and Redmond on Highway 97.

Both pumice companies also produce red or black cinders from local sources in a variety of sizes and have the ability to market either pumice or cinders or a blend of the two materials, which can be used in manufacturing concrete blocks. Almost all of the sized pumice and specialty products are shipped by rail to customers throughout the Pacific Northwest including western Canada.

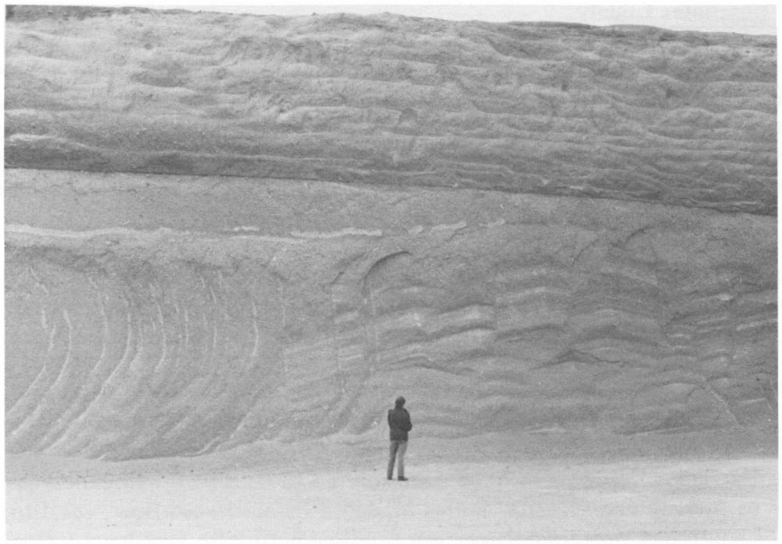


Figure 47. Working face at a pit operated by the Central Oregon Pumice Company at the Bend pumice deposit. Minable thickness of white lump pumice is about 25 feet (8 m).

Figure 48. At Central Oregon Pumice Co. pit, after removal of overburden, mining of pumice is accomplished by large front-end loaders and dump trucks. Truck driver generally also operates the loader.

Pumice deposits of Deschutes County

Bend pumice deposit: The Bend pumice deposit is a layer of ash-flow tuff, as much as 40 feet thick, which may extend over at least 30 square miles. It is the second from the bottom of a series of five ash-flow tuffs (see Figure 15) which originated as a quick succession of violent eruptions from an unknown volcanic vent in the Broken Top-South Sister area. Either the heat of the ash flow was not great or it was quickly dissipated before the particles came to rest, for the deposit has little or no induration or welding, in contrast to the other ash-flow tuffs, and can be easily excavated.

The individual pumice fragments are tightly packed, however, and can stand as a vertical wall without slumping. Fragments range in size from less than one millimeter to 15 centimeters (6 inches), averaging 3 to 5 millimeters ($\frac{1}{4}$ inch). They are holohyaline (glass) pumice, with only occasional small feldspar crystals, showing virtually no alteration or devitrification. They are white to light gray and appear silky and fibrous.

The contact between the Bend pumice and the overlying ash-flow tuff is commonly marked by a few inches of fine ash, white to pink, that makes a smooth horizontal or slightly curved line on the walls of the pits (Figure 49).

The Bend pumice deposit appears to have accumulated to its greatest thickness just west of Bend, where the presence of Awbrey and Overturf Buttes hindered its northward flow, resulting in a thicker-than-average layer to the south and west. Faulting near Laidlaw Butte also may have influenced the thickness of the pumice deposit in this area. In many areas the deposit is covered by ash flows, lava flows, sand and gravel, and surficial debris.

Mining has been concentrated near Bend and at Tumalo, both of which still contain large reserves estimated to be about a 50-year supply. Detailed prospecting probably will add to the known reserves. Current and future open-pit mining of pumice will require reclamation plans. Many of the older pits have been abandoned; a few are being reclaimed as landfill sites (Figure 50).

Block pumice deposits: Large lumps and blocks of pumice occur at two locations in the County. Block pumice has been mined and marketed from the central pumice cone area in the Newberry caldera for many years. Chunks of pumice of good quality are sorted from talus deposits on the east flank of the cone and are mined from massive pumiceous zones associated with the small obsidian dome in the center of the cone. Production has been one to a few carloads each year.

Large quantities of block pumice occur in the near-surface portion of the large obsidian flow at Rock Mesa, in the South Sister area of the High Cascades. The pumice appears to be of commercial quality; however, Rock Mesa is within the Three Sisters Wilderness, and the validity of a group of 10 mining claims owned by the U. S. Pumice Company is being questioned by the U. S. Forest Service.

Volcanic cinders and scoria

Volcanic cinders are the reddish-to-black vesicular fragments that pile up during explosive eruptions of basaltic magma. Most deposits of cinders occur as cones or mounds of stratified fragments that range in size from a fraction of an inch to several inches in diameter. By definition, cinders are essentially uncemented, juvenile glassy and vesicular ejecta ranging chiefly from 4 to 32 mm in diameter. The fragments over 32 mm (about $1\frac{1}{4}$ inches) should technically be called scoria. Individual cones or mounds of cinders and scoria may be several hundreds of feet in diameter and as much as 500 feet (150 m) high (Figure 10).

Cinders and scoria continue to be one of the most important road building and maintenance materials for the extensive network of secondary and logging roads in Deschutes County. It is estimated that nearly 900,000 cubic yards were used during 1973. At least half of the production was used for surfacing and maintenance of roads used by loggers in the Deschutes National Forest. Large quantities were also used by the State Highway Department, County Road Department, and private contractors for road building, maintenance, and winter road sanding. About 100,000 cubic yards were mined, crushed, and screened by the large pumice producing companies for export, mainly as concrete aggregate. Smaller amounts are sold for roofing granules and landscape ground covers. Blocks of agglutinate and large bombs associated with the layered cinder deposits also have some marketability for landscaping.

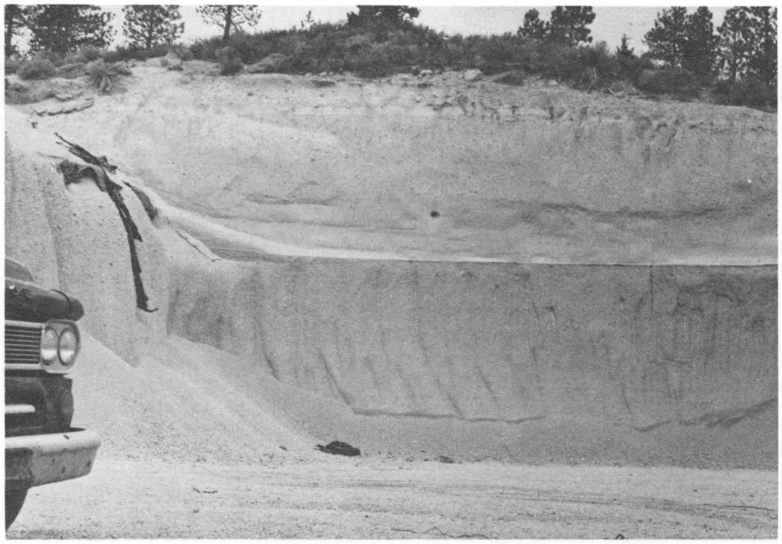


Figure 49. A thin layer of fine-grained pink ash marks the contact between the underlying Bend pumice deposit and the Tumalo ash-flow tuff.

Figure 50. Some of the abandoned pumice pits like the one shown here are being used for solid waste disposal.

A large number of conveniently located cinder pits have been established throughout the County. The locations of most of these are shown on the Mineral Locality Map and listed in Table 1. Only a few of the established pits are active at any one time, depending on road building or maintenance activity in the vicinity. Most of the pits in the western part of the County are in the Deschutes National Forest, and those in the eastern part are generally on lands administered by the Bureau of Land Management, while the largest producing pits in the northern part of the County are on privately owned land. Earlier mining practices whereby large pits with steep vertical walls were developed at the base of a cinder cone or mound (Figure 51) have been modified; now, at least those operations within the Deschutes National Forest are started near the tops of the cones, and reclamation of the surface progresses with mining (Figure 52). This method allows mining of most of the available material, without creating hazardous steep slopes.

Almost any of the innumerable cinder cones and mounds shown on the geologic map are potential sources of usable cinders and scoria. Deschutes County has an adequate supply of this type of construction material for all forseeable future uses.

Sand and Gravel and Crushed Stone

General discussion

Nationwide, about 95 percent of all sand and gravel produced is used in the construction industry, with slightly over half this total in road building and the associated bridges, overpasses, and interchanges. The remainder is used in buildings (private and public) and such appurtenances as driveways and parking lots.

Sand and gravel as aggregate can be loosely defined as the more or less rounded rock fragments (silt, sand, pebbles, cobbles, and boulders) generated mainly by physical weathering processes and transported by the agents of erosion, mainly running water, and usually deposited rapidly in thick-to-massive deposits that are crudely layered and sorted. Abrasion of the rock fragments during stream transport usually insures that the ones that remain will be somewhat sound and durable and usable as an aggregate for asphaltic or portland cement concrete.

Specifications to determine sand and gravel quality or suitability for a certain use are highly variable and depend on the specifying agency or the material available. One or more of the following physical or chemical properties may be significant:

1. Reaction of the aggregate to freezing or thawing
2. Chemical reaction with cement
3. Resistance to abrasion and impact
4. Gradations in size
5. Deleterious constituents (ash, clay, organic material, etc.)

The maximum size acceptable for "gravel" is about 3 inches, and since most occurrences commonly found in Deschutes County contain cobbles and boulders greater than 3 inches, crushing is usually required for total utilization. Contaminants such as clay coating the fragments, chemical salts, organic matter, or weathered particles may require washing or other processing to remove them.

"Crushed stone" substitutes for sand and gravel and is produced in the required sizes by crushing and screening of competent rock types.

This report does not represent a detailed study of the sand and gravel resources of Deschutes County; however, the field reconnaissance, air-photo interpretation, and information received from aggregate producers and users show that large quantities of usable sand and gravel are present. For the near future, sand and gravel deposits in locations convenient to the markets appear to be adequate; however, unless reserves near growing urban areas are protected by zoning, they may be reduced or eliminated, resulting in longer hauls from other locations and increased construction costs.

Figure 51. Large cinder pit in sec. 33, T. 14 S., R. 13 E., at south end of Tetherow Butte. Cinders have been dug here intermittently since about 1940, furnishing Redmond and environs with tremendous quantities of aggregate.

Figure 52. Active cinder pit (1974) has portable screening and loading facility. Near top of Little Pistol Butte. Slopes are smoothed as material is mined.

Aggregate needs for Deschutes County

Most of the population of the County is concentrated in two areas: 1) the triangular area that includes Bend, Redmond, Sisters, Tumalo, and Terrebonne, and 2) the north-south corridor that includes Lapine. These areas have shown the most rapid growth in the past and are predicted to grow at a faster rate than the rest of the County. The projected population for the County to the year 2000, as estimated by the Center For Population Research and Census at Portland State University, will be more than double that of 1970.

A canvas of the largest sand and gravel producers and users shows that in 1973 about 400,000 cubic yards were produced, and in 1974 production had increased to about 460,000 cubic yards. From the above statistics, per capita use is estimated to be about 12 cubic yards. If the high population growth predictions for the County are accurate, by 1990 Deschutes County will be using about 725,000 cubic yards of sand and gravel, including crushed rock, per year, and for the 15 years from 1975 to 1990 the County will have used up about 9,000,000 cubic yards of material (Figure 53).

All known sources of sand and gravel are shown on the Mineral Resources Map and listed in Table 1 with short comments about quantity and quality.

Sand and gravel reserves

Bend-Redmond area: Most of the sand and gravel for the Bend community has been supplied from two areas between Bend and Tumalo. Flood plain and channel gravels of the Deschutes River at Tumalo have furnished the largest quantities and best quality in the past (Figures 54 and 55). Older terrace and previous stream-channel gravels adjacent to Tumalo Creek near its confluence with the Deschutes River northwest of Awbrey Butte have been developed and have furnished large quantities of sand and gravel in recent years (Figures 56 and 57).

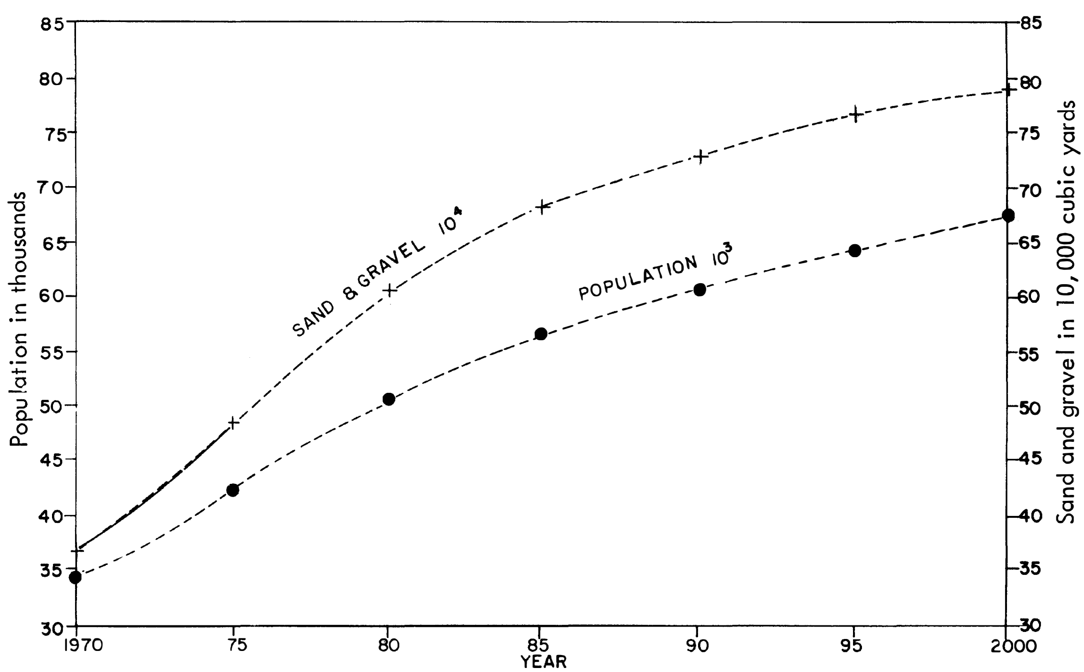


Figure 53. Projected population growth and sand and gravel consumption in Deschutes County for the period 1970 to 2000. Population estimates from Center for Population Research and Census, Portland State University. Sand and gravel estimates based on per capita use of 12 cubic yards per year.

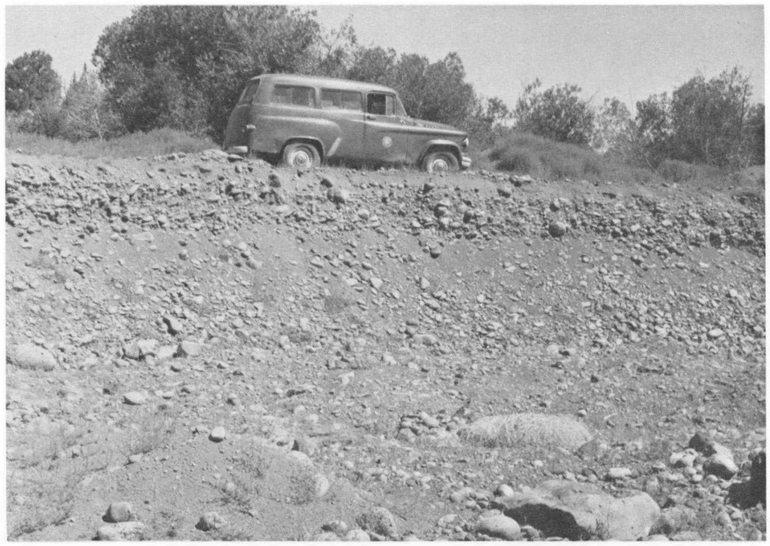


Figure 54. Flood plain and streambank gravels adjacent to Deschutes River north of Tumalo can be mined to depths of 10 or 15 feet (4 or 5 m). Gravels are poorly sorted, containing many large boulders and a high percentage of fine, ashy, and pumiceous material.

Figure 55. Sand and gravel pit near Johnson Road south of Tumalo, in sec. 6, T. 17 S., R. 12 E. Glaciofluvial fan gravels are overlain by 6 to 12 feet (2 to 4 m) of pumiceous sand and soil and underlain by the pinkish ash-flow tuff unit.

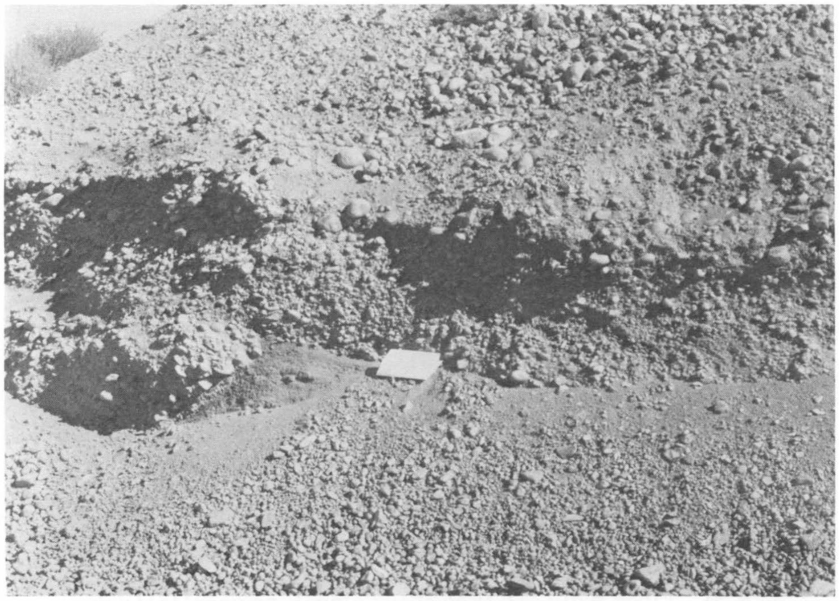


Figure 56. Gravel bank on a terrace between Tumalo Creek and the Deschutes River. Old stream-channel gravels may be as much as 30 feet (10 m) thick. Contains some cobbles as much as 6 feet (2 m) in size and lenses of pumiceous sand and silt.

Figure 57. Modern portable crushing, screening, and washing plant of Deschutes Ready Mix Sand & Gravel Co. can produce large quantities of sized material. Pit is in NW$\frac{1}{4}$ sec. 18, T. 17 S., R. 12 E.

Within 10 miles southwest of Bend, large quantities of sand and gravel of glaciofluvial origin are present in several localities adjacent to the Cascade Lakes Highway. Some evaluation of these largely undeveloped sand and gravel deposits has been done, and minor quantities have been used for nearby roads and highways. Reserves are reported to be at least a few million cubic yards in this area.

Glaciofluvial gravels are also present in large quantities in the area from Plainview to Sisters, with the thickest, best quality materials in the Squaw Creek flood plain southeast of Sisters (Figure 58). Glacially generated clastic materials have been distributed to the flat area adjacent to U. S. Highway 20 and Oregon Highway 126 west and northwest of Sisters. The 15- to 20-mile haul of these gravels to the urban centers of Bend or Redmond will increase transportation cost to the user.

The Redmond community is supplied mainly from the deposits along the Deschutes River at Tumalo and old channel gravels in Deep Canyon near Fryear Butte. A small deposit of Deschutes channel gravels near Lower Bridge is also furnishing some aggregate. The largest reserves close to Redmond are reported to be near Tetherow Bridge in sec. 36, T. 14 S., R. 12 E., where old channel gravels reworked from the Deschutes Formation cover about 100 acres. The gravel appears to have a minable depth of at least 10 feet and consists mainly of rounded basaltic pebbles, cobbles, and boulders averaging about 3 to 4 inches in diameter. As in most other gravel deposits, 40 to 50 percent of the material is fine, and much of it may have to be rejected.

No doubt former stream-channel sand and gravel deposits lie beneath lava flows or ash-flow tuffs west and northwest of Bend, and the Deschutes Formation also may contain some zones of gravel farther north that will contribute reserves for future needs.

Eastern Deschutes County: In the eastern part of the County, an area around Alfalfa, adjacent to Dry River, appears to contain enough fair-quality sand and gravel for current and near-future needs. In Millican Valley, gravel fans from drainages on the northeast flanks of Newberry Volcano and Pleistocene lakeshore gravel deposits adjacent to U. S. Highway 20 can furnish material for road maintenance and resurfacing. Gravel fans deposited along the southwest flanks of Hampton Buttes have some reserves of crusher-run materials (Figure 59).

Southern and western Deschutes County: In the southern part of the County adjacent to U. S. Highway 97, in the Lapine area, thick layers of poorly sorted cindery gravel provide some material suitable for fill and base rock. A limited supply of better quality gravel occurs along lower Paulina Creek. To the west, glacial outwash and glaciofluvial materials are abundant, especially in the area from Wickiup to Crane Prairie Reservoir.

Good-quality sand and gravel deposits are not unlimited. Costs will be influenced by length of haul to the market, land reclamation restrictions, and regulations required to curb air and water pollution.

Crushed stone reserves

The minor production (17,000 cubic yards in 1974) of crushed stone and few quarry sites (shown on the Mineral Location Map) indicate the lack of known deposits of good-quality stone suitable for aggregate. The newly opened quarry on Cline Buttes has ample reserves of flow-banded rhyolite that can be crushed, screened, and marketed for some aggregate uses.

Of the other near-surface rock types, the Pliocene-Pleistocene non-vesicular basaltic lava flows with platy jointing may be the most suitable to crush for an acceptable aggregate. Most of these basalt flows are thin, however, and quarry sites that have the potential of producing large quantities of rock are scarce. If sand and gravel reserves are eventually depleted, a search may have to be made to find better and larger crushed-stone sources.

Figure 58. Bouldery glacial gravel in channel of Squaw Creek south of Sisters. Large quantities of glaciofluvial sand and gravel cover the flat areas adjacent to Squaw Creek in this area.

Figure 59. Stockpiles of crushed and screened aggregate from broad shallow pits in an alluvial fan type of sand and gravel deposit near Hampton.

Surface Soil and Common Fill Material

Common or select fill materials are generally surface soils or those mixed materials that do not meet the specifications for sand and gravel but are suitable for roadway shoulders, backfilling of ditches and trenches that carry such underground utilities as water and sewer lines and power and telephone cables, and for general fill. In most regions, such materials are usually abundant and available as surface deposits and are not considered an important resource. In Deschutes County, however, common fill is lacking within and adjacent to the population centers because lava flows are too near the surface for thick soil zones to exist (see Figure 18), and fill material is limited to the few localities discussed below.

Well logs indicate that relatively fine-grained volcanic sediments are present under the young lavas at variable depths. In a few places the young lavas did not cover these sediments and they are present at the surface, as at the Knott Pit, about 5 miles southeast of Bend ($S\frac{1}{2}$ sec. 14, T. 18 S., R. 12 E.). Here the materials have been excavated for use as fill since about 1953. The pit has been greatly expanded in the past few years and now serves as the City-County sanitary landfill. Large quantities, estimated to be as much as 100,000 cubic yards per year are excavated to make room for the landfill and for sale and use as fill at construction projects in the Bend area. The thinly layered and cross-bedded volcanic sediments (Figure 60) are partially indurated but still easily dug with caterpillar tractor, back hoe, or front-end loader. The County supervises the sanitary landfill and sells the fill material. Large users of fill from this source are the State Highway Department, County Road Department, City of Bend Water Department, and local utility contractors.

Amazingly at the Knott Pit site, excavation of the sediments reached 90 feet below the surface before encountering a lava flow. It appears that surrounding the Knott Pit there are several hundred acres underlain by a thick section of volcanic sediments suitable for fill, representing a large quantity of a valuable resource.

The Anderson clay pit west of Bend in the $SW\frac{1}{4}$, sec. 25, T. 17 S., R. 11 E., has also furnished backfill and surface fill materials from an alluvial deposit which contains considerable quantities of pumice and clay. This source represents a large supply of fill for certain uses.

In the Redmond area, soil zones are somewhat thicker and the cindery soil around Tetherow Buttes could furnish fill material for the Redmond area. Two small areas of volcanic sediments that could probably produce usable fill were noted south of Forked Horn Butte in sec. 31, T. 15 S., R. 13 E., and in secs. 1 and 6, T. 16 S., R. 12-13 E. These occurrences were not examined in detail so the quantity and quality of the material is not known.

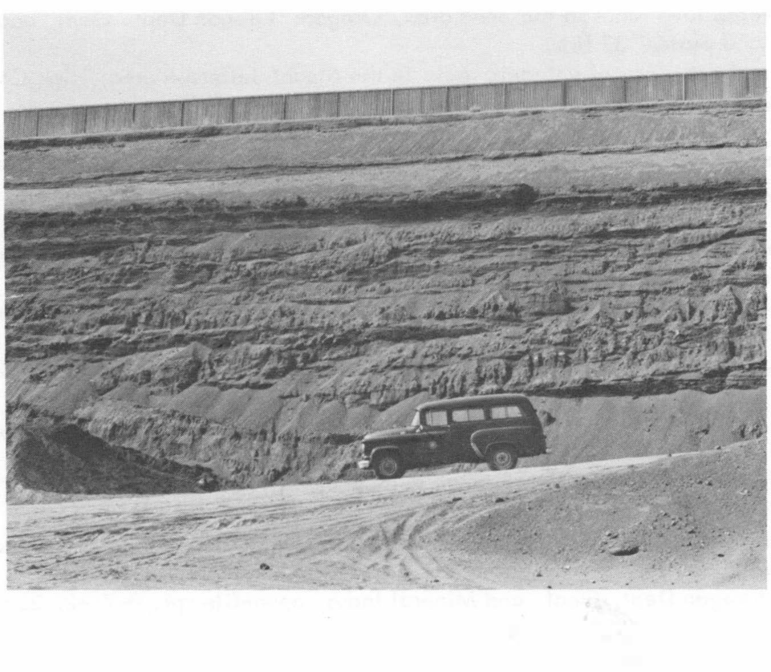


Figure 60. Knott sanitary landfill pit southeast of Bend furnishes large quantities of common fill materials used in the Bend area.

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APPENDIX: INDUSTRIAL MINERAL OCCURRENCES IN DESCHUTES COUNTY, OREGON

Map No.	Type of Material	Location sec.	T. S.	R. E.	Quadrangle	Name-information	References
1	Cinders & scoria	9	14	8	Three Finger Jack 15'	Cashe Mt.-currently inactive	USFS Sisters Dist.
2	Sand & gravel	NW 5	14	9	Sisters 15'	Glacial outwash, inactive	This study
3	Sand & gravel	NW 4	14	9	Sisters 15'	Glacial outwash, inactive	This study
4	Sand & gravel	NE 8	14	9	Sisters 15'	Black Butte-glacial outwash	USFS Sisters Dist.
5	Cinders & scoria	SW 17	14	9	Sisters 15'	Fivemile Butte-not active	USFS Sisters Dist.
6	Cinders & scoria	NE 32	14	9	Sisters 15'	Fourmile Butte-Pleistocene cinder	OSHD-USFS
7	Sand & gravel	SW 19	14	10	Sisters 15'	Hwy 126-glacial outwash	OSHD
8	Cinders & scoria	19	14	10	Sisters 15'	Zimmerman Butte-active large pit, large reserves	OSHD-USFS
9	Cinders & scoria	4	14	10	Sisters 15'	Garrison Butte	USFS
10	Clay	15	14	10	Sisters 15'	Edgar Clay Deposit-gray to dark gray mixed clays	USFS
11	Sand & gravel	NW 33	14	10	Sisters 15'	Lundy Road-layered cindery sand and gravel, glacial outwash	This study
12	Sand & gravel	SW 33	14	10	Sisters 15'	Gun club-medium size material, shallow pit	This study
13	Diatomite	16	14	12	Cline Falls 7½'	Lower Bridge Diatomite (see text)	This study
14	Sand & gravel	15, 16	14	12	Cline Falls 7½'	Lower Bridge-shallow terrace, gravels overlie diatomite	OSHD
15	Cinders & scoria	SE 18	14	13	Redmond 7½'	Deschutes Co.-large well developed pit	MLR, OSHD, This study
16	Cinders & scoria	NW 16	14	13	Redmond 7½'	C. A. Loe-large pit	MLR, OSHD
17	Cinders & scoria	NW 29	14	13	Redmond 7½'	E. A. Moore-north end of Tetherow Butte	MLR, OSHD
18	Cinders & scoria	NW 28	14	13	Redmond 7½'	M&M Rock Co.-Tetherow Butte NE	MLR, OSHD
19	Cinders & scoria	NW 33	14	13	Redmond 7½'	Grote Pit-Tetherow Butte SW	MLR, OSHD
20	Cinders & scoria	SW 33	14	13	Redmond 7½'	City Pit-Tetherow Butte S	MLR, OSHD
21	Cinders & scoria	NE 33	14	13	Redmond 7½'	Mid-Oregon Pit-Tetherow Butte SE	MLR, OSHD
22	Sand & gravel	S½ 36	14	13	Redmond 7½'	Tetherow Rd. Pit-reports indicate 100 ac of good quality gravel	This study
23	Sand & gravel	SW 16	15	13	Redmond 7½'	Deschutes Fm.-only fair quality	OSHD
24	Cinders & scoria	NW 29	15	13	Forked Horn Butte 7½'	Limited supply and quality?	OSHD
25	Sand & gravel	SE 11	15	12	Cline Falls 7½'	Terrace gravels, good quality	OSHD
26	Sand & gravel	NE 14	15	12	Cline Falls 7½'	Terrace gravels, good quality	OSHD
27	Quarry rock	SW 16	15	12	Cline Falls 7½'	Cline Buttes-banded rhyolite, large supply	MLR, This report
28	Cinders & scoria	W 18	15	12	Cline Falls 7½'	Not active, small pit	OSHD
29	Sand & gravel	9	15	11	Henkle Butte 7½'	Deep canyon, active pit, good quality	OSHD
30	Sand & gravel	5	15	11	Henkle Butte 7½'	Cloverdale-fine materials, only fair quality	OSHD
31	Cinders & scoria	NE 12	15	10	Henkle Butte 7½'	Cyrus Pit-large cinder pit, reserves unknown	MLR, This study
32	Sand & gravel	NE 11	15	10	Sisters 15'	Squaw Creek-outwash, good quality	OSHD
33	Sand & gravel	9	15	10	Sisters 15'	Weigh Station-Squaw Creek outwash	USFS, OSHD
34	Sand & gravel	16	15	10	Sisters 15'	Squaw Creek-outwash gravels	OSHD
35	Quarry rock	21	15	10	Broken Top 15'	No name, platy basalt	USFS
36	Cinders & scoria	SW 4	16	9	Broken Top 15'	Pole Creek	USFS
37	Quarry rock	11	16	9	Broken Top 15'	Squaw Creek-basalt	USFS
38	Cinders & scoria	SW 12	16	9	Broken Top 15'	Melvin Butte	USFS
39	Cinders & scoria	SE 15	16	9	Broken Top 15'	Black Pine	USFS
40	Sand & gravel	W½ 36	15	10	Tumalo Dam 7½'	Plainview-quantity or extent unknown	OSHD
41	Cinders & scoria	SE 10	16	11	Tumalo Dam 7½'	Large pit, more available	OSHD
42	Cinders & scoria	S 12	16	11	Tumalo 7½'	Small privately owned pit	This study
43	Sand & gravel	SE 11	16	12	Tumalo 7½'	Peterson Road-small deposit, layered fine to coarse; Deschutes Fm.-poor to fair quality	OSHD
44	Cinders & scoria	22	16	12	Tumalo 7½'	Long Butte-large supply available	OSHD
45	Cinders & scoria	22	16	12	Tumalo 7½'	Long Butte-large supply available	MLR
46	Quarry rock	22	16	12	Tumalo 7½'	Inactive, platy basalt	OSHD
47	Sand & gravel	30	16	12	Tumalo 7½'	Bend Aggregate-reworked Deschutes Fm. river terrace	OSHD
48	Sand & gravel	29	16	12	Tumalo 7½'	Bend Aggregate-river terrace, large supply, good quality	OSHD
49	Sand & gravel	31	16	12	Tumalo 7½'	" " "	OSHD

APPENDIX (Continued)

Map No.	Type of Material	Location sec.	T. S.	R. E.	Quadrangle	Name-information	References
50	Cinders & scoria	NW 36	16	11	Tumalo 7½'	Laidlaw Butte-active pit	This study
51	Pumice	1, 2, 35, 36	16	11	Tumalo 7½'	Cascade Pumice-active pits, ash-flow pumice, south of Laidlaw Butte	This study
52	Sand & gravel	SW 6	17	12	Tumalo 7½'	Terrace gravels, good quality, partly removed	OSHD
53	Sand & gravel	12	17	12	Bend 7½'	Thick good quality gravels	OSHD
54	Sand & gravel	NW 18	17	12	Bend 7½'	Deschutes Redi Mix S&G-large quantity, fair to good quality	This study
55	Sand & gravel	S½ 12	17	11	Bend 7½'	" " "	This study
56	Cinders & scoria	NE 23	17	11	Bend 7½'	Tumalo Butte-not active	This study
57	Cinders & scoria	NW 2	17	9	Broken Top 15'	Three Creek	USFS
58	Cinders & scoria	16	17	10	Broken Top 15'	Triangle Hill	USFS
59	Quarry rock	23	17	12	Bend 7½'	Small quarry, Pleistocene basalt	OSHD
60	Sand & gravel	NE 26	17	14	Alfalfa 7½'	Dry River-outwash, 10' thick, pebbly gravel, fine to medium	This study
61	Quarry rock	32	17	13	Bend Airport 7½'	Small quarry, Badlands Lava flows	OSHD
62	Cinders & scoria	33, 34	17	12	Bend 7½'	Pilot Butte Cone-black cinders, limited use	OSHD
63	Pumice, clay, cinders	SE 25	17	11	Bend 7½'	D.B. Anderson-pit run materials	This study
64	Pumice	S½ 35, 36	17	11	Bend 7½'	Central Oregon Pumice-active pumice production	This study
65	Sand & gravel	3	18	11	Shevlin Park 7½'	Mainline-thin, only fair quality gravels	OSHD, USFS
66	Building stone	NE 10	18	11	Shevlin Park 7½'	Active quarry, black ash-flow tuff stone	This study
67	Pumice	11	18	11	Shevlin Park 7½'	Central Oregon Pumice-extensive pumice deposits	This study
68	Sand & gravel	4	18	11	Shevlin Park 7½'	Skyline Road-thin outwash gravels, mostly removed	OSHD, USFS
69	Cinders & scoria	18	18	11	Shevlin Park 7½'	Swede Ridge	USFS
70	Cinders & scoria	13	18	10	Shevlin Park 7½'	Swede Ridge #2	USFS
71	Cinders & scoria	10	18	10	Broken Top 15'	East Tumalo	USFS
72	Cinders & scoria	W½ 18	18	9	Broken Top 15'	Todd Creek-no development	USFS
73	Cinders & scoria	SW 18	18	9	Broken Top 15'	Todd Creek #2-active pit	USFS
74	Cinders & scoria	28, 29	18	9	Bachelor Butte 7½'	Red Butte	USFS
75	Cinders & scoria	4	19	8	Elk Lake 7½'	Red Crater	USFS
76	Cinders & scoria	S½ 30	18	10	Wanoga Butte 7½'	Sand shed, active pit	USFS
77	Cinders & scoria	SE 6	19	10	Wanoga Butte 7½'	Katalo Butte	USFS
78	Cinders & scoria	3	19	10	Wanoga Butte 7½	Kiwa Butte-inactive	USFS
79	Not used	-	-	-	-	-	-
80	Cinders & scoria	30, 31	18	11	Benham Falls 7½'	Brooks Scanlon Pit-not active	USFS
81	Cinders & scoria	28	18	11	Benham Falls 7½'	Central Oregon Pumice-cinder pit	This study
82	Sand & gravel	21	18	11	Benham Falls 7½'	Flagstone-glacial outwash	OSHD, USFS
83	Sand & gravel	15, 22	18	11	Shevlin Park 7½'	Central Oregon Pumice-gravel pit	This study
84	Cinders & scoria	35, 36	18	11	Lava Butte 7½'	Lava	USFS
85	Cinders & scoria	30	18	12	Lava Butte 7½'	Weigh Station-cinder mound, small source	This study
86	Cinders & scoria	NE 21	18	12	Bend 7½'	Central Oregon Pumice-good quality, large supply	OSHD
87	Silt, sand & gravel	S½ 14	18	12	Bend 7½'	Volcanic sediments, fine to coarse, fill material removed for sanitary landfill	This study
88	Cinders & scoria	3, 10	19	12	Lava Butte 7½'	Bessie Butte	USFS
89	Cinders & scoria	NE 36	18	12	Kelsey Butte 7½'	Horse Butte-large quantity of good quality avaliable	USFS
90	Cinders & scoria	SE 1	19	12	Kelsey Butte 7½'	Cabin Butte-large quantity of good quality avaliable	USFS
91	Cinders & scoria	SE 6	19	13	Kelsey Butte 7½'	Coyote Butte-red cinders, large supply	USFS
92	Sand & gravel	31	18	14	Horse Ridge 7½'	Fine materials, small quantity borrow pits	OSHD
93	Sand & gravel	11	19	14	Horse Ridge 7½'	Gravel fan from Dry River, large quantity, fair quality	OSHD
94	Cinders & scoria	16	19	15	Millican 7½'	Reserves not known	OSHD
95	Sand & gravel	25, 26	19	14	Horse Ridge 7½'	Borrow material, reworked lake sediments	OSHD
96	Sand & gravel	NW 3	20	14	Evans Well 7½'	Borrow pit, gravel fan, fair quality	This study

APPENDIX (Continued)

Map No.	Type of Material	Location sec.	T. S.	R. E.	Quadrangle	Name-information	References
97	Sand & gravel	SE 36	19	13	Horse Ridge 7½'	Borrow pit, fair med. to fine gravel	This study
98	Cinders & scoria	SW 16	19	12	Lava Butte 7½'	Lava River-eroded cinder mound, inactive	USFS
99	Cinders & scoria	SE 18	19	12	Lava Butte 7½'	East Lava Butte-inactive	USFS
100	Cinders & scoria	33, 34	19	12	Lava Butte 7½'	Klawhop Butte-not active	USFS
101	Cinders & scoria	34	19	11	Benham Falls 7½'	N. Camp Abbott-mostly removed	USFS
102	Cinders & scoria	SE 3	20	11	Benham Falls 7½'	Camp Abbott-active, large supply	USFS
103	Cinders & scoria	19	19	11	Benham Falls 7½'	Boundary, small pit	USFS
104	Cinders & scoria	24	19	9	Wanoga Butte 7½'	Dutchman Creek-developed	USFS
105	Cinders & scoria	24	19	9	Wanoga Butte 7½'	Dutchman Creek #2-status unknown	USFS
106	Cinders & scoria	NE 36	19	9	Bachelor Butte 7½'	Sheridan-not active	USFS
107	Sand & gravel	4	20	8	Crane Prairie 7½'	Deschutes Bridge-glacial outwash, extent & quantity not known	USFS
108	Cinders & scoria	31	19	9	Bachelor Butte 7½'	Sheridan #2	USFS
109	Cinders & scoria	6	20	9	Round Mt. 7½'	Loop	USFS
110	Cinders & scoria	5	20	9	Bachelor Butte 7½'	1945	USFS
111	Cinders & scoria	5	20	9	Round Mt. 7½'	Junction	USFS
112	Cinders & scoria	5	20	9	Round Mt. 7½'	Junction #2	USFS
113	Cinders & scoria	35	19	9	Wanoga Butte 7½'	North End	USFS
114	Cinders & scoria	SE 11	20	9	Pistol Butte 7½'	Lolo Butte-active pit	USFS
115	Cinders & scoria	4	20	10	Pistol Butte 7½'	Straight	USFS
116	Cinders & scoria	4	20	10	Pistol Butte 7½'	Straight #2-developed	USFS
117	Cinders & scoria	34	19	10	Wanoga Butte 7½'	Fire Break	USFS
118	Cinders & scoria	11	20	10	Anns Butte 7½'	Little Ann-active pit	USFS
119	Cinders & scoria	19, 20	20	10	Pistol Butte 7½'	Pistol Pit-used in 1974, active, large quantity	USFS
120	Cinders & scoria	15	20	9	Round Mt. 7½'	Ridge	USFS
121	Cinders & scoria	17	20	9	Round Mt. 7½'	Lumrum Butte	USFS
122	Cinders & scoria	19	20	9	Round Mt. 7½'	North Cone	USFS
123	Cinders & scoria	19	20	9	Round Mt. 7½'	South Cone	USFS
124	Cinders & scoria	30	20	9	Round Mt. 7½'	Lookout Mt.	USFS
125	Sand & gravel	14	20	8	Round Mt. 7½'	Lodgepole	USFS
126	Sand & gravel	23	20	9	Round Mt. 7½'	Flat	USFS
127	Sand & gravel	21	20	8	Crane Prairie Res. 7½'	Deschutes River	USFS
128	Sand & gravel	22	20	8	Crane Prairie Res. 7½'	Snow Creek	USFS
129	Sand & gravel	30	20	8	Crane Prairie Res. 7½'	Cultus Junction	USFS
130	Sand & gravel	30	20	8	Crane Prairie Res. 7½'	Cultus Creek	USFS
131	Sand & gravel	36	20	7	Crane Prairie Res. 7½'	Spruce	USFS
132	Sand & gravel	1	21	7	Crane Prairie Res. 7½'	Quinn	USFS
133	Cinders & scoria	4	21	7	Irish Mountain 7½'	Lemish	USFS
134	Quarry rock	34	21	7	The Twins 7½'	Annex	USFS
135	Sand & gravel	NE 36	21	7	Davis Mt. 7½'	West Browns Creek	USFS
136	Sand & gravel	NE 36	21	7	Davis Mt. 7½'	East Browns Creek	USFS
137	Cinders & scoria	6	22	8	Davis Mt. 7½'	#217-not developed	USFS
138	Cinders & scoria	SW 14	22	7	Davis Mt. 7½'	Pine Butte-active pit, good quality	USFS
139	Cinders & scoria	NE 22	22	7	Davis Mt. 7½'	North Davis Mt.-active pit, red cinders	USFS
140	Sand & gravel	NW 28	21	8	Davis Mt. 7½'	Sheep Bridge	USFS
141	Cinders & scoria	16	21	8	Crane Prairie Res. 7½'	Crater & Crater #2-developed	USFS
142	Cinders & scoria	16	21	8	Crane Prairie Res. 7½'	Dam	USFS
143	Cinders & scoria	9, 10	21	8	Crane Prairie Res. 7½'	Shuckash	USFS
144	Cinders & scoria	10	21	8	Crane Prairie Res. 7½'	Palanush	USFS
145	Cinders & scoria	6, 7	21	9	Round Mt. 7½'	Round Mt. Pass-active pit	USFS
146	Cinders & scoria	E½ 13	21	8	Round Mt. 7½'	Round Mt.	USFS
147	Cinders & scoria	33	20	9	Round Mt. 7½'	South Dry Butte	USFS
148	Cinders & scoria	SW 34	20	9	Round Mt. 7½'	Addition	USFS
149	Cinders & scoria	SW 34	20	9	Round Mt. 7½'	1808	USFS
150	Cinders & scoria	SW 34	20	9	Round Mt. 7½'	1808 #2	USFS
151	Quarry rock	14	21	9	LaPine 7½'	Pringle Falls	USFS
152	Cinders & scoria	NW 36	21	9	LaPine 7½'	Cruiser Butte	USFS
153	Sand & gravel	25	20	10	Anns Butte 7½'	Gassner-pit run, fill	USFS
154	Sand & gravel	NE 6	21	11	Anns Butte 7½'	Med. to fine, poor quality	OSHD
155	Sand & gravel	NW 5	21	11	Anns Butte 7½'	Hwy 97 #13-mostly fine, fair to poor quality, pebbly gravel	OSHD, USFS
156	Sand & gravel	SW 5	21	11	Anns Butte 7½'	Hwy 97 #14-mostly fine, fair to poor quality, pebbly gravel	OSHD, USFS

APPENDIX (Continued)

Map No.	Type of Material	Location sec.	T. S.	R. E.	Quadrangle	Name-information	References
157	Sand & gravel	W 18	21	11	Anns Butte $7\frac{1}{2}$'	Paulina Creek	OSHD
158	Sand & gravel	1, 6	22	10	Finley Butte $7\frac{1}{2}$'	BLM pits, active, fine to med. cindery gravels	OSHD
159	Sand & gravel	SW 24	21	10	Finley Butte $7\frac{1}{2}$'	Little Deschutes-outwash	OSHD
160	Sand & gravel	18	22	11	Finley Butte $7\frac{1}{2}$'	Fine to med., cindery sand & gravel	OSHD
161	Cinders & scoria	20, 21	22	11	Finley Butte $7\frac{1}{2}$'	Finley Butte-active pit, large supply	OSHD, USFS
162	Cinders & scoria	14	22	11	Paulina Peak $7\frac{1}{2}$'	Pipeline-not active	USFS
163	Sand & gravel	NE 28	21	11	Finley Butte $7\frac{1}{2}$'	Prairie-Paulina Creek outwash, good quality	USFS, OSHD
164	Quarry rock	NE 26	21	11	Paulina Peak $7\frac{1}{2}$'	McKay Butte-rhyolite vitrophyre	OSHD
165	Cinder & scoria	5	22	12	Paulina Peak $7\frac{1}{2}$'	Paulina Lake	USFS
166	Cinders & scoria	SE 19	20	12	Lava Cast Forest $7\frac{1}{2}$'	Sugar Pine Butte	USFS
167	Cinders & scoria	SE 21	20	12	Lava Cast Forest $7\frac{1}{2}$'	Lava Cast	USFS
168	Cinders & scoria	NW 24	20	12	Fuzztail Butte $7\frac{1}{2}$'	Lost Buttes	USFS
169	Cinders & scoria	NE 1	21	12	Fuzztail Butte $7\frac{1}{2}$'	Pilpil Butte	USFS
170	Cinders & scoria	NE 34	20	13	Fuzztail Butte $7\frac{1}{2}$'	Company Butte	USFS
171	Cinders & scoria	NE 2	21	13	Fuzztail Butte $7\frac{1}{2}$'	Orphan Butte	USFS
172	Cinders & scoria	SW 14	21	13	Fuzztail Butte $7\frac{1}{2}$'	Cinder Hill	USFS
173	Cinders & scoria	4	22	13	No map	The Dome	USFS
174	Cinders & scoria	29	22	13	No map	Kweo Butte	USFS
175	Cinders & scoria	28	22	13	No map	Box Butte	USFS
176	Cinders & scoria	NW 25	22	13	No map	Cinder Cone	USFS
177	Cinders & scoria	SE 34	22	14	No map	Lava Pass	USFS
178	Cinders & scoria	34	21	14	No map	Sabol Butte	USFS
179	Cinders & scoria	NE 36	21	14	No map	Ground Hog Butte	USFS
180	Cinders & scoria	30	22	15	No map	Firestone Butte-active pit	USFS
181	Cinders & scoria	SE 32	22	15	No map	Rogers Butte-intermittently active	USFS
182	Cinders & scoria	SW 27	22	16	No map	Watkins Butte	USFS
183	Cinders & scoria	8, 9	22	16	No map	Plot Butte-active pit, large quantity mined	USFS
184	Quarry rock	SW 28	20	15	Pine Mt. $7\frac{1}{2}$'	Pine Mt.-rhyolite	USFS
185	Cinders & scoria	11, 14	21	15	No map	Antelope Spring	USFS
186	Sand & gravel	33, 35	19	15	Millican $7\frac{1}{2}$'	Layered pebbly gravels	OSHD
187	Quarry rock	SW 33	19	16	Millican SE $7\frac{1}{2}$'	Small quarry, basalt lava flows	OSHD
188	Sand & gravel	4	20	16	Millican SE $7\frac{1}{2}$'	Gravelly lake sediments, borrow material	OSHD
189	Sand & gravel	3	20	16	Millican SE $7\frac{1}{2}$'	" " "	OSHD
190	Sand & gravel	2	20	16	Millican SE $7\frac{1}{2}$'	Fine to coarse layered lake sediments, borrow pit	OSHD
191	Quarry rock	1	20	16	Millican SE $7\frac{1}{2}$'	Small quarry, flow basalt	OSHD
192	Quarry rock	14	20	17	Brothers $7\frac{1}{2}$'	Small quarry, flow basalt	OSHD
193	Sand & gravel	S$\frac{1}{2}$ 1	20	18	Brothers $7\frac{1}{2}$'	Pit-run gravel, derived from John Day Formation	This study
194	Cinders & scoria	19, 20	20	19	No map	Active pit, large quantity of Grassy Butte red cinders available	OSHD
195	Sand & gravel	1	20	19	No map	-	OSHD
196	Quarry rock	NE 7	21	19	No map	Small quarry, flow basalt	OSHD
197	Sand & gravel	13	21	19	No map	-	OSHD
198	Sand & gravel	20, 21	21	20	No map	Silty gravels, fill material	OSHD
199	Sand & gravel	16	21	20	No map	Alluvial fan, silty gravels, some usable gravel	OSHD
200	Quarry rock	26	21	20	No map	Platy rhyolite, large pit	OSHD
201	Sand & gravel	15, 22	22	21	No map	Reported to be gravel & rock	OSHD
202	Cinders & scoria	28, 33	22	23	No map	Active pit	OSHD
203	Sand & gravel	14	22	23	No map	Misery Flat-pit run gravel prospect	OSHD

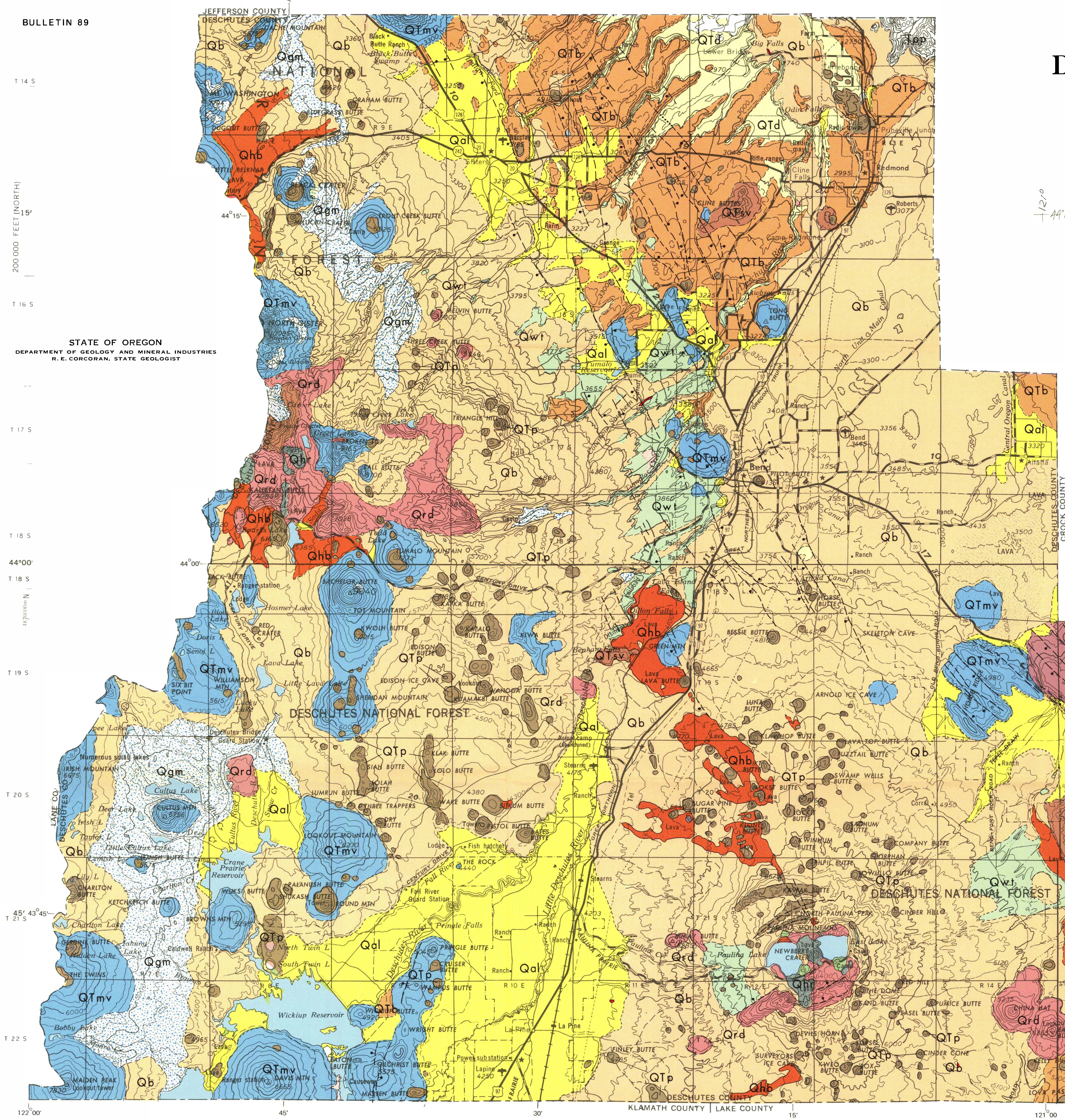
BULLETIN 89

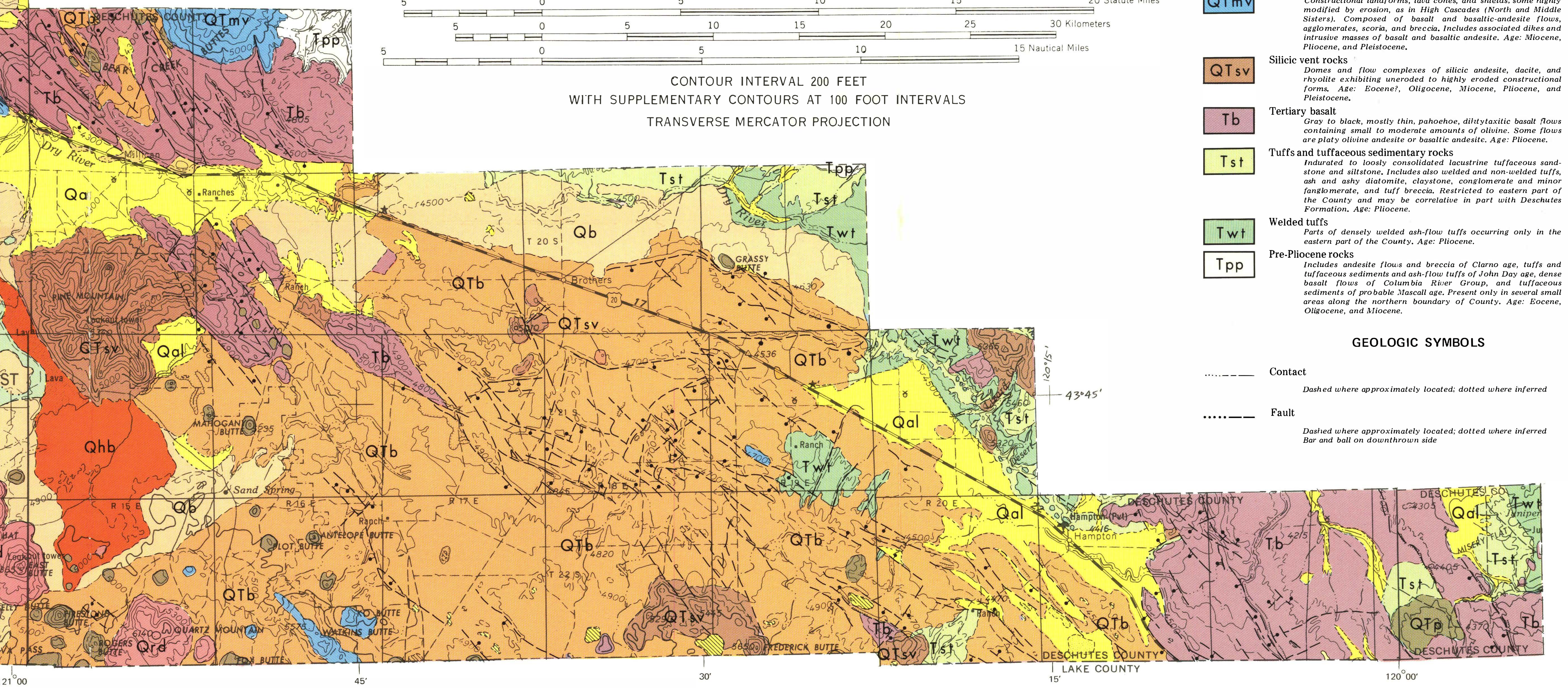
GEOLOGIC COMPILATION MAP *of* DESCHUTES COUNTY OREGON

Geology compiled by Norman V. Peterson and Edward A. Groh, 1974

Cartography by S. R. Renoud and W. H. Pokorny

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST





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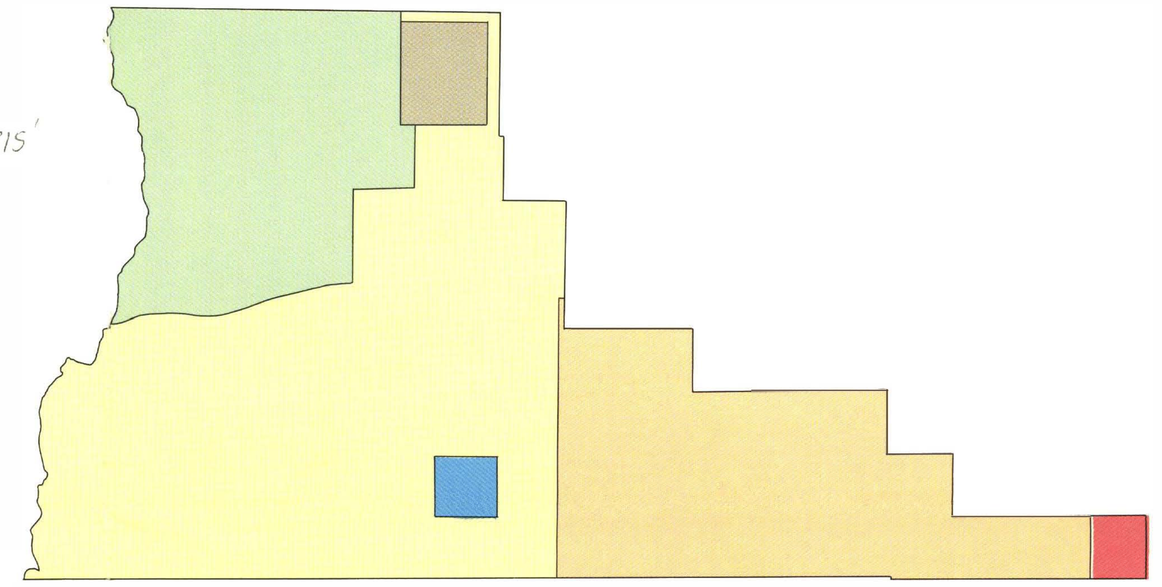
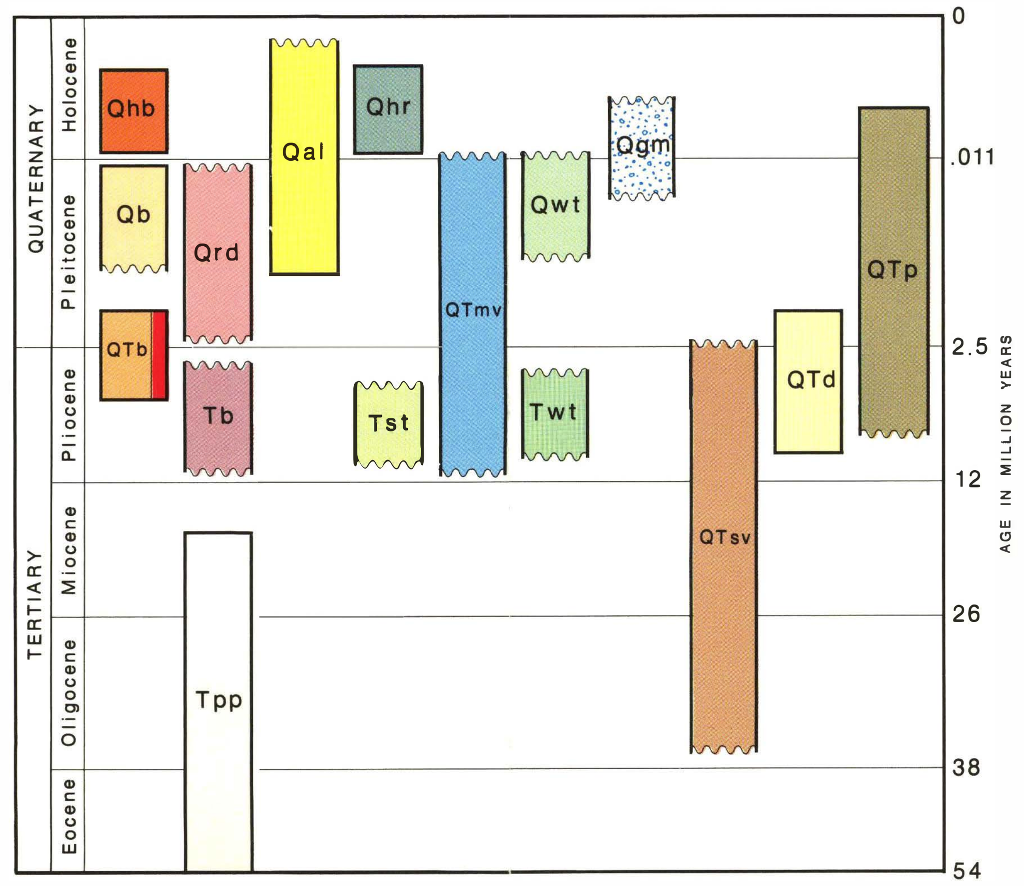


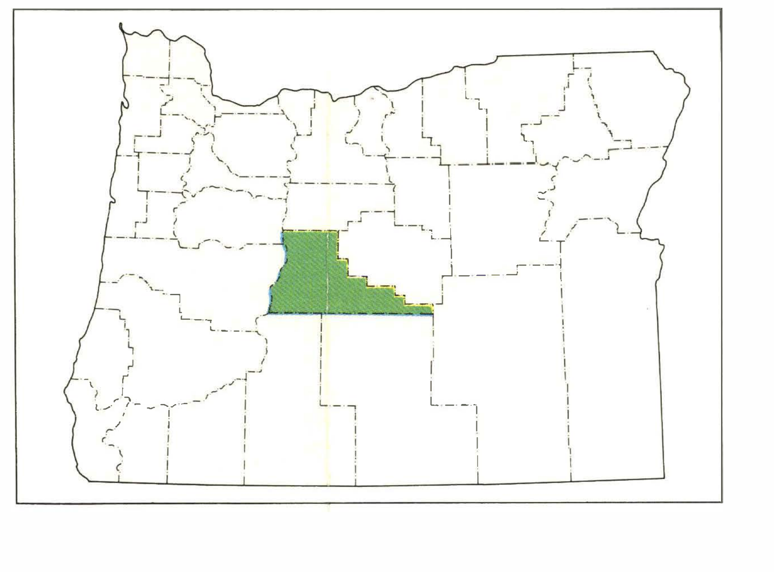
INDEX TO GEOLOGIC MAPPING

- Edward M. Taylor, 1974
- Donald Stensland, 1974
- Norman V. Peterson and Edward A. Groh, 1974
- George W. Walker, Norman V. Peterson, and Robert C. Greene, 1967
- Robert C. Greene, George W. Walker, and Raymond E. Corcoran, 1972
- Michael W. Higgins and Aaron C. Waters, 1968

1970 MAGNETIC DECLINATION FROM TRUE NORTH VARIES FROM 19° EASTERLY FOR SOUTHEAST TIP TO 20° EASTERLY TO NORTHWESTERN BOUNDARY OF COUNTY.

Base Map from Army Map Service 1:250,000 (Topographic)
Map Sheets: Bend, 1964 and Crescent 1962





LOCATION MAP

5 0 5 10 15	20 Statute Miles
5 0 5 10 15 20 25	30 Kilometers
5 0 5 10	15 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

EXPLANATION

Qhb Holocene basalt flows
Holocene basalt and basaltic andesite flows less than 11,000 years old. Most are dark-gray to black, dense basaltic lavas of aa or block flows. Age determined by radiocarbon, absence of Mazama pumice mantle (6,600 radiocarbon years), or estimated by comparison with other known Holocene surfaces.

Qhr Silicic flows and domes
Holocene silicic lava flows, obsidian domes, pumice cones, and ash flows. Mostly rhyolite to dacite in composition. Age determined by radiocarbon and hydration-rind dating, absence of Mazama pumice, or estimated by comparison with other known Holocene surfaces.

Qal Alluvium and surficial deposits
Unconsolidated gravels, sands, and silts laid by streams, with minor wind-deposited silt and ash. Pumiceous and cindery at many locations. Includes slope wash, playa deposits, alluvial fans, lake-bed deposits, and dune sand. Numerous patches of alluvial deposits too small to map occur on lava flows and ash flows.

Qb Pleistocene basalt flows
Gray, diktytaxitic, olivine basalts originating on and about flanks of Newberry Volcano and associated with Brothers Fault Zone in eastern part of County. Also includes large area of medium- to dark-gray, vesicular to dense olivine basalts and basaltic-andesite lavas of High Cascades, some of which are porphyritic.

Qgm Glacial and fluvio-glacial deposits
Gravels, sands, silts of glacial and fluvio-glacial origin. Includes lateral moraines, terminal moraines, drift, and outwash. Distinction between glacial and fluvio-glacial deposits and interfingering alluvium is mostly inferred. Bedrock is mapped in many places where only thinly mantled by glacial debris.

Qrd Silicic lavas and domes
Domes and flows of silicic andesite, dacite, and rhyolite mostly in Newberry Volcano area and in High Cascades, particularly in Broken Top-South Sister area.

Qwt Ash-flow deposits
A series of at least five ash-flow tuffs separated by minor erosional unconformities. Exposed mostly west of the Deschutes River; source near Broken Top volcano in High Cascades. Ash-flow units vary in color from red through gray to black and are semi-welded to highly welded. The ash-flow unit east of Newberry Caldera (Newberry Crater) is brownish, contains many rock fragments, and is believed to have been erupted from a source at Newberry Volcano.

QTb Older basalts
Thick to thin flows of vesicular to dense basalts and basaltic-andesites. Some are diktytaxitic and many dense varieties show characteristic platy jointing. Typically form rimrocks along lower Deschutes River Canyon in the northern part of County. Also a major unit in eastern part of County. Age: Pliocene and Pleistocene.

QTd Deschutes Formation
Fluviatile and lacustrine sediments composed of gravels, sands, and silts of volcanic ejecta and reworked volcanic material; much of sediment pumiceous and cindery. Interbedded basalt flows and ash-flow tuffs occur in the section; best exposed in Deschutes River Canyon in northern part of County. Diatomite deposits in Lower Bridge area of Deschutes River Canyon are included. In northern part of County, Deschutes Formation reported to be Pliocene in age but near Bend it appears to be part of a continuous depositional sequence from Pliocene into Pleistocene.

Dike Dikes
Narrow sinuous basalt spines associated with the cinder and lava mounds which in some cases mark fissure sources for the QTb flows.

QTp Pyroclastic volcanic rocks
Basaltic and andesitic scoria cones (cinder cones), mounds, and spatter cones. Composed of coarse to fine fragments varying from red to black and large to small bombs and lapilli with some agglutinate zones. Includes tuff cone Sitkum Butte, maars of North and South Twin Lakes, and eroded palagonite tuff cones of Wake Butte, also three eroded palagonite tuff cones within Newberry Caldera (Newberry crater). Includes hundreds of symmetrical cinder cones on flanks of Newberry Volcano and the east flank of the High Cascades. Many pyroclastic features modified by erosion to low mounds with intrusive spine and dike-like masses. Age: Pliocene, Pleistocene, and Holocene.

QTmv Mafic vent rocks
Constructional landforms, lava cones, and shields; some highly modified by erosion, as in High Cascades (North and Middle Sisters). Composed of basalt and basaltic-andesite flows, agglomerates, scoria, and breccia. Includes associated dikes and intrusive masses of basalt and basaltic andesite. Age: Miocene, Pliocene, and Pleistocene.

QTsv Silicic vent rocks
Domes and flow complexes of silicic andesite, dacite, and rhyolite exhibiting uneroded to highly eroded constructional forms. Age: Eocene?, Oligocene, Miocene, Pliocene, and Pleistocene.

Tb Tertiary basalt
Gray to black, mostly thin, pahoehoe, diktytaxitic basalt flows containing small to moderate amounts of olivine. Some flows are platy olivine andesite or basaltic andesite. Age: Pliocene.

Tst Tuffs and tuffaceous sedimentary rocks
Indurated to loosly consolidated lacustrine tuffaceous sandstone and siltstone. Includes also welded and non-welded tuffs, ash and ashy diatomite, claystone, conglomerate and minor fanglomerate, and tuff breccia. Restricted to eastern part of the County and may be correlative in part with Deschutes Formation. Age: Pliocene.

Twt Welded tuffs
Parts of densely welded ash-flow tuffs occurring only in the eastern part of the County. Age: Pliocene.

Tpp Pre-Pliocene rocks
Includes andesite flows and breccia of Clarno age, tuffs and tuffaceous sediments and ash-flow tuffs of John Day age, dense basalt flows of Columbia River Group, and tuffaceous sediments of probable Mascall age. Present only in several small areas along the northern boundary of County. Age: Eocene, Oligocene, and Miocene.

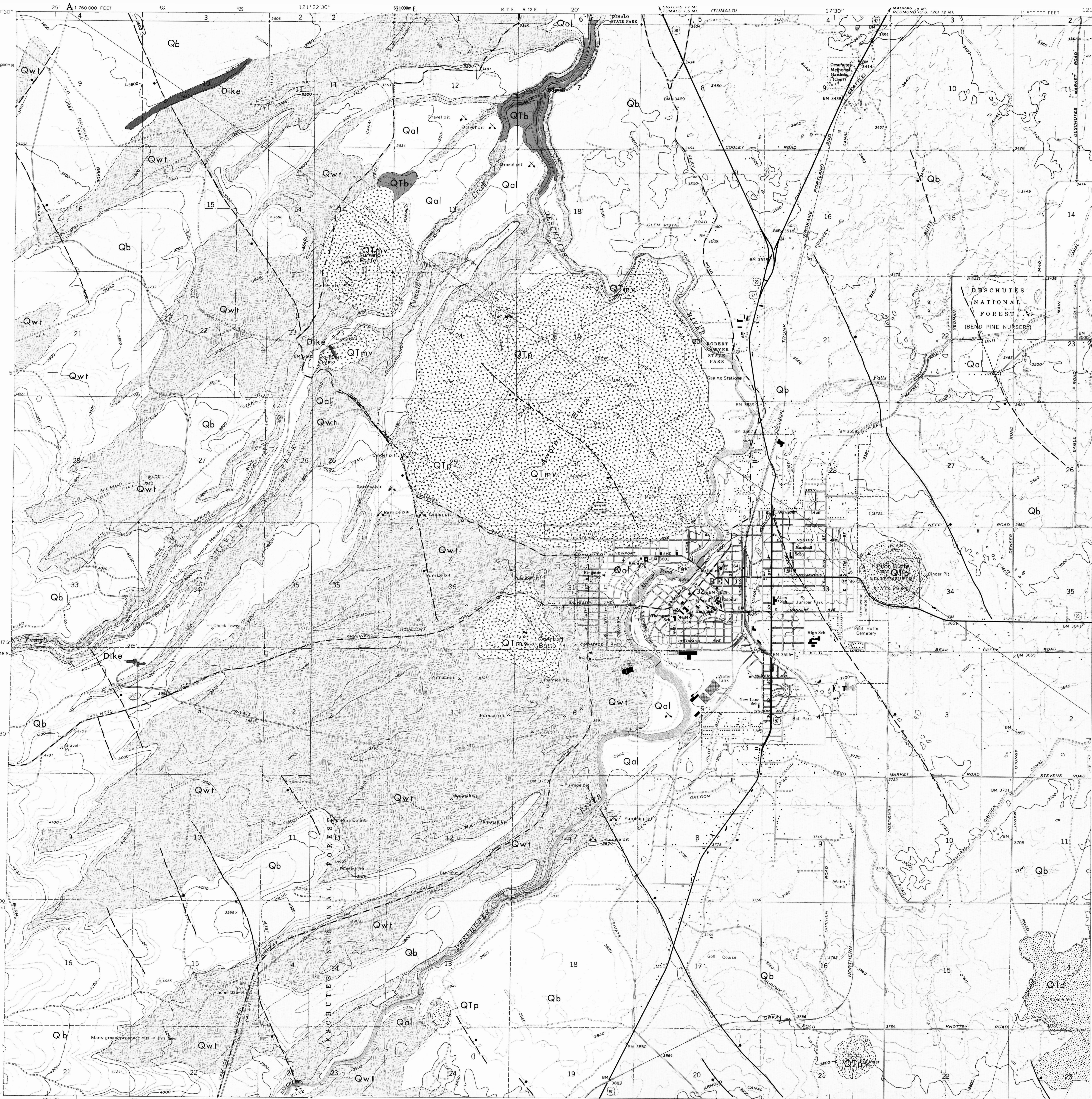
GEOLOGIC SYMBOLS

Contact
Dashed where approximately located; dotted where inferred

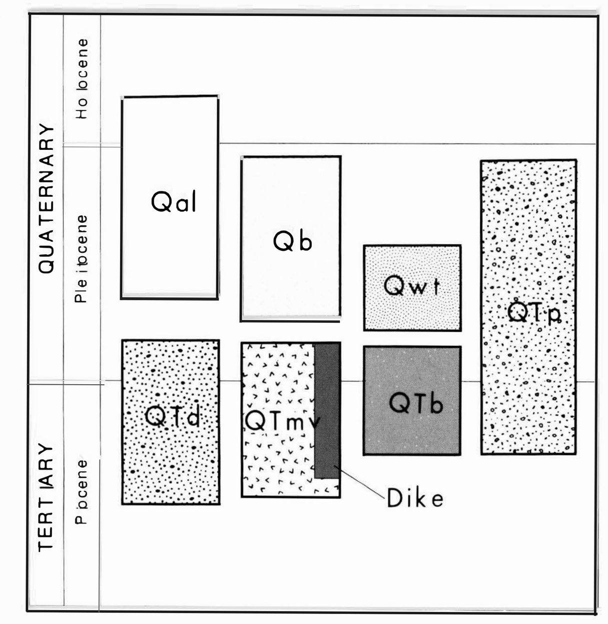
Fault
Dashed where approximately located; dotted where inferred
Bar and ball on downthrown side

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

GEOLOGIC MAP *of the* BEND AREA OREGON



Stratigraphic Time Chart



EXPLANATION

Qal Alluvium and Surficial Deposits

Unconsolidated gravels, sands and silt deposited by streams and minor silt and ash deposited by wind. Pumiceous and cindery in many places. Numerous small patches of gravels and sand overlying Qwt not mapped. Similar small areas of silts and ash in depressions surrounded by lava flows also not mapped. Elongate to fan shaped gravel deposits on terraces mark former channels of main drainages.

Qb Younger Basalts

Gray, diktytaxitic, olivine basalts originating on and about the northern and western flanks of Newberry Volcano. Also includes medium- to dark-gray, vesicular to dense basalt and basaltic-andesite lavas of the High Cascades, some of which are porphyritic.

Qwt Ash-flow and Air-fall Deposits

Includes a series of at least five ash-flow tuffs and a pumice fall separated by small to large erosional unconformities. Gravels and finer sediments may be found as lenses between the ash flow units, and in places thin gravels and sands of glacial outwash origin overlie the uppermost ash-flow tuff.

QTb Older Basalts

Thick flows of mainly dark-gray, dense to vesicular basalts and basaltic-andesites. Many show characteristic platy jointing and form the rimrocks along the lower Deschutes River Canyon.

QTd Deschutes Formation

Fluviatile and lacustrine sediments composed of gravels, sand and silts of volcanic debris. Much of the debris is pumiceous and cindery. Interbedded basalt flows and ash-flow tuffs occur in the section. Farther north the Deschutes Formation is reported to be Pliocene in age but in the Bend area there appears to be a continuous depositional sequence from Pliocene into the Pleistocene.

QTp Pyroclastic Volcanic Rocks

Basaltic scoria cones (cinder cones) and mounds consisting of red to black scoriaceous fine to coarse fragments and large to small bombs with some agglutinate. Modified in some instances by erosion to low mounds with intrusive spines and dike-like masses. Age: Pliocene and Pleistocene.

QTmv (Dike) Mafic Vent Rocks

Constructional landforms, lava cones and shields, some of which are highly modified by erosion. Made up of basaltic and basaltic-andesite flows, agglomerate, scoria and breccia. Age: Pliocene and Pleistocene. Also includes dikes of basalt and basaltic andesite.

GEOLOGIC SYMBOLS

Contacts

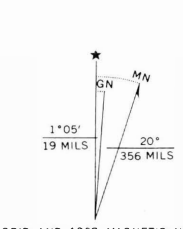
- Definite contact
- Approximate contact
- Inferred contact
- Concealed contact

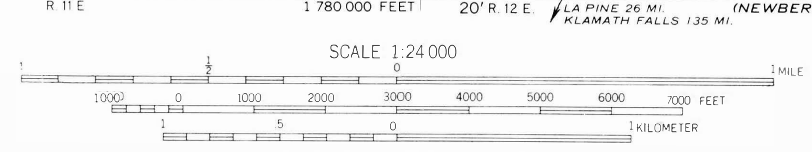
Faults

- Definite fault, ball on downthrown side
- Approximate fault
- Inferred fault
- Concealed fault

Base Map from U. S. G. S. 7 1/2' Shevlin Park, 1962 and Bend, 1962. Quadrangle Series (Topographic).

Cartography by S. R. Renoud and W. H. Pokorny

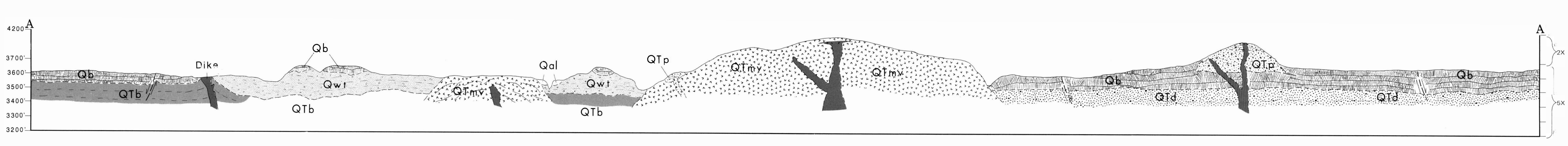




CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

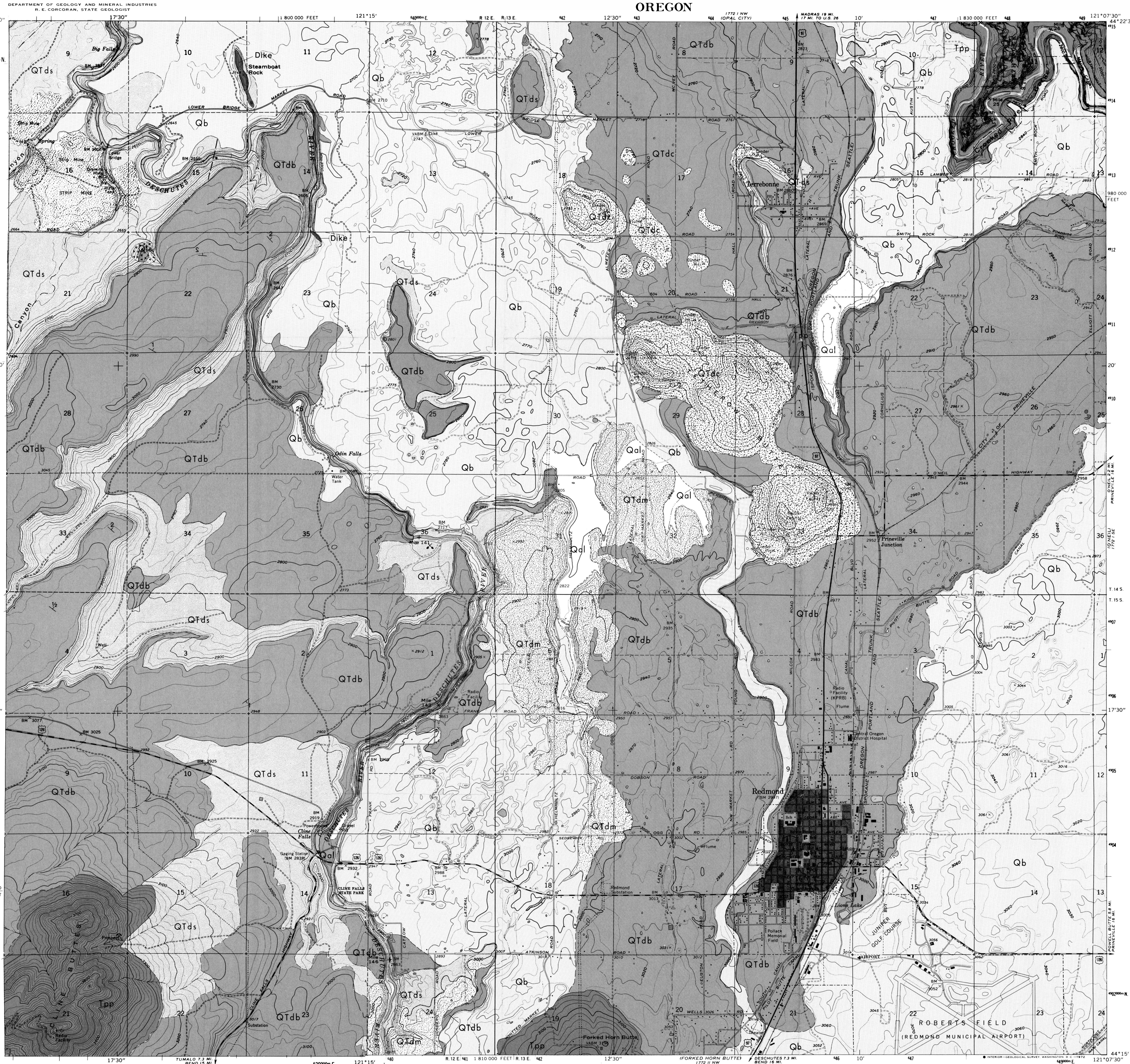
Geology by Norman V. Peterson and Edward A. Groh, 1974

Geologic Cross Section

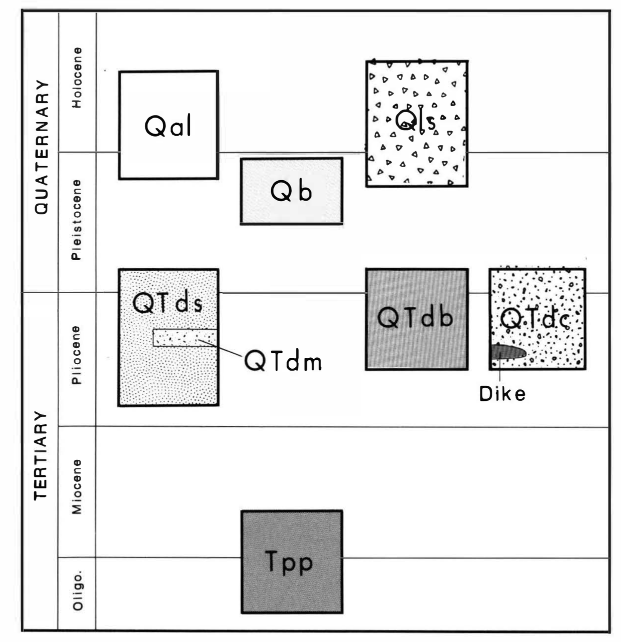


GEOLOGIC MAP *of the* REDMOND AREA OREGON

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST



STRATIGRAPHIC TIME CHART



EXPLANATION

Qal Alluvium

Unconsolidated fluvial deposits of silt, sand, and gravel along streams and valley bottoms.

Qls Landslide Deposits

Slumped blocks of sediments, tuffs, and basalts along canyon walls.

Qb Basalt Flows

Intracanyon and plateau-forming pahoehoe flows of medium gray diktytaxitic olivine basalt.

Unconformity

QTds Deschutes Formation

Volcanic sediments and ash flows. Fine vitric tuffs, cindery ash and lapillic tuffs, pumice lapilli tuffs, other air-fall tuffs, and volcanic breccia, interlayered with fluvial sands, conglomerates, and breccia, some eolian sand. Also included are at least three distinctive ash-flow tuffs that range from welded to non-welded.

QTdb Basalt Flows

Mainly plateau-forming and intracanyon flows with some thin flows interbedded with QTds. Color ranges from medium to dark gray and texture from platy dense to porphyritic and diktytaxitic varieties.

QTdm Mudflow Breccia

Non-sorted, non-stratified, angular debris, predominantly cobbles, boulders, and blocks of dark-gray to black vitrophyre with large detached blocks of stratified sediments and tuffs.

QTdc Dike — Cinder and Lava Mounds

Prominent cones and low elongate mounds of cinders, scoria, and associated basalt flows and probable vents for some of the QTdb flows. Also includes dikes of basalt andbasaltic andesite.

Tpp Pre-Pliocene Rocks

Includes rocks mapped as John Day Formation at Smith Rocks and Terrebonne; other siliceous intrusive-extrusive volcanic rocks at Cline Butte and Forked Horn Butte. Composition includes silicified air-fall tuffs, flow-banded rhyolite, perlite, and andesite vitrophyre.

GEOLOGIC SYMBOLS

Contact

- Definite contact
- Approximate contact
- Inferred contact
- Concealed contact

Fault

- Definite fault, ball on downthrown side
- Approximate fault
- Inferred fault
- Concealed fault

Strike and dip of beds

Base Map from U.S.G.S. 7 1/2' Quadrangle Series (Topographic) Maps: Redmond sheet, 1962 and Cline Falls sheet 1962.

Cartography by S. R. Renoud and W. H. Pokorny

1976

Geology modified from Donald Stensland 1974 by Norman V. Peterson and Edward A. Groh. 1975

MINERAL LOCATION MAP *of* DESCHUTES COUNTY

OREGON

Compiled by Norman V. Peterson 1974

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

LEGEND

- Rock Quarries
- Sand and Gravel Pits
- Pumice, Diatomite, Clay & others
- Cinder Pit

5 0 5 10 15 20 Statute Miles
5 0 5 10 15 20 25 30 Kilometers
5 0 5 10 15 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

1970 MAGNETIC DECLINATION FROM TRUE NORTH VARIES FROM 19° EASTERLY FOR SOUTHEAST TIP TO 20° EASTERLY TO NORTHWESTERN BOUNDARY OF COUNTY.

Base Map from Army Map Service 1:250,000 (Topographic) Map Sheets: Bend, 1964 and Crescent 1962.

Cartography by S. R. Renoud & C. A. Schumacher