Geology of Portland, Oregon and Adjacent Areas

By DONALD E. TRIMBLE

GEOLOGICAL SURVEY BULLETIN 1119

A study of Tertiary and Quaternary deposits, lateritic weathering profiles, and of Quaternary history of part of the Pacific Northwest

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GEOLOGY OF PORTLAND, OREGON, AND ADJACENT AREAS

By Donald E. Trimble

ABSTRACT

The geologic investigation and mapping of five 15-minute quadrangles embodying about 1,040 square miles within a radius of 25 miles of Portland, Oreg., are the basis for this report. The study has resulted in redefinition of the basic stratigraphy of the area, has yielded data on the nature of laterization and the time required for the formation of several profiles of weathering—including fully developed laterite—and has permitted a fuller understanding of late Quaternary history related to flooding of this area. A previously unknown laterite horizon was discovered during the geological investigation.

The rocks of the Portland area range in age from late Eocene to Recent. The Tertiary rocks comprise four formations of volcanic origin: the Skamania volcanic series, the Columbia River basalt, the Rhododendron formation, and the Boring lava (Tertiary and Quaternary); the Silver Star granodiorite; the marine Scappoose formation; and two sedimentary formations of terrestial origin, the Sandy River mudstone and the Troutdale formation.

The Scappoose formation, of late Oligocene and early Miocene age, is the marine sedimentary equivalent, in part, of the upper part of the Skamania volcanic series, the oldest rocks in the area. The Skamania was intruded by the Silver Star granodiorite before the Columbia River basalt was erupted in middle Miocene. The Rhododendron formation, consisting primarily of volcanic mudflow breccia in this area, was erupted in late Miocene onto a slightly warped surface of the Columbia River basalt on the west flank of the growing Cascade Range in Oregon. The surface of the Rhododendron formation was laterized.

The terrestrial sediments of the Sandy River mudstone and the Troutdale formation were deposited in early Pliocene in structural basins formed by the warping of the Columbia River basalt and the Rhododendron formation. The Boring lava was erupted discontinuously on a post-Troutdale erosional surface.

Late Tertiary and Quaternary deposits include several formations of similar physical character and origin, but distinguished by differences in relative topographic position and degree of weathering. These units are, from oldest to youngest: the Walters Hill, the Springwater, the Gresham, and the Estacada formations. These formations all consist of mudflow deposits and fluvially deposited bouldery cobble gravel. A loessial deposit, younger than Springwater but older than the Gresham, is distributed south and west of the valley of the lower Columbia River, and thins away from the valley.

Lacustrine deposits of late(?) Pleistocene age form an extensive fill in the valley of the lower Columbia River, the Willamette Valley, and the Tualatin Valley. These deposits were emplaced by flood waters of great volume that had their source in the sudden release of glacial Lake Missoula. The flood water was successively impounded behind several upstream channel constrictions and finally in the valley system of this area by hydraulic damming.

Recent downcutting has modified the terrain, and the deposits of this epoch, including terrace, landslide, and bog deposits, and alluvial deposits of the flood plains, are related to this downcutting in large part.

Weathering has produced several profiles of weathering of Quaternary age and two laterite profiles in this area. A low-silica laterite crust formed on the Columbia River basalt represents an end product of weathering lasting from Miocene time to the middle of the Pleistocene epoch. The high-silica laterite, formed on the Rhododendron formation and, locally, on the Columbia River basalt, was produced before the deposition of the early Pliocene terrestrial sediments now represented by the Sandy River mudstone and the Troutdale formation. All Quaternary time was insufficient to produce laterite, but the profile of weathering on the Quaternary deposits is deeper and the rocks are more severely altered with increasing age of the deposit. The younger deposits are but slightly weathered; the older Quaternary deposits are completely decomposed to a saprolite as much as 75 feet in depth.

These several profiles of Tertiary and Quaternary weathering and lateritic development probably represent successive stages in progressive weathering. Time was the only significant variable, and ultimate weathering produced a deep profile with a low-silica laterite crust.

The metallic resources of this area currently are of slight importance, but the value of sand and gravel, stone, and clay produced in this area accounted for nearly one-third of the State's mineral production in 1954.

Most construction problems in this area are related to the instability of deposits, such as loess and weathered material, when wet.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The area discussed in this report includes about 1,040 square miles in northwestern Oregon and southwestern Washington within a radius of 25 miles of Portland, Oreg. (fig. 1). Five of six 15-minute quadrangles bounded by parallels 45°15′ and 45°45′ north latitude and meridians 122°15′ and 123°00′ west longitude were mapped geologically. Recently published topographic maps of the 7½-minute quadrangle series also are available for most of the area (fig. 2).

PURPOSE AND SCOPE OF WORK

Portland is one of the major west-coast ports, although it is more than 100 miles up the Columbia River from the Pacific Ocean. The population of the urban area is more than half a million. Portland is primarily a marketing and trading center, but also has considerable industrial development in and adjacent to it.

The investigations were intended to provide basic geologic information broadly applicable to the construction industry for use in the investigation of foundation conditions and in the search for earth materials for construction. The data, however, are equally useful in the search for industrial minerals, in the development of ground-water resources, and in a great many other ways.

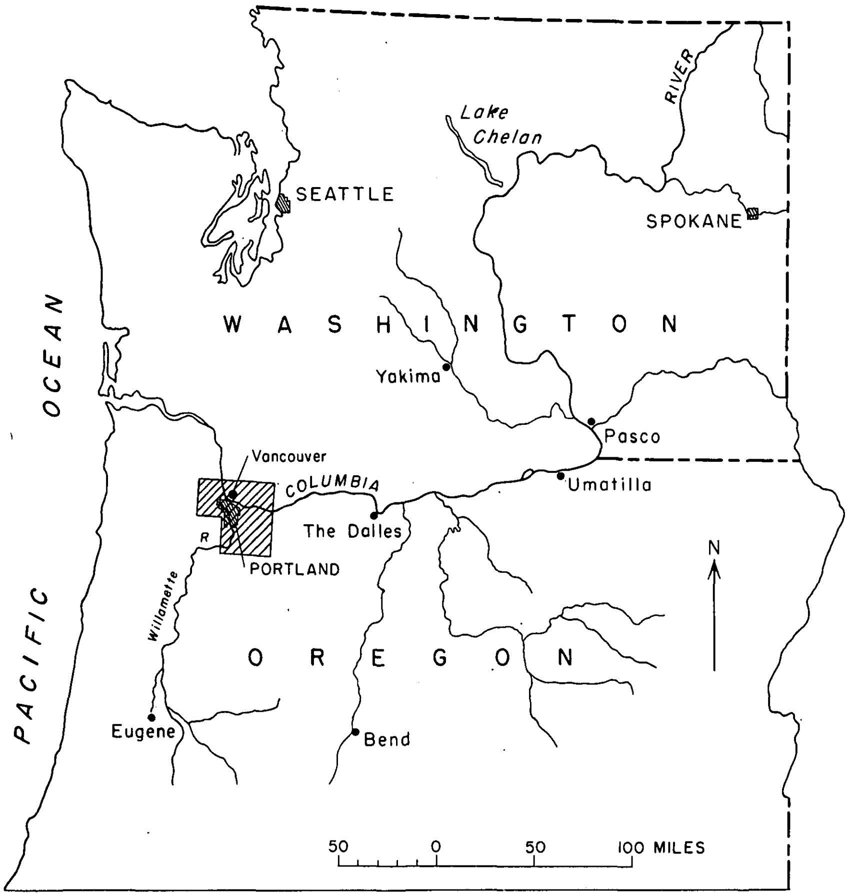

FIGURE 1.—Index map showing location of the area of this report.

PREVIOUS WORK

Many had visited the region and contributed to the geologic knowledge concerning it, but no detailed studies were undertaken prior to this investigation. Diller (1896) made an early geological reconnaissance of the region in the latter part of the 19th century, and revisited the area about 20 years later (1915). Darton (1909) discussed the structural materials (sand, gravel, and building stone) available in the Portland area. Washburne (1914) and Williams (1916) made limited observations on the geology of Portland and vicinity. Bretz (1925, 1928) and Allison (1932, 1935) discussed the origin of the unconsolidated deposits on the valley floors. Hodge (1938) named and described the Troutdale formation.

Few geologic maps have been published that cover any part of the present area of investigation. A map of structural materials by Darton (1909) includes part of the Portland quadrangle. A reconnaissance map by Treasher (1942b) is of the Oregon City and

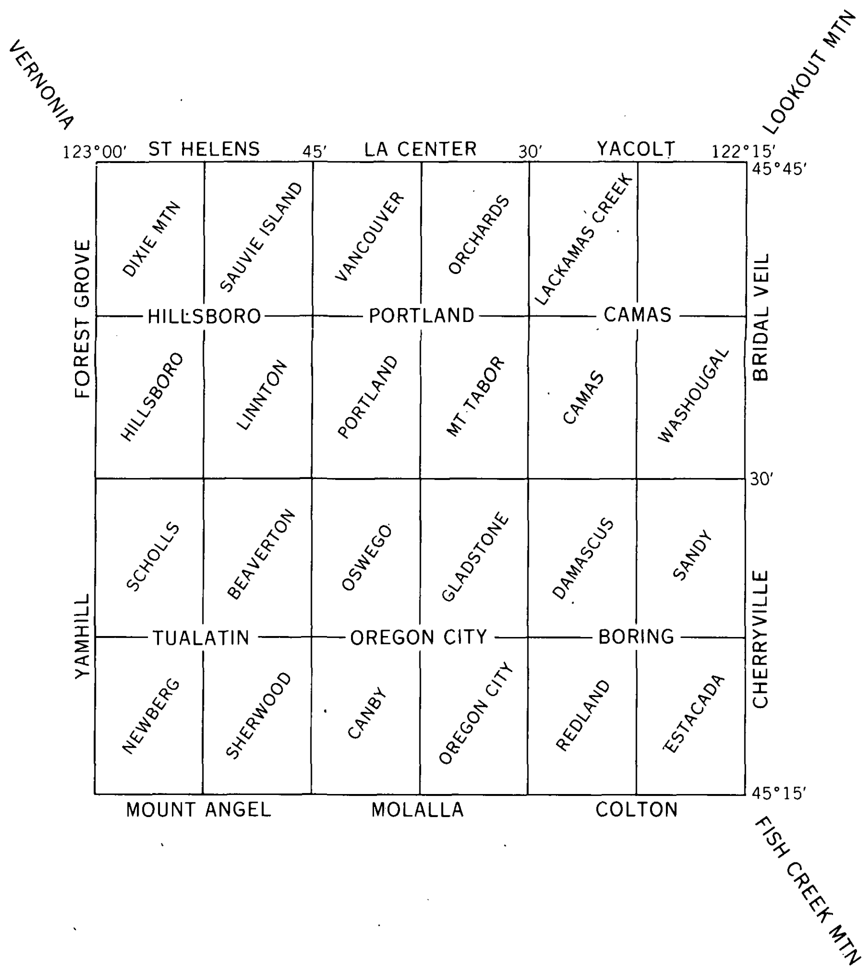

FIGURE 2.—Index to topographic maps for the area of this report.

Boring quadrangles and that part of the Portland and Camas quadrangles within the state of Oregon. A small-scale reconnaissance map by Warren, Norbisrath, and Grivetti, published in 1942, covers much of northwestern Oregon and includes the Hillsboro quadrangle. Several thesis studies were made in adjacent areas, but the only applicable published results are those of Felts (1939a) on the Silver Star stock in Washington.

FIELDWORK AND ACKNOWLEDGMENTS

The field investigations consisted of geologic mapping of the five 15-minute quadrangles at a scale of 1 inch equals 1 mile, and of related stratigraphic studies. Fieldwork was begun in the summer of 1948 and was continued seasonally each year through 1955, except for 1952.

The writer was assisted in the mapping in 1948 by L. M. Gard, Jr., and L. S. Rolnick, and in 1950 and for 6 weeks in 1951 by D. R. Mullineaux. Mullineaux also made most of the petrographic studies. D. R. Crandell and C. A. Kaye acted as field consultants in 1951 and 1953, respectively.

The paleontologic determinations were made by R. W. Brown, Ralph Stewart, and Ellen J. Trumbull. A pollen analysis of a peat sample was made by Estella B. Leopold. Clay minerals were determined by A. J. Gude, 3d, using X-ray diffraction methods. Laterite samples were analyzed chemically by Faye H. Neuerburg. Vug minerals in Boring lava were identified petrographically by E. J. Young, and the determinations were checked by R. P. Marquiss by X-ray diffraction methods.

The investigations benefited from the continued cooperation and interest of F. W. Libbey, former director, H. M. Dole, director, and the staff of the Oregon State Department of Geology and Mineral Industries. Much of the subsurface information came from well records supplied by this agency. Well drillers gave freely of their time and knowledge and provided records of many wells. Field conferences with R. C. Roberts of the Soil Conservation Service were most helpful in solving some of the problems related to weathering.

Useful information also was provided by the Washington State Highway Department, the Portland City Engineers Office, the Portland City Planning Commission, the Alcoa Mining Company (Hillsboro exploration office), and the Portland General Electric Company.

The writer acknowledges with gratitude the help rendered by all those listed above, which contributed materially to this investigation.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The topography of the Portland area is varied. The area spans parts of the lower Columbia River valley and Willamette Valley in the Puget Trough section of the Pacific Border province (Fenneman, 1931) and extends into the Oregon Coast Range section on the west and into the Middle Cascade Mountains section of the Sierra-Cascade province on the east.

The floors of the lower Columbia River valley and Willamette Valley are nearly flat to gently rolling terraced surfaces. Altitudes range from near sea level in the vicinity of Portland to nearly 400 feet on some of the higher terraces. The Willamette Valley is separated from the lower Columbia River valley, and segments of the Willamette Valley are separated from each other by hills, composed mainly of volcanic rocks, that are more than 1,000 feet high in places. The highest point in the area, which is in the Middle Cascade Mountains section in the extreme northeast corner of the Camas quadrangle, is more than 4,000 feet above sea level. The highest points in that part of the Oregon Coast Range section included in the map area are in the Tualatin Mountains near the western boundary of the area and are as much as 1,700 feet in altitude.

The Columbia River, the master stream, leaves its gorge near the east edge of the area, flows westward and is joined by the Willamette River near Portland. It then flows northward out of the map area.

The Willamette River, the major tributary of the Columbia River, flows northward through the area. Its tributaries, the Pudding and Molalla Rivers, join and flow into the Willamette River in the southern part of the area. The Tualatin River drains the Tualatin Valley and adjacent mountains and flows eastward into the Willamette River at Willamette, just southwest of Oregon City. Abernethy Creek joins the Willamette River at Oregon City, and the Clackamas River, a major tributary heading in the Cascade Mountains, flows into the Willamette River at Gladstone, a mile north of Oregon City.

Other tributaries of the Columbia River are the Sandy River and the Washougal River. The Sandy River, which has its source in the glaciers of Mount Hood, joins the Columbia at Troutdale, Oreg. The Washougal River, which heads in the Cascade Mountains in Washington, flows into the Columbia opposite the mouth of the Sandy River at Camas, Wash.

The only other drainage flowing into the Columbia River in the map area are small creeks including Salmon Creek, Burntbridge Creek, and South Scappoose Creek.

CLIMATE

The region has a moderate climate characterized by long frost-free growing seasons, moderately heavy rainfall, mild rainy winters, and warm to hot dry summers. More than 200 days in each year commonly are free of frost. Temperatures below zero and more than 100° F. have been recorded at nearly all stations. The record high in Portland is 107° F., but the average maximum temperature for July, the hottest month, is less than 80° F. The average minimum temperature for January is above freezing.

The average annual precipitation, which is mainly rainfall, is between 35 and 45 inches for most of the valleys. The average annual precipitation in Portland during the period 1871-1952 was 42.04 inches. The range of total annual precipitation, however, is considerable. A low of 26.11 inches was recorded in Portland in 1929 and a high of 67.24 inches was recorded in 1882 (fig. 3).

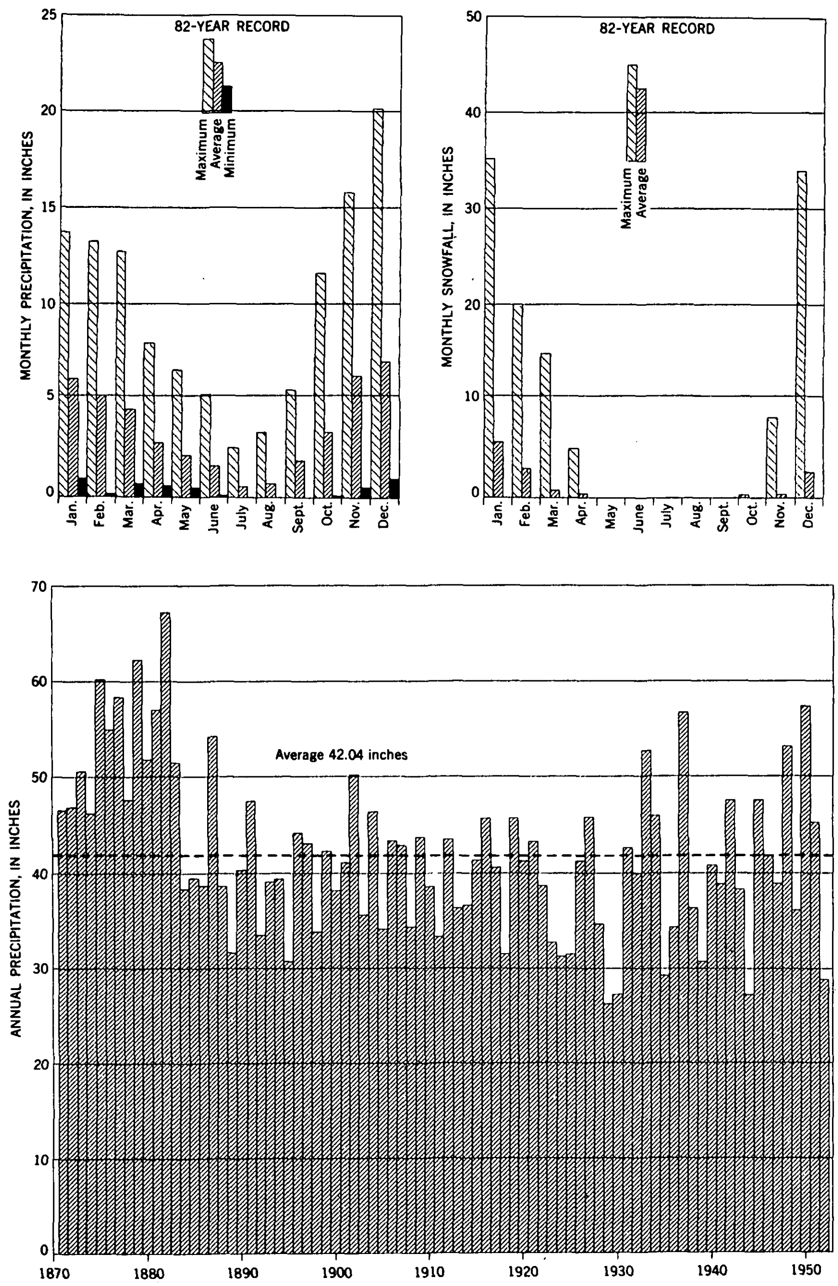

FIGURE 3.—Precipitation at Portland, 1871–1952 (from Griffin and others, 1956, p. 4).

More than three-fourths of the annual precipitation falls during the 6-month period from October through March. In the vicinity of Portland, July and August are the driest months, averaging less than 1 inch per month. November, December, and January are the wettest with more than 6 inches per month.

The prevailing winds are from the northwest in summer and from the south in winter, although east winds prevail at times in and near the mouth of the Columbia River gorge. Winds from the south attain the highest velocities but seldom reach destructive force.

VEGETATION

The moderately heavy rainfall and mild climate promote a lush vegetation that is a deterrent to fieldwork. Uncultivated cleared or burned-over land commonly supports abundant second-growth including gorse, huckleberry, nettles, poison-oak, salal, wild blackberry, many varieties of fern, and smaller fast-growing deciduous trees such as alder and vine maple. Devilsclub grows in some moist creek bottoms and swampy areas.

The main forest trees are Douglas-fir, western hemlock, western redcedar, Pacific dogwood, bigleaf maple, Oregon ash, red alder, cascara buckthorn, Pacific madrone, and Oregon white oak.

POPULATION

Portland is in an area of expanding population. Before World War II, the city had a population of 305,394 (1940 census) and the Portland urban area had a population of 422,000 (Head, 1955, p. 32). According to the 1950 census, Portland had a population of 373,628. At that time the urban area had a population of about 600,000, which was nearly 75 percent of the urban population of the State. Unofficial population figures for the year 1955 are 402,900 for the city and 666,300 for the Portland urban area (Head, 1955, p. 32).

The increase in the Portland urban-area population from 422,000 in 1940 to 600,000 in 1950 is emphasized by the spectacular growth of some of the cities and towns adjacent to Portland. Vancouver, Wash., with a population of 41,644 in 1950, more than doubled its population in the 10-year period, 1940–1950. Gladstone, Milwaukie, and Oswego, Oreg., more than doubled their population during the period 1940–1954.

Only 5 cities in the area have populations exceeding 5,000 and only 10 have more than 2,500. Portland and Vancouver are the largest, followed by Oregon City, Milwaukie, and Hillsboro in order of size. Camas, Oswego, Gladstone, Gresham, and West Linn have populations of between 2,500 and 5,000. Other towns in the area include Washougal, Wash., and Boring, Canby, Clackamas, Estacada, North Plains, Sandy, Troutdale, and Willamette, Oreg.

INDUSTRIES

Portland has been primarily a merchandising and trading center since its founding in 1845, but the area now also has many industries.

Industry, however, is not new to the region. Iron was mined near Oswego and smelted there during the period 1867–1894 (Hotz, 1953, p. 91) and the paper mill at Oregon City was begun in 1885. Now there are large paper mills at Camas, Wash., and at Oregon City and West Linn, Oreg. A cement manufacturing plant is located at Oswego, Oreg. Aluminum reduction plants are located at Vancouver, Wash., and at Troutdale, Oreg. There are large shipyards at Vancouver and at Portland, Oreg. The manufacture of industrial chemicals is important in Portland.

Most of the raw materials for these major industries are shipped into the area from distant sources. The paper industry is an exception, although it, too, utilizes large quantities of raw materials not available locally, such as sulfur and limestone. The availability of large quantities of relatively cheap power has promoted the development of many industries, and there is a market for locally derived industrial minerals.

In addition to these major industries, a variety of other items are manufactured. Food processing of local products is a leading industry, and logging is still an important factor in the economy.

SEDIMENTARY AND VOLCANIC ROCKS

GENERAL FEATURES

The sedimentary and volcanic rocks are discussed in stratigraphic sequence, because the volcanic rocks of this area are treated as stratigraphic units (fig. 4). They are of Tertiary and Quaternary age.

The Tertiary rocks are mainly volcanic, but terrestrial sedimentary deposits that represent basin fill are abundant. Marine sediments underlie flood basalt in the western part of the area and are exposed in the northwest part of the area. The volcanic rocks include (1) a lower Tertiary highland mass of altered and folded basic lava rocks, the Skamania volcanic series; (2) widespread thick flood basalt, the Columbia River basalt; (3) volcanic mudflow deposits and lava flows emanating from the early Cascade Mountains, the Rhododendron formation; (4) and the rocks of small volcanoes and lava plains of local extent, the Boring lava. The terrestrial sedimentary rocks (Rhododendron? formation, Sandy River mudstone, and Troutdale formation) include deposits of both fluvial and lacustrine origin. Much of the material incorporated in the deposits

SYSTEM	SERIES		MAP UNIT	THICKNESS (FEET)	LITHOLOGY
QUATERNARY	Recent		Alluvium	0–50	Sand, silt, and gravel
			Bog deposits	0–10	Silt, clayey, contains a large percentage of organic material.
			Landslide deposits	— — —	Debris from adjoining formations.
	Pleistocene	Upper	Terrace deposits	0–50	Sand, silt, and gravel
			Sand and silt deposits	0–100	Sand and silt
			Lacustrine deposits	0–150	Gravel, sand, and very fine sand, silt, and clay; laterally gradational.
			Estacada formation	30–100	Cobble gravel and bouldery-cobble gravel with minor amounts of mudflow deposits.
		Middle	Gresham formation	100–150	Cobble gravel, bouldery, and mudflow deposits.
			Loess	0–100	Silt, yellowish-brown, clayey
		Lower	Springwater formation	0–225	Cobble gravel, bouldery, and mudflow deposits.
			Walters Hill formation	0–400	Conglomerate and sandstone with minor amounts of mudflow deposits.
TERTIARY	Pliocene		Boring lava	100–200	Olivine basalt, light-gray, open-textured.
			Troutdale formation	0–900	Quartzite-bearing conglomerate and vitric sandstone; lenticular bedding.
			Sandy River mudstone	9–725	Mudstone, siltstone, and claystone; even-bedded.
	Miocene	Upper	Rhododendron formation	600+	Hypersthene andesite volcanic mudflow deposits and lava flows.
			Possible equivalent of Rhododendron formation	200+	Conglomerate, sandstone, and tuffaceous siltstone.
		Middle	Columbia River basalt	0–1000±	Basalt, low in olivine
		Lower	Scappoose formation	1500	Shale, tuffaceous, marine, and sandstone, minor amounts of conglomerate.
	Oligocene		Skamania volcanic series	— — —	Basalt and basaltic andesite flows, minor amounts of pyroclastic material; extensive alteration.
	Eocene	Upper	Silver Star granodiorite		

FIGURE 4.—Stratigraphic chart.

is of volcanic origin, but a considerable part of the Troutdale formation is metasedimentary and was derived from a remote source. The lower Tertiary volcanic rocks have been intruded by a granodiorite stock, the Silver Star granodiorite.

The Quaternary formations are mainly unconsolidated fluvial and lacustrine deposits of Pleistocene age. They represent multiple stages of alluviation and an episode of spectacular flooding.

Recent deposits include landslide products, bog deposits, terrace deposits, and flood-plain deposits.

TERTIARY SYSTEM

EOCENE TO MIOCENE(?)

SKAMANIA VOLCANIC SERIES

The oldest rocks in the area are altered basalt and basaltic andesite flows and associated pyroclastic rocks that are exposed extensively in the Cascade Mountains in Washington. These rocks have been called Skamania series, Skamania andesites, and Skamania andesitic series by Felts (1939a, 1939b) because of their distribution in Skamania County, Wash. Felts' terminology is retained here with some modification.

The Skamania volcanic series is exposed mainly in the mountainous area in the northeast corner of the map area and along the Washougal River. The formation underlies Woodburn Hill, north of Washougal, and is exposed northwestward along the north side of Lackamas Lake. Altered flows and breccias of the Skamania volcanic series are exposed in western Camas and along the south side of Prune Hill. The formation also underlies the Troutdale formation on Prune Hill and has been penetrated by well borings. Skamania rocks are also exposed on Lady Island, in the Columbia River south of Camas. Stratified tuffs and volcanic breccias of the Skamania series are exposed along Highway 830 at the western city limits of Camas. Similar pyroclastic rocks are also exposed on a spur south of the Washougal River, at an altitude of about 500 feet in the SE¼ sec. 28, T. 2 N., R. 4 E., and at about 2,300 feet in the drainage basin of Jones Creek, a tributary of the Little Washougal River.

Amygdaloidal Skamania lavas containing amygdules of calcite and zeolite minerals are known at many localities. Zeolitic lava is well exposed along the highway on the north side of Lackamas Lake, on the south side of Livingston Mountain just west of the road junction at BM 1392, north of Livingston Mountain, in the beds of Lackamas Creek and the Washougal River, along the road east of the Camp Bonneville military reservation, along the Forest Service road above the headwaters of Cedar Creek, and in other places. Zeolitic lavas at Rock Island, in the Willamette River about 3 miles southwest of Oregon City, are included with the Skamania volcanic series although direct correlation is not possible at this time.

The thickness of the formation in this area can not be measured directly, but it probably is many thousand feet.

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Felts (1939a, 1939b) described the lower two-thirds of the series in Skamania County as andesitic flow rocks that have been propylitized and folded, and the upper third as nearly horizontal andesitic flow rocks.

The Skamania volcanic series in the Portland area also appears to be divisible into a lower altered and deformed sequence and an upper generally unaltered and undeformed sequence of mafic volcanic rocks, similar to the sequence to the east described by Felts. The contact between the upper and lower parts is so poorly exposed that it was not practical to map the units separately. The rocks in the area of this report, however, are mostly basalt and basaltic andesite with lesser amounts of andesite and dacite. Regional jointing is common and many of the joints are mineralized by quartz, zeolite, calcite, opal, hornblende, epidote, or chlorite.

The lower part of the formation contains all the pyroclastic rocks noted in the unit although flow rocks constitute most of the strata. The pyroclastic rocks include both tuffs and breccias. The lower part has been extensively propylitized and commonly the rocks have a drab, greenish appearance. Locally, near the contact with an intrusive body, they are a dense black hornfels. The rocks have been folded, and locally dips as high as 37° were measured. Too few dips were obtained, however, to give more than a general impression of southeastward-dipping beds.

The rocks of the lower part of the Skamania volcanic series are porphyritic to nonporphyritic with an intergranular, hyalopilitic, or trachytic groundmass. Most feldspars, both in phenocrysts and in the groundmass, are labradorite, and most are not zoned. Zoned feldspars commonly have labradorite cores and more sodic outer zones. The groundmass feldspar in rocks containing zoned feldspar is most commonly andesine. Magnetite commonly composes as much as 10 percent of the groundmass and locally exceeds 20 percent. It is present in nearly everything except the feldspar. Olivine is a rare constituent.

The rocks have been altered extensively. The feldspars have been altered largely to heulandite, and the clinopyroxene and glass have been altered to chlorite and chlorophaeite. Epidote locally has replaced feldspar but is not abundant.

The upper part of the formation is exposed in the map area only on the higher ridge crests south of Larch Mountain and on Sturgeon Rock near the extreme northeast corner of the map area. The rocks are nearly horizontal porphyritic mafic flows. At Sturgeon Rock columnar jointing is well developed. Propylitization of the upper part of the series is incipient as compared with the rocks of the lower part.

A single sample of the upper unit that was studied is a porphyritic basalt with a pilotaxitic groundmass. The phenocrysts are mainly labradorite crystals as much as 2.5 mm long. Plagioclase, hornblende(?), and magnetite compose the groundmass of the rock. Magnetite constitutes about 20 percent of the groundmass. The amphibole (hornblende?) is probably an alteration product of a pyroxene. The plagioclase is unaltered.

The rocks that have been converted to hornfels have been extensively silicified. Some plagioclase has been replaced by epidote. The alteration is characterized by the introduction of large amounts of silica, in the form of anhedral quartz, and considerable amounts of pyrite. The feldspars have been recrystallized and the rocks may have been feldspathized, in part. Similar hornfelsed rocks adjacent to intrusive bodies in the Cascade Range of Oregon have been described by Buddington and Callaghan (1936, p. 447), who termed them "siliceous hornfels."

Roof pendants within the Silver Star stock at two localities on the top of Larch Mountain are of basic volcanic rocks that have been silicified, chloritized, and feldspathized. The original nature of the rock has been largely obliterated in much of the material, although some relict textures are retained.

The Skamania volcanic series intrudes and nonconformably overlies indurated tuffaceous sediments of unknown age in the headwaters of Dougan Creek in the Bridal Veil quadrangle to the east. The oldest formation known to overlie the Skamania volcanic series in the map area is the lower Pliocene Troutdale formation.

The age of the Skamania volcanic series has not been determined precisely but several lines of evidence, both direct and indirect, suggest that it is late Eocene to early Miocene(?), but mainly Oligocene in age. The lack of alteration, jointing, and vein filling in the Columbia River basalt suggests that at least the lower part of the Skamania volcanic series was intruded by the Silver Star granodiorite prior to the extrusion of the Columbia River basalt in middle Miocene time. Rocks believed to be part of the Skamania volcanic series contain upper Eocene flora at a locality on the north bank of the East Fork of the Lewis River just west of the bridge at Heisson about 6½ miles north of Hockinson (R. W. Brown, oral communication). A floral assemblage from a locality on the east bank of the West Fork of the Washougal River a short distance north of the bridge on State Highway 8B was of probable Oligocene age (R. W. Brown, oral communication). The differences in alteration and amount of deformation between the lower and upper parts suggest an age difference. The upper part may be as young as early Miocene age.

Felts (1939a, 1939b) tentatively correlated these rocks with the Keechelus andesitic series, which was named by Smith and Calkins (1906) for an area in the Snoqualmie, Wash., 30-minute quadrangle, about 100 miles north of Portland. The Keechelus andesitic series is widespread in the region around Mount Rainier and first was reported to be of Miocene or younger age (Smith and Calkins, 1906). (See figure 5). Smith and Calkins suggested the possibility of subdividing the series into an upper and lower Keechelus, but they did not map the two units separately. Coombs (1936) described similar rocks in Mount Rainier National Park where they form the platform for Mount Rainier. Warren (1936) established that the Keechelus andesitic series was older than the middle Miocene Yakima basalt (Columbia River basalt of this paper) and younger than the Eocene Guye formation, and suggested that the Keechelus might be as old as middle or late Eocene, in part. Warren (1936, 1941) also described the two-fold nature of the Keechelus and applied the name Fifes Peak andesite to the upper part (1941), but was unable to map the units separately. An oreodont skull found in tuffaceous sediments in the Keechelus series dates it as Oligocene, at least in part (Grant, 1941). Fisher (1954) indicated that the Keechelus is interbedded with the upper part of the Puget group of probable late Eocene age. Abbott (1955) mapped the Keechelus series and the Fifes Peak andesite separately. He, too, noted intertonguing with the Puget group, but referred the Keechelus mainly to the Oligocene and the Fifes Peak andesite to the Miocene (pre-Columbia River basalt).

The Skamania volcanic series described in this paper may correlate with both the Keechelus series and the Fifes Peak andesite of Warren and Abbott as the similarity of rock sequence and stratigraphic position make Felts' correlation seem most probable.

The Goble volcanic series of probable late Eocene and perhaps, in part, early Oligocene age (Warren and others, 1945; Wilkinson and others, 1946) may correlate with part of the lower Skamania volcanic series. The stratigraphic limitations of the Hatchet Mountain formation of the Toutle River area (Roberts, 1958, p. 21) are similar to those of the Goble volcanic series.

OLIGOCENE AND MIOCENE SERIES

SCAPPOOSE FORMATION

The only marine beds exposed in the map area are the tuffaceous shale, sandstone, and conglomerate beds of the Scappoose formation. These rocks are probably the marine equivalent of part of the Skamania volcanic series.

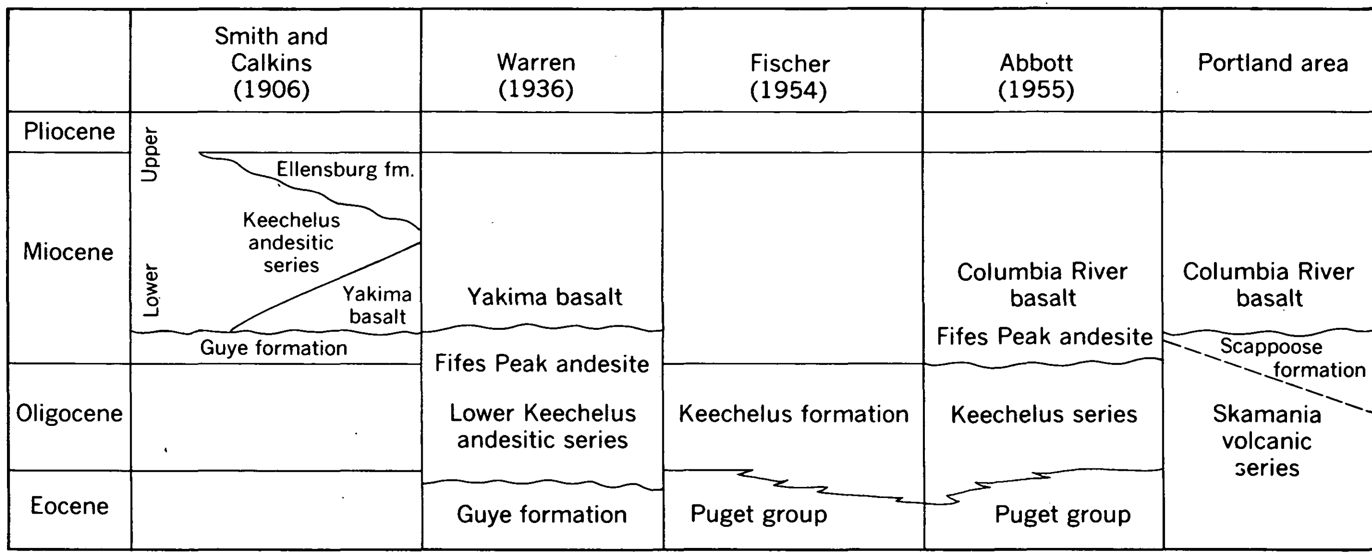

FIGURE 5.—Development of the present concept of the stratigraphic relations of the Keechelus andesitic series, and a tentative correlation with the lower Tertiary rocks of the Portland area.

The name Scappoose formation was applied to these rocks by Warren and Norbisrath (1946, p. 231). Exposures in the valley of South Scappoose Creek and along Rocky Point road a few miles east and southeast of the town of Scappoose are mentioned by Warren and Norbisrath as typical of the Scappoose formation. Both localities cited are within the area of this report. All exposures of the Scappoose in the report area are in the northwest quarter of the Hillsboro 15-minute quadrangle (Dixie Mountain, Oreg., 7½-minute quadrangle). The largest area of exposure is along South Scappoose Creek and its tributaries. Another large area of exposure is on the east side of the Tualatin Mountains, in the north-central part of T. 2 N., R. 1 W., between Rocky Point road and Logie Trail and west of U.S. Highway 30. Other exposures of the Scappoose in the mapped area are along the valley of McKay Creek, and the formation is exposed extensively west and north of this area.

The Scappoose is overlain by the Columbia River basalt. Most outcrops of Scappoose are actually parts of a landslide complex, and therefore are not in place. The topography of the exposed Scappoose is characterized by multiple scarps and the steplike levels that are the tops of landslide unit blocks.

This investigation yielded no data on thickness of the Scappoose formation, but Warren and Norbisrath (1946, p. 232) reported an approximate thickness of 1,500 feet in the Buxton-Manning area, less than 10 miles west of the Portland area. The log of an oil well drilled in the Tualatin Mountains in the NW¼SE¼ sec. 23, T. 1 N., R. 1 W., indicates about 1,200 feet of fossiliferous sedimentary rock below Columbia River basalt.

The formation is composed primarily of fossiliferous tuffaceous shale and sandstone, but locally contains a few conglomeratic lenses of granule and pea-size gravel. Locally basalt flows appear to be interbedded with the sedimentary rocks. Most exposures, are of the yellowish-gray clayey weathered shale and sandstone. The formation has been deeply weathered. Moderately weathered or fresh rock rarely is exposed, but is light olive-gray or moderate brown and is well indurated. The beds locally contain carbonized or silicified wood fragments. Because of the deep weathering, fossil shells are preserved mostly as fragile casts. Most of the rocks are poorly bedded and no doubt weathering has destroyed some of the structural features. The few measurements of dip were considered meaningless because of the disorientation of nearly all the exposed marine sediments owing to landsliding.

Almost all the beds are tuffaceous. Feldspar, quartz, and mica are the predominant mineral constituents, and glass shards are numerous. Locally authigenic pyrite dendrites are conspicuous microscopic constituents. Shale and shaly sandstone beds compose the bulk of the formation, and the sandstone beds are fine- and medium-grained. Pebbles of the conglomeratic beds are mostly rounded chert, quartz, and basic volcanic rock. Nearly all fragments smaller than pebble size are angular crystals, fragments of crystals, or glass shards.

The tuffaceous character of the formation probably is responsible for its marked susceptibility to alteration and weathering. Most exposures are moderately soft and greasy when dry, and slippery when wet because of the clay minerals. The clay mineral of the normal weathered shale and sandstone is montmorillonite. Fine tuffaceous material along Dixie Mountain road, in the SW¼SW¼ sec. 19, T. 2 N., R. 2 W., has been altered to bentonite that swells to twice its initial volume when wet.

The base of the Scappoose formation has not been recognized in this area. The Scappoose formation overlies the Pittsburg Bluff formation about 10 miles west of the map area. According to Warren and Norbisrath (1946, p. 232), "The Scappoose formation seems to rest disconformably on the underlying Pittsburg Bluff formation and is separated from it by a conglomerate of variable thickness." The Scappoose formation is overlain by the Columbia River basalt and the writer agrees with Warren and Norbisrath (1946, p. 234) that the Columbia River basalt rests unconformably on a strongly eroded surface of the Scappoose formation.

Fossils are distributed generally throughout the formation but are chiefly fragile casts that are difficult to collect and identify. Collections of well-preserved fossil mollusks were made, however, in the Jackson Creek drainage basin and in a small tributary of McKay Creek.

The McKay Creek locality yielded well-preserved fossils from a 2-foot layer of pea gravel interbedded with weathered tuffaceous sandstone on the north side of a small tributary. The exposure is about 15 feet above the floor of the canyon and about 200 yards west of an unimproved road in the SE¼NE¼ sec. 13, T. 2 N., R. 3 W. (U.S.G.S. Cenozoic locality 19864). Ellen J. Trumbull of the U.S. Geological Survey reports the following fauna, which is probably late Oligocene or early Miocene:

Gastropods:
- *Cryptonatica* sp.
- *Crepidula* sp.

Bruclarkia? sp. cf. *B. acuminata* (Anderson & Martin)
Unidentified turrid
Unidentified scaphandrid

Scaphopod:
Dentalium sp.

Pelecypods:
Acila (*Truncacila*) sp. cf. *A.* (*T.*) *muta* (Clark)
Unidentified nuculanid?
Mytilus sp. cf. *M. mathewsoni* Gabb
Unidentified lucinid?
Diplodonta? sp. cf. *D.*? *parilis* (Conrad)
Tellina sp. cf. *T. oregonensis* Conrad
Spisula ramonensis Packard, subsp. cf. *S. ramonensis attenuata* Clark
Unidentified cardiid
Panope cp. cf. *P. ramonensis* Clark

Barnacle: Unidentified fragments

Seven mollusks not well enough preserved to be specifically identified are compared with species that have all been reported from the Scappoose formation by Warren and Norbisrath (1946, p. 232, 233).

The Jackson Creek locality, at an altitude of about 400 feet in the SE¼SE¼ sec. 22, T. 3 N., R. 2 W., yielded fossil remains from sandstone in a sandstone and shale section. The collection contained about 220 specimens, most of them fragmentary or poorly preserved. They were examined by Ralph Stewart and Ellen J. Trumbull of the U.S. Geological Survey, who identified the following eight forms of probable early Miocene age:

Pelecypods:
Gari sp.
Spisula ramonensis Packard, subsp. cf. *S. ramonensis* attenuata Clark
Yoldia sp. aff. *Y. oregona* (Shumard)

Gastropods:
Aulacofusus? sp.
Bruclarkia sp. cf. *B. gravida* (Gabb)
Neverita sp. cf. *N. recluziana* (Deshayes)
Polinices sp. cf. *P. galianoi* Dall
Whitneyella? sp.

Two pelecypods not well enough preserved to be specifically identified are compared with species reported from the Scappoose by Warren and Norbisrath (1946, p. 232, 233); none of the gastropods were reported by them, but they list only two. The *Spisula* is the only form also identified in the McKay Creek fauna, but according to Ellen J. Trumbull (written communication, 1959) the two faunas are probably contemporaneous.

The age of the Scappoose formation appears to be late Oligocene and early Miocene. The Scappoose fauna has been correlated with the fauna of the Sooke formation of Vancouver Island (Warren and Norbisrath, 1946, p. 233). The Scappoose probably may be correlated with the Yaquina sandstone of the Oregon coastal area, which has also been correlated with the Sooke (Vokes, Norbisrath, and Snavely, 1949).

Much of the material composing the Scappoose formation appears to be water-deposited volcanic ash. The contemporaneity of Skamania volcanism, in part, suggests the adjacent eastern area of distribution of the Skamania volcanic series as the source of volcanic material in the Scappoose formation. The scarcity of pyroclastic debris in the Skamania, however, makes this conclusion questionable.

MIOCENE SERIES

COLUMBIA RIVER BASALT

Overlying the Scappoose formation are the lava flows of the Columbia River basalt. The Columbia River basalt in this region is part of the vast flood of middle Tertiary basalt that extends from Idaho to the Pacific Ocean and covers wide areas in southeastern Washington and northeastern Oregon.

The Columbia River basalt is widely distributed west of the Willamette and Columbia Rivers. It underlies much of the Tualatin Mountains, and also Palatine Hill, the Rosemont area, and Petes Mountain to the south. It occurs up to an altitude of about 1,700 feet. East of the Willamette River the formation is exposed principally between Milwaukie and Gladstone, in the Willamette River gorge between Canby and Oregon City, and along the south side of the Columbia River from the east edge of the mapped area to just west of Corbett. Columbia River basalt also crops out in a small area on the east bank of the Sandy River in the SW¼ sec. 11, T. 1 S., R. 4 E. The basalt underlies the sediments of the intervening lowland areas and has been penetrated in many places by wells drilled for water. A map prepared by D. H. Hart and R. C. Newcomb (1956), showing altitudes on the upper surface of the Columbia River basalt beneath the Tualatin Valley, indicates that the basalt underlies the entire valley in a closed basin, whose center is at Hillsboro.

The basalt is best exposed in hilly or mountainous areas where it has not been buried by later sediments. It is hard and resistant, and forms prominent ridges into which steep-walled canyons have been cut. Where erosion has exposed the underlying marine sediments of the Scappoose formation, the basalt has failed in great landslides.

The Columbia River basalt rests on an eroded surface of considerable relief, but locally in this area, at least, it had an original thickness of as much as 1,000 feet. An oil well drilled by The Texas Co. in the NE¼SE¼ sec. 25, T. 1 S., R. 2 W., on the top of Cooper Mountain, penetrated approximately 1,000 feet of Columbia River basalt (Griffin and others, 1956, p. 28). This well is only 3 miles south of the southern edge of the Hillsboro quadrangle. Two wells drilled in the west half of the SW¼ sec. 23, T. 1 N., R. 1 W., penetrated between 700 and 800 feet of Columbia River basalt. The formation just north of the Hillsboro quadrangle is about 700 feet thick (Wilkinson and others, 1946, p. 19). In the upper Nehalem River basin northwest of the Hillsboro quadrangle, it is at least 500 feet thick (Warren and Norbisrath, 1946, p. 234). Locally, however, much or all of the Columbia River basalt has been removed by erosion. About 20 miles east of the map area, in the Columbia River gorge between Eagle Creek and Herman Creek, the basalt is about 2,500 feet thick (Williams, 1916, p. 86).

The Columbia River basalt consists of a pile of basaltic lava flows of varying thickness. Complete vertical sections of flows are rare, and at only a few places are both top and bottom exposed. The few flows that could be measured are about 50 feet thick and have pahoehoe crusts. The thickness is in accord with that of 46 feet shown for flow 2, the thickest flow shown in graphic logs of typical drill holes of a limonite property northwest of Scappoose and about 2 miles north of the map area (Hotz, 1953, p. 80). Pillow lava crops out at an altitude of about 425 feet near Rooster Rock in SE¼ sec. 25, T. 1 N., R. 4 E.

Interbasalt sediments or pyroclastic rocks are scarce in the map area but have been reported nearby (Wilkinson and others, 1946, p. 20; Warren and Norbisrath, 1946, p. 233). Palagonitized stratified lapilli tuff or tuff breccia is part of the Columbia River basalt section outside the report area at the base of Crown Point, just east of Rooster Rock at the eastern edge of the Camas quadrangle. Similar material has been seen only at Rooster Rock, above the saddle on the East Rock in the area of this report but occurs at the base of the Columbia River basalt at several localities in the Columbia River gorge.

The only other sediments known in the Columbia River basalt of this area are the interbasalt limonitic deposits and associated sedimentary rocks near Oswego Lake, which were mined for iron from 1867 to 1894 (Hotz, 1953, p. 91). The mine workings are no longer accessible. These deposits were described by Diller (1896, p. 508–511) who reported logs, as much as 6 feet in diameter, in the upper part of the ore beds and in "sandrock" immediately overlying the ore beds. Similar deposits northwest of Scappoose, Oreg., and a few miles north of the map area have been described by Hotz (1953), Wilkinson, Lowry, and Baldwin (1946, p. 20–23), and Williams and Park (1923). The Columbia River basalt has been broadly folded, and dips as high as 15° have been measured on the east side of the Tualatin Mountains.

The unweathered basalt flows are black to dark-gray fine-grained rocks that commonly are vesicular to scoriaceous in their upper parts. Weathering of the basalt has been extensive and deep. Unweathered rock is exposed only where steep-walled canyons have been incised into the basalt. The basalt exposures mostly are lighter gray to brownish tones because of partial to complete weathering of the rock. The rock has been altered locally to a depth of about 170 feet (Allen, V. T., 1948, p. 61). Most of the residual product of weathering is saprolite,[1] in which the relict textures, structures, and mineral outlines are discernible.

The unaltered basalt has a low content of olivine and ranges in texture from subophitic or hyalo-ophitic to intergranular or intersertal. Locally the basalt is porphyritic with phenocrysts of labradorite. Augite composes 30 to 40 percent of the groundmass. The remainder is mainly labradorite in euhedral to subhedral laths and brown to black turbid glass that contains many crystallites of magnetite. The groundmass commonly contains a small percentage of olivine.

Alteration of the basalt by weathering results in nearly complete decomposition, mostly to the clay mineral halloysite. Magnetite appears to be the only basaltic mineral that survives prolonged deep weathering. The glass and the labradorite are more rapidly altered than the pyroxene. The Columbia River basalt in this region has been decomposed to great depths by weathering, which has produced a laterite crust that is preserved locally (p. 86).

The Columbia River basalt unconformably overlies the Scappoose formation of late Oligocene and early Miocene age. This unconformity is an eroded surface of considerable relief, and regional

[1] Becker (1895, p. 289) introduced the term "saprolite" as a general term for thoroughly decomposed, earthy, but untransported rock.

relationships suggest that it is a nonconformity. In the Columbia River gorge to the east the basalt overlies the Eagle Creek formation, considered to be of early Miocene age by Chaney (1944, p. 12, 354). To the south the basalt is underlain by the Molalla formatoin of Lowry and Baldwin (1952) of early or middle Miocene age (Dallas L. Peck, U.S.G.S., written communication). Closely adjacent to the mapped area the Columbia River basalt is overlain unconformably by the Rhododendron formation of late Miocene age. The Columbia River basalt, in the Portland area, by these stratigraphic relations, is restricted in age to the Miocene. Weaver (1937, p. 171) states that lavas similar to Columbia River basalt, on the Washington side of the Columbia River northwest of this area, contain intercalated marine sandstone with fossils of Astoria formation of middle Miocene age. No fossils have been found in the Columbia River basalt during this investigation.

RHODODENDRON FORMATION

The volcanic mudflow deposits and lava flows of the Rhododendron formation in the southeast corner of the area are marginal rocks of the unit, which is one of the most widely exposed formations on the west flank of the Cascade Mountains north of the McKenzie River (Dallas Peck, U.S. Geol. Survey, written communication).

The first published usage of the term Rhododendron formation was by Hodge (1933, p. 157), who applied it to pyroclastic rocks that buried the Columbia River basalt surface in the Cascade Mountains and that were assigned an age of late Pliocene or early Pleistocene. Barnes and Butler (1930, unpublished thesis, The structure and stratigraphy of the Columbia River gorge and Cascade Mountains in the vicinity of Mount Hood: Oregon Univ.) gave what is perhaps the best early definition of the formation. They described it as consisting of conglomerate and agglomerate with some interbedded andesite flows, overlying the Columbia River basalt and underlying younger volcanic rocks of the Cascade Mountains. The type locality given by Barnes and Butler is Zigzag Mountain at Rhododendron, Oreg., near Mount Hood. They said that the formation was in contact with Columbia River basalt along Alder Creek and North Side Boulder Creek, tributaries of the Sandy River, and that the basalt was exposed near the mouths of these creeks. According to Allen (1932, unpublished thesis, Contributions to the structure, stratigraphy, and paleontology of the lower Columbia River gorge: Oregon Univ.) the westernmost exposure of the Rhododendron formation is in the bed of the Sandy River just below the junction of the Bull Run River. He also says that the formation extends up the Bull Run River for several miles on the south side of the river but is absent on the north side from a mile or so above the town of Bull Run to the junction of the North Fork of the Bull Run River, where it crops out at 1,100 feet to 1,600 feet in altitude, overlying Columbia River basalt. Allen further stated that the Rhododendron is older than Troutdale because agglomerate of the Rhododendron is overlain by Troutdale formation near the mouth of the Bull Run River.

The stratigraphic relations and general age assignment of the formation described by Barnes and Butler and by Allen have been verified by field studies for this report. The rocks here mapped as the Rhododendron formation have been assigned previously to the Boring lava by Treasher (1942b, 1942a, p. 10), and to the Molalla formation by Nichols (1944) and by Lowry and Baldwin (1952, p. 13). The same rocks were considered the equivalent of the Troutdale formation by Wilkinson, Lowry, and Baldwin (1946, p. 29) and by Lowry and Baldwin (1952, p. 13, 14, 15). Harper, on the other hand, referred to them as Pleistocene till (Nichols, 1944). Later Hodge (1942, p. 23) considered the Rhododendron formation to be equivalent to all, or part of the Dalles formation, which he considered to be of Pliocene or possibly earliest Pleistocene age. Hodge (1938, p. 860, 869, 878–879) also included volcanic rocks of the Boring lava in the Rhododendron formation.

The Rhododendron formation in the Portland area is exposed only in the valleys of Eagle Creek and the Clackamas River, and in one small area in the valley of Clear Creek. These localities are all in the southeastern part of the map area. The formation is exposed widely in the Cascade Mountains to the east, however, and crops out in the valleys of the Bull Run River, the Little Sandy River, and the Sandy River within 1 or 2 miles of the map boundary on the east. It also crops out in the valleys of Clear Creek, Mill Creek, and the Molalla River in adjoining areas to the south.

The formation along this northwestern marginal belt is estimated to be about 600 feet thick, but it thickens abruptly to the east.

The formation in this area is composed entirely of volcanic mudflow breccia along its margin. Lava flows are absent in the westernmost 1 or 2 miles of this marginal phase. East of Estacada, in the Clackamas River valley, there are many flows in the formation and farther eastward flow rocks become dominant. The unaltered volcanic breccia contains abundant woody material, which is chiefly noncarbonized. Angular blocks, as much as 5 or 6 feet in maximum size, compose most of the breccia. The weathered outcrops generally have a brownish or reddish-brown cast. Relatively unaltered breccia and flows form cliffs and steep slopes along the Clackamas River and in the steep-walled valley of Eagle Creek above The Falls.

Locally the Rhododendron formation is deeply weathered. The upper surface of the formation was subjected to weathering that produced a laterite crust 8 to 10 feet thick before the overlying Sandy River mudstone was deposited. This crust is preserved locally at the contact of the Rhododendron and Sandy River. The laterite is discussed in greater detail on pages 89–90. Alteration of the breccia below the laterite has produced a saprolite that is more than 50 feet thick. The saprolite has a mottled appearance owing in part to the preservation of relict textures and structural features in the rock and probably in part to variation in iron content of the original fragmental constituents.

Bedding has not been observed in the breccia, but altitudes at widely separated localities on the top of the formation indicate that it strikes generally northeast and dips less than 2° to the northwest in the this area.

The rocks of the Rhododendron formation are mainly hypersthene andesites. The feldspar is plagioclase intermediate in composition between andesine and labradorite. It forms both phenocrysts and crystallites that compose most of the groundmass. Hypersthene is abundant, and twinned diopside and augite are conspicuous in some of the rocks. Most of the rocks are partly altered to clay minerals.

The stratigraphic relations of the Rhododendron formation in the southeastern part of the report area and in immediately adjoining areas restrict the age of the Rhododendron and establish the validity of its status as a formational unit. Volcanic mudflow breccias of the Rhododendron formation nonconformably overlie lower or middle Miocene Molalla formation of Lowry and Baldwin (1952) along the Molalla River, 2 to 3 miles southeast of the town of Molalla, Oreg. (fig. 6). The Rhododendron formation overlies the Columbia River basalt of middle Miocene age about a mile southeast of the mouth of the North Fork in the Clackamas River valley, and also in the valleys of Eagle Creek and the Sandy and Bull Run Rivers.

The Rhododendron formation overlies or encloses sedimentary rocks of late Miocene age that are exposed downstream for only about a quarter of a mile from the Cazadero powerhouse on the south bank of the Clackamas River. A vertical section of leaf-bearing tuffaceous siltstone and claystone more than 100 feet thick

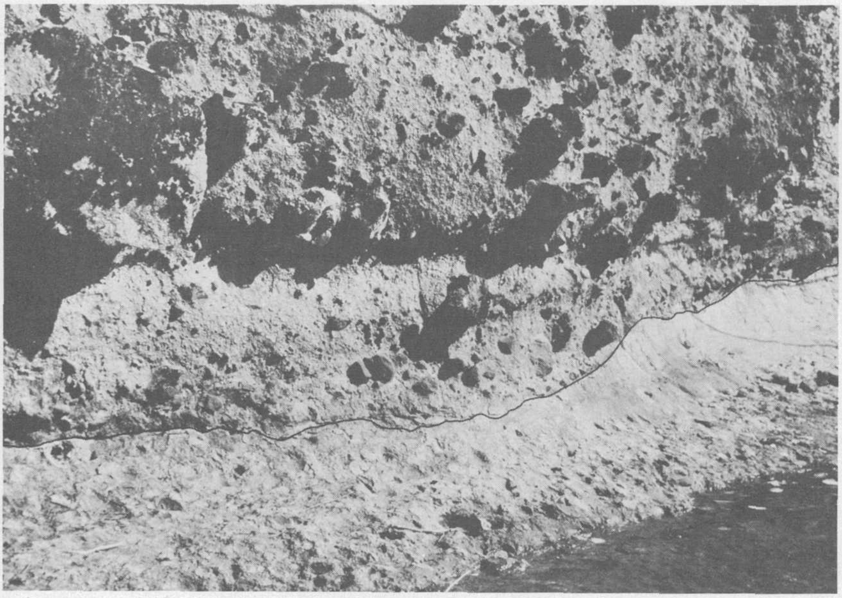

FIGURE 6.—Mudflow breccia of the Rhododendron formation unconformably overlying weathered conglomerate of the Molalla formation of Lowry and Baldwin (1952) at the east end of the bridge across the Molalla River about 2 miles southeast of Molalla, Oreg.

is exposed just west of the powerhouse. Breccia of the Rhododendron formation crops out above the siltstone and claystone at an altitude of about 550 feet. A few hundred yards west of the forebay spillway, near the trail along the Oregon City water pipeline, breccia in the Rhododendron overlies coarse sandstone and pebble conglomerate composed of lava fragments at about 500 feet above sea level. Locally the upper part of the section is cobbly conglomerate. The rocks contain some lignitic woody material, and the tuffaceous siltstone or claystone just west of the powerhouse yields a well-preserved florule dated as late Miocene by R. W. Brown (written communication).

The lower contact of the sedimentary rocks is not exposed, but the upper contact at one place appears to be a zone about 6 feet thick that is gradational with the Rhododendron formation. The overlying mudflow breccia appears to have dislodged and incorporated part of the underlying sedimentary materials. The formations do not appear to be separated by a profile of weathering.

Although the Rhododendron formation is not known to contain sedimentary rocks at any other locality in this area, the sedimentary rocks at the Cazadero locality are correlated with the Rhododendron formation. When more is known however, these rocks may be either definitely assigned to the Rhododendron formation or given a separate formational name. Roberts (1958, p. 34) mapped nonmarine sedimentary beds of late Miocene age in southeastern Washington, which he named the Wilkes formation. The possibility of correlation with these beds is uncertain but should be considered.

The Rhododendron formation is separated from the overlying Sandy River mudstone of early Pliocene age by laterite. The best exposure of the contact is about 50 feet above river level on the north bank of the Clackamas River about 0.4 mile below River Mill Dam. The contact also may be seen in the valley of Eagle Creek. The presence of the laterite suggests that the Rhododendron is not younger than late Miocene, because of the time required for the formation of a laterite (see p. 92–94). No fossils have been found in the formation, unless the fossiliferous sedimentary rocks at Cazadero prove to be Rhododendron. The validity of the Rhododendron as a formation is emphasized by (1) the laterized upper surface, (2) the nonconformable relations of its basal contact along the Molalla River, and (3) the marked differences in lithology between the Rhododendron and the enclosing formations, which reflects their different origins.

Although the Rhododendron is of volcanic origin, the breccia of the marginal phase of the unit exposed in this area probably is not air-fall breccia. The vent sources of this material are unknown, but the lateral extent of the exposed breccia, which is several hundred feet thick, is between 25 and 30 miles. Although the breccia is not sorted or bedded, it contains many wood fragments, many of which are not carbonized. The wide lateral extent of the breccia, the abundance of noncarbonized wood in it, and the absence of sorting and stratification in the formation suggest that the breccia is the product of volcanic mudflows. The breccia probably was emplaced as several coalescing mudflows that originated at many volcanic vents on the west flank of the Cascade Mountains and merged westward into one vast composite mudflow deposit of more than 25 miles lateral extent. The mudflow deposit intertongues with lava flows mountainward. The mudflow origin of the breccia in the Rhododendron was recognized by most of the previous workers (Hodge, Treasher, Nichols, Lowry and Baldwin, previous citations).

PLIOCENE SERIES

SANDY RIVER MUDSTONE

Mudstone, siltstone, claystone, and sandstone beds that overlie the Rhododendron formation and underlie the Troutdale formation, are here named the Sandy River mudstone. These rocks formerly were considered to be the lower part or member of the Troutdale formation (Trimble, 1957), but the distinct difference in lithologic character and genesis between the Sandy River mudstone and the Troutdale formation is sufficient basis for separating them. The name is for the Sandy River along which it is well exposed. The best exposures of the formation are along the Clackamas River in the Boring quadrangle downstream from the point of contact with the Rhododendron formation, which is about 0.4 mile downstream from the River Mill Dam, and this general area is designated as the type area. There are other exposures in the valleys of Abernethy Creek, Clear Creek, Eagle Creek, and Deep Creek and its tributaries, all in the Boring and Oregon City quadrangles. One other small area of exposure is along the southeast margin of the Camas quadrangle. The mudstone probably underlies much of the Portland quadrangle at depth, and beds thought to be equivalent underlie the Quaternary deposits in the Tualatin Valley. The best exposures of the formation are in steep cutbanks along streams or in landslide scarps. The unit is susceptible to slumping. In some places, such as along the Mosier Creek tributary of Clear Creek southwest of Viola, the area mapped as Sandy River mudstone is almost entirely a landslide complex.

The maximum exposed thickness of the Sandy River mudstone is between 200 and 300 feet in the valley of Buck Creek, a tributary of the Sandy River in the northeast corner of the Boring quadrangle. The greatest inferred thickness of about 725 feet overlying Columbia River basalt is from the log of a well drilled for water on the Hudson-Duncan farm in the NE¼SE¼ sec. 21, T. 2 S., R. 4 E. This thickness is considered a minimum thickness at this locality. The log of another well, drilled for the Salvation Army youth camp in the NE¼SW¼ sec. 14, T. 2 S., R. 3 E., indicates about 550 feet of mudstone inferred to be Sandy River. The total thickness of the formation at this point probably was not more than 600 feet. A well drilled at the Camp Collins YMCA camp in the NW¼ sec. 10, T. 1 S., R. 4 E., penetrated Columbia River basalt at a depth of 300 feet. The formation is probably less than 400 feet thick at that locality. The log of a well in the NE¼SE¼ sec. 22, T. 1 S., R. 3 E. (Griffin and others, 1956, p. 28), however, shows only 100 to 110 feet of strata inferred to be Sandy River mudstone. The formation is not present between the Troutdale formation and the Columbia River basalt along the Union Pacific railroad track west of Corbett.

The Sandy River mudstone consists mainly of lake beds of silt or very fine sand. Some thin conglomerate beds of limited lateral extent are present in the formation. The rocks have uniform parallel bedding but, probably owing to moderate lithification, are not fissile. The lithologic units composing the formation, therefore, are classed as mudstone, siltstone, claystone, and very fine sand-

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stone. Locally a thin lapilli tuff has been recognized about 100 feet below the top of the formation. This bed is exposed between elevations of 410 and 425 feet on a farm road in NW¼NW¼ sec. 29, T. 3 S., R. 3 E., west of The Hogback, where the top of the formation is between 500 and 550 feet above sea level. Ash beds, 15 to 20 feet thick, east of The Hogback at an elevation of about 550 feet in the SE¼NW¼ sec. 28, T. 3 S., R. 3 E., may be the same bed as the lapilli tuff farther west, but their position only about 50 feet below the top of the formation makes this conclusion questionable. Pyroclastic deposits have not been recognized elsewhere in the formation.

The faces of most bluff exposures are wet and slippery because the formation acts as a barrier to downward percolating ground water, which migrates along the upper surface of the unit and emerges on exposed banks. Most exposures show the uniform bedding of the formation.

The Sandy River mudstone disconformably overlies the laterized Rhododendron formation and underlies the Troutdale formation. Dips are commonly less than 2° to the west or northwest. The attitude of the top of the Sandy River mudstone is shown on figure 7. The configuration of the upper surface probably is due mainly to structural deformation, but perhaps is partly the result of modification by erosion. The upper contact zone commonly is leaf bearing. The fossil leaves have been found at many localities within the area at this contact zone, but they have not been found within the body of the Sandy River mudstone.

The age of the formation as determined from the flora at the upper contact zone is probably early Pliocene (R. W. Brown, written communication). The early Pliocene age assigned to the Troutdale formation by Chaney (1944, p. 339) was based on flora that probably came from this same horizon at the Buck Creek locality (Chaney, 1944, p. 325) and at the Camp Collins locality (Treasher, 1942a, p. 8; Chaney, 1944, p. 26).

The even bedding, the perfection of sorting, the fine grain size, the lack of marine fossils, and the presence of the leaves indicates lacustrine (fresh-water) deposition of these beds. The sedimentary rocks overlying the Columbia River basalt in this region are thought to represent filling of a structural basin coincident with its formation. The lacustrine sediments of the Sandy River mudstone may represent filling of a closed structural basin prior to the development of drainage from the basin. A similar history of origin is postulated for the Wilkes formation in southwestern Washington (Roberts, 1958, p. 34). Age assignments suggest that the Sandy River mudstone may be equivalent to at least the upper part of the Wilkes formation.

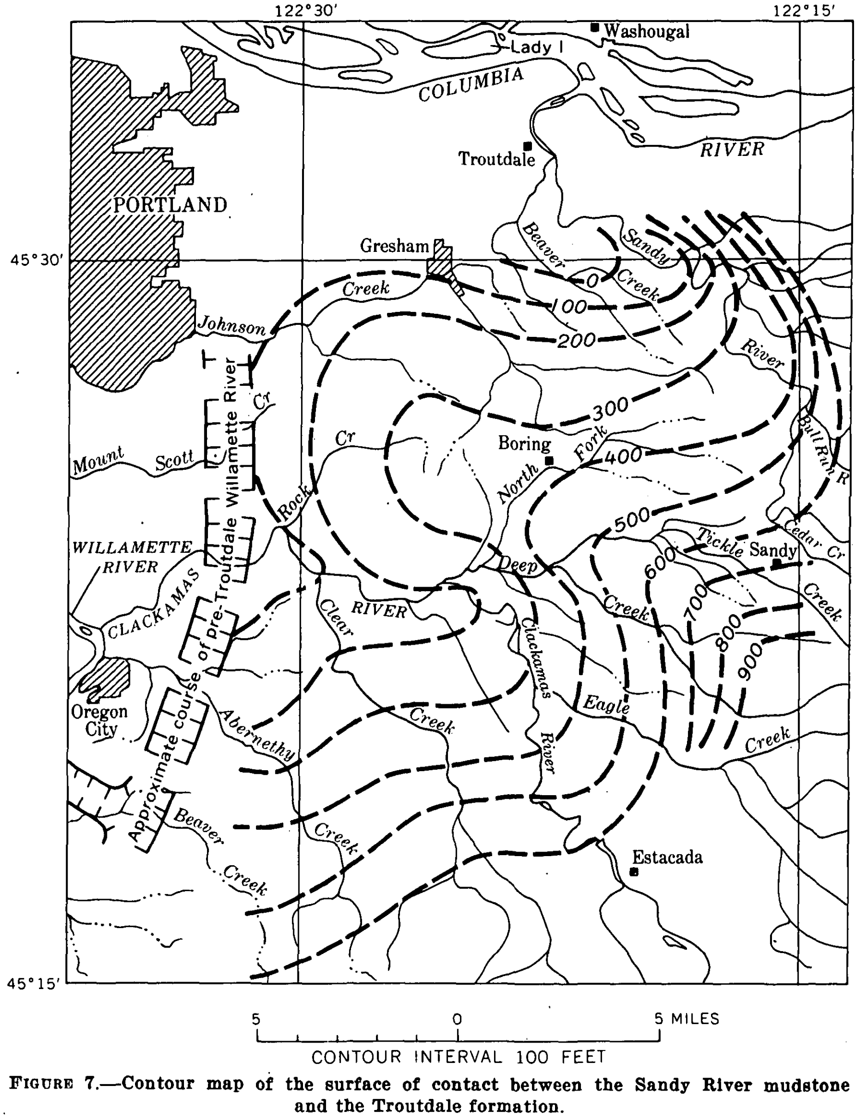

FIGURE 7.—Contour map of the surface of contact between the Sandy River mudstone and the Troutdale formation.

TROUTDALE FORMATION

Sandstone and conglomerate that overlie the Sandy River mudstone and locally overlie the Columbia River basalt compose most of the lower Pliocene Troutdale formation. The name Troutdale formation was introduced by Hodge (1933, p. 157) who formally proposed the term in 1938 (Hodge, 1938, p. 873) for deposits that he considered to be a great piedmont fan of Pleistocene age lying on the west side of the Cascade Mountains. The name is taken from the town of Troutdale, Oreg., which is near the excellent cliff exposures of the formation along the lower Sandy River. The name has received general acceptance. These rocks formerly were correlated with the Satsop formation of the Washington coastal area (Bretz, 1915, p. 131; 1917, p. 450–451; Williams, 1916, p. 25). The Troutdale formation of this report includes only the upper member of the Troutdale formation of the Portland Geologic Quadrangle Map series report (Trimble, 1957), as the beds formerly referred to the lower part of the Troutdale formation are now called the Sandy River mudstone.

The beds here referred to the Troutdale formation include those exposed in the Sandy River type locality of Hodge. The Troutdale formation is also widely exposed in areas to the north, south, and west. It crops out in the adjacent Corbett Heights area and along the north side of Chamberlain Hill from the Sandy River east to near Corbett, where it overlies Columbia River basalt. North of the Columbia River it underlies much of Prune Hill and the town of Camas, Wash., and the weathered surface of the formation is exposed continuously from the east edge of the report area northwestward to the north edge, marginal to the mountainous area of the Skamania volcanic series. The formation also is exposed along the Washington bank of the Columbia River both north and east of Vancouver, Wash., in the valley of Salmon Creek, and in a topographic prominence north of Salmon Creek near the north edge of the map area. In Oregon, the Troutdale formation also is exposed nearly continuously along the valley of the Sandy River, in the valley of the Clackamas River and its tributaries, in the area east and south of Oregon City to the south edge of the report area, and in topographic prominences in or near the city of Portland. Small remnants have been mapped along the east side of the Tualatin Mountains west of Portland. With the exception of a few exposures of conglomerate beds on the east side of the Tualatin Mountains thought to be Troutdale, the formation is not present at the surface in the Hillsboro quadrangle. Locally along the west slope of Tualatin Mountains between 200 and 300 feet of clay separates the Boring lava and Columbia River basalt. This may be, in part, Troutdale equivalent. At Hillsboro nearly 1,500 feet of valley sediments overlie Columbia River basalt. Probably more than 1,300 feet of these sediments are Tertiary and, in part, equivalent to the Troutdale formation. Sandy River mudstone equivalent also is probably represented in that section. The distribution of the Troutdale in the Washington Park district, south of West Burnside Street in west Portland (secs. 32 and 33, T. 1 N., R. 1 E., and secs. 4 and 5, T. 1 S., R. 1 E.), has been inferred entirely from records of shafts and drill holes (Clarke, 1904, p. 341–387).

The Troutdale commonly forms cliffs along valley walls and locally is susceptible to slumping, especially where overlain by Boring lava. The large landslide area along the Washougal River resulted from failure of Troutdale formation beneath Boring lava. The topography of deeply weathered surfaces, such as the benchlike surface of the Troutdale marginal to the mountainous area in Clark County, Wash., is subdued.

The total thickness of the Troutdale formation is unknown. The greatest exposed thickness is in the area between Mount Norway and the Columbia River. If it is assumed that the beds there are nearly horizontal, a thickness of about 900 feet of conglomerate in the Troutdale is indicated. The attitude of the beds, however, is not known precisely. The true thickness in this locality probably is greater, because the base of the exposure most likely is several hundred feet above the base of the formation. The basal contact with the Columbia River basalt passes beneath ground level along the north side of the Columbia River about 2 miles east of the report area. A thickness of more than 800 feet is inferred for the Troutdale formation in east Portland from the altitude difference between the minimum depth of the interpreted base of the formation at about 200 feet below sea level (from well record) and the top of Mount Tabor (645 feet above sea level). The surface of the Troutdale formation is an erosional surface, and originally the formation probably was more than 1,000 feet thick.

The Troutdale formation consists mainly of sandstone and conglomerate. In the eastern part of the area the sandstone is largely a vitric sandstone composed mostly of sideromelane grains. Commonly the lower part of a vitric sandstone bed is cobbly or bouldery. The larger particles are of mafic lava. The sandstone composes the bulk of the formation in some places. Locally in the eastern part of the area, as at Viking Park bridge across the Sandy River in sec. 6, T. 1 S., R. 4 E., and along the road north of Gibbons Creek, east of Washougal, Wash., the Troutdale contains micaceous quartzose sandstone. The sandstone of the western part of the area, such as that exposed near the intersection of NW Nicolai Street and NW Wardway in Portland and in cuts along U.S. Highway 99 near the north border of the area, is a micaceous arkosic sandstone. The sandstone of the southern part of the area, such as on The Hogback in the southwest part of the Boring quadrangle, commonly is tuffaceous.

The conglomerate of the formation is mostly a poorly stratified pebble conglomerate that contains as much as 30 percent of quartzite pebbles. Cobbly pebble conglomerate appears to constitute the entire formation near the east edge of the map area in Clark County, Wash., and it is well exposed in the valley of Lawton Creek. A few miles to the west, vitric sandstone becomes abundant, and in the vicinity of Camas it appears to predominate. Some conglomerate beds in the Troutdale formation are cobbly, lack stratification, and do not contain quartzite pebbles; but the stratified quartzite-bearing pebble conglomerate characterizes much of the formation.

A layer of stratified fine sandstone, siltstone, and claystone is exposed in the formation along the Sandy River in the Camas quadrangle about 100 feet above the base of the formation. This stratum is about 25 to 50 feet thick and averages about 30 feet thick. It is a persistent unit that locally contains leaves. The generalized composite stratigraphic section of the Troutdale formation shown in figure 8 indicates the relationship between this layer and the rest of the formation. This stratum is exposed in the type area of the formation between the town of Troutdale and the bridge across the Sandy River at Viking Park, but most of the beds exposed there are stratigraphically above it. Most of the Troutdale formation exposed

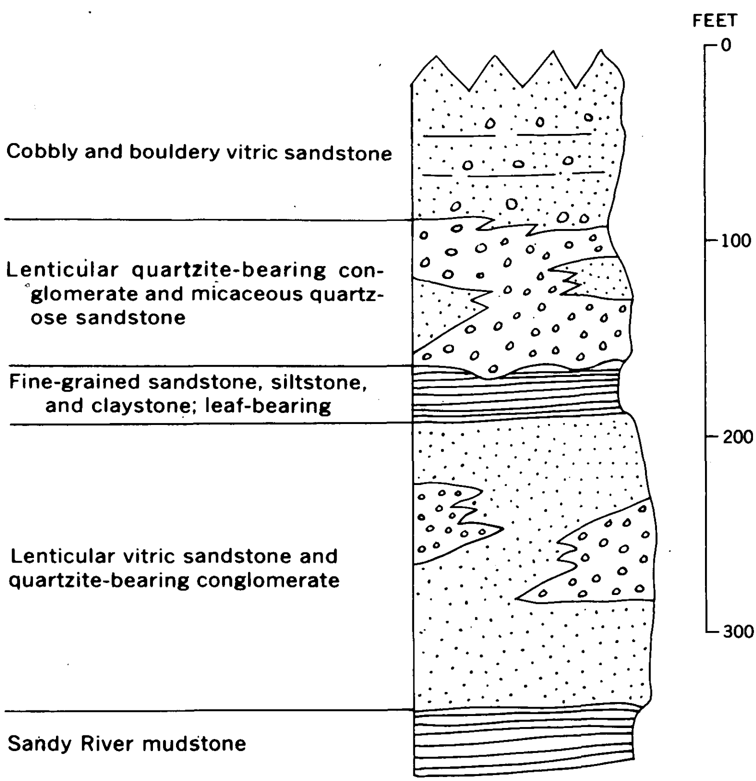

FIGURE 8.—Generalized composite stratigraphic section of the Troutdale formation exposed along the Sandy River between Troutdale, Oreg., and Gordon Creek.

north of the Columbia River is also probably above this layer. The stratified claystone and siltstone formerly exposed in the old clay pit at Russell Landing, in the SW¼SW¼ sec. 33, T. 2 N., R. 2 E. (Darton, 1909, p. 18), prior to grading operations for the relocation of U.S. Highway 830 in 1953 may be this unit.

The Troutdale formation, particularly the sandstone and conglomerate is commonly well indurated. The cement consists mainly of clay minerals. The least weathered outcrops generally are stained brownish or reddish by iron minerals, but the weathered exposures are more vivid red, yellow, or brown. Bedding in the formation is commonly irregularly lenticular (fig. 9), and locally is crossbedded as near Crown Point on the old Columbia River Highway. The beds are almost horizontal, generally dipping less than 2° to the west or southwest in the eastern part of the area, to the north or northwest in the southern part of the area, and generally southward in the north-central part of the area.

The vitric sandstone, which composes such a large percentage of the formation, is unusual in its composition. It consists almost entirely of a basaltic glass (sideromelane) that has an index of refraction slightly less than 1.60, which indicates a silica content of a little less than 50 percent (Williams and others, 1954, p. 28). Grains in the vitric sandstone are mostly of coarse to very coarse sand size, although the sandstone is conglomeratic in places. The unaltered particles are of angular black fragmental glass. The unaltered material, however, is seen only as cores surrounded by shells of palagonite and clay. The clay predominates. Locally the vitric sandstone is completely decomposed.

The sandstone is well sorted and is remarkably free of constituents other than glass or its alteration products, although locally it contains minor amounts of muscovite and quartz. Because of the good sorting the sandstone is permeable. The clayey alteration product apparently is responsible for the cohesion of the rock.

The quartzite pebbles that are characteristic constituents of the conglomerate in the Troutdale are smooth, well rounded, and light colored. The white, yellow, and red quartzite pebbles stand out against the somber background of basaltic pebbles and cobbles that compose most of the conglomerate. Locally the surface of the formation has been subjected to long and severe weathering, and the original character of the rock so completely destroyed that the unaltered quartzite pebbles in a residual red clay are the only clue to its parent identity. The abundance of quartzite pebbles in the conglomerate has been described by Williams (1916, p. 23), Bretz (1917, p. 451), Hodge (1938, p. 874), Treasher (1942a, p. 8), and Lowry and Baldwin (1952, p. 9).

The Troutdale formation overlies the Sandy River mudstone and underlies the Boring lava. The basal contact recognized in this report is between the parallel-bedded siltstone and claystone of the Sandy River mudstone and the lowermost coarse lenticular sand-

FIGURE 9.—Lenticular bedding in the Troutdale formation along the north side of the Sandy River in SE¼NE¼ sec. 6, T. 1 S., R. 4 E.

stone and conglomerate of the Troutdale. The upper contact is an erosional surface of considerable relief upon which the Boring lava was extruded. On the south side of Bear Prairie in the NW¼ sec. 30, T. 2 N., R. 5 E., less than a quarter of a mile east of the Portland area, conglomerate of the Troutdale below hard unaltered Boring lava has been completely decomposed to a saprolitic clay. Elsewhere the surface of the Troutdale formation beneath the Boring lava is relatively unweathered.

Over much of the area the Troutdale formation is overlain by Quaternary deposits. It is distinguished from the younger Quaternary deposits with ease, but some of the older, deeply weathered Quaternary deposits may be and have been mistaken for Troutdale formation. Treasher (1942b) mapped large areas of weathered Pleistocene mudflow deposits and alluvial cobble gravels south of Gresham, Oreg., as Troutdale formation, presumably because of similarity in severity of weathering of these deposits and the Troutdale formation. Stratigraphic relationships and lithologic differences, however, generally will distinguish the formations.

The early Pliocene age assigned to the Troutdale formation by Chaney (1944, p. 339) apparently was based on flora from the top of the Sandy River mudstone as discussed previously. The 25 to 50 foot stratum of fine sediments about 100 feet above the base of the Troutdale formation has also yielded fossil flora, which were well preserved at only two of the localities examined. Florules were collected at a locality found during this investigation, on the east side of the Sandy River opposite the town of Troutdale, Oreg., in the NE¼SE¼ sec. 25, T. 1 N., R. 3 E. Similar fossils also were found at a locality discovered by Murray Miller, a member of the Geological Society of the Oregon Country, in the NW¼SW¼ sec. 21, T. 2 S., R. 2 E., just east of Park Place, Oreg. These collections were examined by R. W. Brown of the U.S. Geological Survey, who considered them also to be more probably of early Pliocene age (written communication). Chaney considered the Troutdale formation to be virtually equivalent to the Dalles formation of the east flank of the Cascade Mountains (1944, p. 339), which he correlated with the Ellensburg formation of eastern Washington (1944, p. 308).

The lithologic character and bedding of the Troutdale formation indicate fluvial deposition, locally by torrential waters. The lithologic differences between the Sandy River mudstone and the Troutdale formation are believed to reflect a rather abrupt change from lacustrine to fluvial conditions. The coarse grain size and lenticular bedding in the Troutdale probably indicate piedmont conditions as suggested by Hodge (1938, p. 873). The great thickness of conglomerate adjacent to the mouth of the Columbia River gorge indicates that the region was undergoing continued deformation and that the ancestral Columbia River was in nearly its present position in early Pliocene time.

The distinctive lithologic differences between the two major units of the Troutdale formation, the conglomerate containing an abundance of quartzite pebbles and the vitric sandstone, are difficult to explain. I believe that they imply deposition by an ancestral Columbia River, perhaps with a drainage system similar to its present one, that derived only the conglomeratic part of its load in the upper part of its drainage system. The mica and the quartzite pebbles in the formation probably have traveled far, perhaps from northeastern Washington. The vitric sandstone, however, consists mostly of angular glass particles and is relatively uncontaminated with other material, suggesting that its source was not far distant. Its main constituent, sideromelane, is a product of rapid chilling such as occurs when liquid lava pours into water (Williams and others, 1954, p. 39). It is entirely possible that the vast quantities of sideromelane incorporated in the Troutdale formation resulted from the lava flowing into the ancestral Columbia River along its Pliocene course through the Cascade Mountains, vitrifying and disrupting into the sand-sized glassy fragments that were transported only a few miles downstream to their present site. Intermittence of the volcanism would account for the lenticular association of strata of such dissimilar lithologic character.

TERTIARY AND QUATERNARY SYSTEMS

BORING LAVA

In late Tertiary and early Quaternary time scores of volcanoes erupted in the Portland area, and in adjoining areas, particularly to the east. The products of this episode of volcanism have been named the Boring lava by Treasher (1942a, p. 10) for their occurrence near the town of Boring, Oreg. They are basaltic flows and pyroclastic rocks of local origin, mostly near their source vents. The rocks of late Pliocene to late(?) Pleistocene age here mapped as Boring lava include those that have been referred in part to both the Rhododendron and Cascan formations by Hodge (1938, p. 877–879 and 884–885), and to the Troutdale formation by Lowry and Baldwin (1952, p. 10).

The Boring lava is exposed in eruptive vents, many of which still have their initial cone shape, and in dissected lava plains. The Boring lava is exposed only on higher topographic levels and prominences, but probably it is present locally also beneath the mantle of Quaternary sediments that covers much of the area. Reconnaissance of adjoining areas to the north, west, and south indicates that the Boring volcanism did not extend more than 6 miles to the north or south of the report area and was nearly limited to the area on the west. The extent of equivalent rocks in the Cascade Mountains to the east is unknown, but is probably great. With the exception of the lava plain south and east of Oregon City and the eroded margin of the lava plain south of the Columbia River and east of the Sandy River, all the Boring lava is locally found around a single vent source or a small complex of vents. The Boring vents in the northeastern part of the map area are the symmetrical cone of Green Mountain, the volcanic center of Prune Hill, lesser vents at Brunner Hill, and the multiple vent areas of Mount Norway, Nichols Hill, and Bear Prairie near the Washougal River. In the central part of the area are the Chamberlain Hill vent, the many eruptive centers in the Mount Scott area and in the hills near the town of Boring, and the smaller volcanic centers such as Rocky Butte, Mount Tabor, Kelly Butte, and Powell Butte in or near the city of Portland. The tongue of lava near the east edge of the area, between Deep Creek and Eagle Creek, probably came from Lenhart Butte, about 4 miles to the east. The lavas exposed east of the Sandy River are the marginal rocks of a lava plain extending eastward that probably originated in such cones as Ross Mountain, Pepper Mountain, Larch Mountain, and Lookout Point. Boring lava underlies much of the surface in the southern part of the area between the Clackamas and the Willamette Rivers. With the exception of the multiple vents between Abernethy Creek and Clear Creek, most of these lavas constitute a vast plain and are thought to have originated in Highland Butte and associated smaller vents. Highland Butte is located about a mile south of the area in sec. 9, T. 4 S., R. 3 E. The Boring lava west of the Willamette River lies along a northwestward-trending belt on the west side of the Tualatin Mountains and their southern extensions, which form the east side of the Tualatin Valley. The two southern areas of Boring lava in this belt are the eruptive centers north and south of Oswego Lake; the southern one is near Hazelia and the northern one is Mount Sylvania. The largest area of Boring lava west of the Willamette River extends from the crest of the Tualatin Mountains westward to the floor of the Tualatin Valley and lies between Bronson Creek and the upper part of Beaverton Creek, just south of the Portland area. That area probably contains at least four source vents, including Swede Hill, Elk Point, and two vents north and south of Cornell Road on the crest of the hills. The area of Boring lava north of Bronson Creek is probably an extension of the larger area, separated from it by erosion.

The conical form of a volcano is preserved in many of the Boring eruptive vents, such as Green Mountain and Mount Sylvania.

The lava plains slope gently, commonly less than 200 feet per mile and locally less than 50 feet per mile. The surface of the plain is nearly flat to gently rolling except where entrenched by streams or surmounted by cones.

The Boring lava is usually thicker at or near a vent than it is farther away. For example, a well more than 400 feet deep on Prune Hill, in the NE¼ sec. 8, T. 1 N., R. 3 E., was still in Boring lava at the bottom. Likewise, more than 500 feet of Boring lava was penetrated in a well drilled for water at the Willamette National Cemetery on the east side of Mount Scott, in the NE¼NE¼ sec. 27, T. 1 S., R. 2 E. About 2 miles to the southeast, however, in the saddle in the NE¼SW¼ sec. 36, T. 1 S., R. 2 E., the lava is little more than 100 feet thick. Similarly, the Boring lava is about 300 feet thick near Cornell Road on the west side of the Tualatin Mountains in the NE¼NE¼ sec. 35, T. 1 N., R. 1 W., but a half a mile west along Cornell Road, in the NW¼SW¼ sec. 35, T. 1 N., R. 1 W., it is less than 200 feet thick, and near Cedar Mill it is between 100 and 150 feet thick. Near the intersection of Barnes Road and the Sunset Highway, in the SE¼ sec. 2, T. 1 S., R. 1 W., the Boring lava is about 200 feet thick. The thickness of the Boring lava along the west side of Mount Sylvania, just east of the Willamette meridian, is about 150 feet. In an area a mile or two south of Oregon City the Boring lava is about 100 feet thick, and this may be 10 miles from the source of the lava. The thickness of the Boring lava less than a mile southwest of Highland Butte, in the SE¼ sec. 8, T. 4 S., R. 3 E., however, is less than 150 feet, at least locally. The Boring lava is probably between 100 and 200 feet thick in most places except at or near the vent. This generalization probably is true in most cases but there will be many exceptions, both greater and less than the indicated thickness.

The Boring lava is composed mainly of basaltic flow rocks, but locally contains tuff breccia, ash, tuff, cinders, and scoriaceous phases. The flows commonly are light-gray to nearly black, with lighter tones predominating, and are characterized by columnar jointing and flow structure which in places results in platiness of the rock. Typical jointing is exposed along Boones Ferry Road in NW¼SE¼ sec. 33, T. 1 S., R. 1 E., where a tongue of lava from Mount Sylvania flowed down a small valley, cut in the underlying Troutdale sediments. The columns are perpendicular to the walls of the small valley (fig. 10).

Tuff breccia, ash, and tuff in the Boring lava are known at only one locality. A Boring vent just northeast of Carver, in the NW¼ sec. 18, T. 2 S., R. 3 E., apparently was explosive in the early stages of eruption, but later became quietly effusive. More than 300 feet of tuff-breccia, with a minor interstratified tuff about 10 feet thick, is overlain by lava at this locality. The tuff breccia on the east side of the hills dips 15° to 20° to the northeast, but that on the southwest side dips steeply to the southeast. Loosely consolidated sandy ash beds are associated with the tuff breccia near the base of the exposure on the east side. To the west, below highway level opposite the Carver school, 10 to 20 feet of scoriaceous lava, which is capped by 15 to 20 feet of terrace gravel, lies on stratified tuff, ash, and cinders that represent the early stage of the eruptive activity. From 5 to 10 feet of the pyroclastic rocks are exposed to within 15 feet of the Clackamas River flood plain.

Although the tuff breccia and tuff are known only at the Carver vent, cindery pyroclastic rocks of the Boring lava are present at several localities. The structure of the cinder cone on Mount Tabor is visible in an excavation that exposed the throat and the dipping cinder beds on the flanks (fig. 11). The cinder cone is the southwest patch of Boring lava shown on Mount Tabor. The small area of Boring lava northeast of the cone is flow rock that probably was extruded near the base of the cone in a manner similar to flows emanating from "bocas" at Parícutin in Mexico (Krauskopf, 1948, p. 716). The peculiar topographic feature in SE¼ sec. 18, T. 1 S., R. 3 E., about 2 miles southwest of Gresham, is a breached cinder cone. Weathered cinders are exposed along a small creek draining the crater through the breached wall on the west side. Cindery

FIGURE 10.—Fanlike columns in Boring lava along Boones Ferry Road in NW¼SE¼ sec. 33, T. 1 S., R. 1 E.

deposits are exposed also along Skyline Boulevard on the west side of the Tualatin Mountains, between Cornell Road and Thompson Road in sec. 25, T. 1 N., R. 1 W., on the small hill east of Brunner Hill in sec. 24, T. 2 N., R. 3 E., and on Prune Hill, near the road intersection in the SE¼NE¼ sec. 8, T. 1 N., R. 3 E.

The bluff along the south side of Prune Hill, in the SE¼ sec. 8, and the SW¼ sec. 9, T. 1 N., R. 3 E., is red scoriaceous lava that is quarried for ornamental stone (rock walls, rock gardens). This scoriaceous phase is probably vent material of the Prune Hill volcano. Thick jointed flows are exposed a mile to the west in a large quarry.

Although the pyroclastic rocks at the Carver vent and the scoriaceous rock at Prune Hill are thought to be closely associated with their respective vents, and Troutdale pebbles are common in Boring lava, the only place that a feeder column for the Boring lava can be seen cutting Troutdale sedimentary rocks is in an abandoned quarry on the west end of Kelly Butte. Here a column of basalt about 20 feet wide cuts about 50 feet of conglomerate of the Troutdale formation, whose bedding has been arched adjacent to the feeder. The lava fed by this vent flowed down a preexisting slope and thickened beyond the point of emission. Local eruption on a sloping Troutdale surface also is represented by the Boring lava on Powell Butte, in NW¼ sec. 13, T. 1 S., R. 2 E., on the hill south

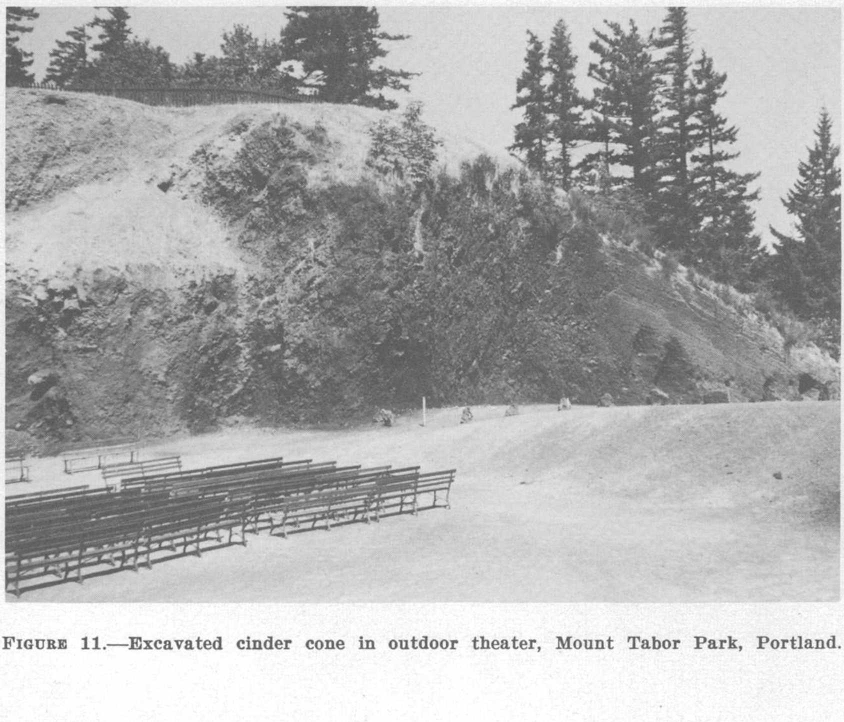

FIGURE 11.—Excavated cinder cone in outdoor theater, Mount Tabor Park, Portland.

of Foster Road, in the south half of sec. 13, T. 1 S., R. 2 E., and on Mount Talbert, in sec. 3, T. 2 S., R. 2 E. On Mount Talbert a small vent apparently erupted near the eastern crest and a single flow poured southeastward down a previously carved slope. The eruption at Rocky Butte, in east Portland, must have buried a small hill of Troutdale formation, because conglomerate is exposed at an altitude of about 500 feet, just above the road parapet below the tunnel on the west side of the butte. These occurrences may represent eruptions on an irregular post-Troutdale topography, which was subsequently eroded.

The Boring lava is characteristically a light-gray olivine basalt with a pilotaxitic to diktytaxitic texture. Light-brown altered olivine phenocrysts, altered in part or entirely to iddingsite, are characteristic of the rock. The plagioclase is labradorite.

Vugs in Boring lava in the Multnomah County prison quarry on the east side of Rocky Butte, in the NE¼SE¼ sec. 28, T. 1 N., R. 2 E., contain an assemblage of minerals that were identified optically by E. J. Young of the U.S. Geological Survey, with supplementary determinations of three of the minerals by X-ray diffraction methods made by R. P. Marquiss, also of the U.S. Geological Survey. The sample (U.S.G.S. serial no. 251789) contained several well-crystallized vug minerals of which five were identified. Pale-brown hairlike prismatic crystals were identified as pargasite (optically positive hornblende). They are several millimeters in length, some are twinned, and all have perfect prismatic cleavage. Tiny equant dark-green pyroxene crystals were identified as hedenbergite (70 percent hedenbergite, 30 percent diopside). White ball-like aggregates, slightly more than a millimeter in diameter, are colorless plates of tridymite that have wedgelike edges. Brown granular wedge-shaped crystals of olivine (80 percent fosterite, 20 percent fayalite) are associated with the tridymite. The olivine within the basalt is optically identical with the olivine in the vug. Tiny hexagonal black metallic plates of hematite with beveled edges also were identified from the vug. The assemblage of minerals in the vug is unusual and the association of free silica in the form of tridymite with the low-silication mineral olivine is unexplained.

The surface of much of the Boring lava has been weathered to depths of 25 feet or more. The upper 5 to 15 feet commonly is a red clayey soil that retains none of the original character of the parent rock. Spheroidal weathering is common in the lava and is evident in exposures along the roads at the bluff south of Oregon City, in SW¼ sec. 31, T. 2 S., R. 2 E., and along the highway in the NE¼SW¼ sec. 32, T. 3 S., R. 3 E. (fig. 12).

FIGURE 12.—Spheroidal weathering of Boring lava in NE¼SW¼ sec. 32, T. 3 S., R. 3 E.

Most of the Boring lava was erupted onto a surface of erosion on the Troutdale formation. Locally, however, it may lie directly on older rocks, such as the Skamania volcanic series. Such a relationship probably occurs on the north side of Bear Prairie, but the contact is not exposed. At other localities the Boring lava is probably in direct contact with either the Columbia River basalt or the Rhododendron formation. Locally, the surface of the underlying strata was deeply weathered prior to the extrusion of the Boring lava. The Boring is overlain only by Quaternary surficial deposits, of which the oldest are alluvial cobble gravel and mudflow deposits thought to be of late Pliocene or early Pleistocene age (Walters Hill formation). The preservation of the breached cinder cone southwest of Gresham at an altitude lower than adjacent early(?) Pleistocene alluvial deposits (Springwater formation) suggests that this cone is younger than early Pleistocene. Furthermore, Boring lava at the Carver vent has flowed into a Clackamas valley cut deeper than the late(?) Pleistocene floor. The Boring lava, therefore, is of late Pliocene to late(?) Pleistocene age.

The Boring lava probably is the product of local and discontinuous volcanic activity. Scores of small volcanoes contributed to the formation, but they probably were not in eruption simultaneously. The lava apparently was viscous, because most of the flows did not move far from their source vent. However, the relatively minor amounts of pyroclastic rocks in the Boring lava indicate that explosive eruptions apparently were rare.

WALTERS HILL FORMATION

Conglomerate, sandstone, and mudflow deposits, preserved locally in the area of hills south of Gresham, are of questionable origin and age. Treasher (1942b) recognized the presence of sedimentary rocks in this area and mapped them in part as Troutdale formation. In other places probably because of lack of exposure, he mapped the deposits as Boring lava. The name Walters Hill formation is proposed here for these deposits. The name is taken from the hill immediately south of Gresham, which is named Walters Hill on the new U.S. Geological Survey Damascus, Oreg., 7½-minute topographic quadrangle map (1954 edition).

Deposits tentatively assigned to this group of rocks are of limited distribution. Poorly indurated cobbly gravel deposits and mudflow deposits apparently compose most of the hill in secs. 25 and 26, T. 1 S., R. 3 E., 1½ miles northwest of the town of Boring. Weathered gravel is exposed to within 50 feet of the top of a terrace on the east side of the hill just northwest of Hillsview School, in sec. 27, T. 1 S., R. 3 E. Weathered gravel is also exposed between 750 and 800 feet above sea level along a private road in NW¼SW¼ sec. 28, T. 1 S., R. 3 E. Walters Hill immediately south of Gresham is composed of conglomerate and sandstone. The relatively level area that extends southward from this hill at an altitude of less than 850 feet to about 3 miles south of Gresham is underlain by sedimentary rocks. These are mostly conglomerate as determined from a limited number of logs of wells drilled for water. One well, in the SW¼SW¼ sec. 15, T. 1 S., R. 3 E., penetrated 414 feet of conglomerate, which may be in part Troutdale formation. None of the gravel of the conglomerate contains quartzite pebbles. Deposits underlying a terrace between 800 and 925 feet in altitude, on the southeast side of the hill immediately west of Boring, lack quartzite pebbles and are differentiated, mainly for this reason, from the underlying conglomerate, which contains them. The deposits capping the hill south of Foster Road, in sec. 24, T. 1 S., R. 2 E., and extending around the east side of the East Mount Scott area are known from well logs to overlie Boring lava. They are included with the Walters Hill formation because of topographic position, although they may belong, in part, to the next younger group of alluvial deposits. The cobbly gravel composing Grant Butte also probably belongs to this group of deposits. Gravel deposits of this age may mantle part of Powell Butte, but this has not been established definitely. Therefore the unit has not been mapped in that locality. The highest altitude at which the deposits occur is more than 900 feet on the hill northwest of Boring, but in the hill south of Foster Road the upper limit is 600 feet. The crest of the hill south of Gresham is in accordance with the higher part of the level farther south, which is a little more than 850 feet above sea level. This suggests that the deposits are remnants of a former more continuous deposit, whose surface sloped westward at less than 100 feet per mile. The greatest known thickness of the Walters Hill formation is less than 300 feet; the actual thickness is probably about 400 feet, but may be more.

The Walters Hill formation consists for the most part of poorly indurated, poorly stratified conglomerate, in which cobbles are more numerous than pebbles and boulders. Unsorted, unstratified masses of predominantly angular rock fragments that are probably mudflow deposits are interstratified with gravel beds in the hill northwest of Boring. Particle size in the mudflow deposits is mostly less than 2 inches. Mudflow deposits occur at two levels in the hill; one, about 20 feet thick, at 700 feet above sea level, and another at an altitude of 870 feet. Both are apparently overlain and underlain by gravel. Sandstone is interstratified in the conglomerate in the hill south of Gresham. Locally the beds are moderately well indurated, but in places the gravels are merely consolidated. Weathering of these deposits has been so complete that the original state of induration of most of the exposed rocks cannot be determined. The gravel is composed of mafic lava rocks and apparently lacks quartzite pebbles. The mudflow deposits also are composed of mafic lava rocks, but most of the constituent fragments are angular. The presence of considerable subangular to subrounded particles, however, is the basis for classifying these deposits as mudflow deposits rather than as lapilli tuff or tuff breccia. The possibility that the mudflow deposits are lapilli tuff or tuff breccia was considered, because of an apparent intertonguing of the deposits with a thin (5- or 6-foot) lava flow along a farm road at an altitude of about 700 feet on the north side of the hill northeast of Boring (fig. 13). The lava is thought to represent a local recurrence of volcanism that is much later than the main episode at this locality. Boring lava that composes most of the hill a mile to the south, that is exposed along the road in the saddle between the two hills, and that probably underlies the hill composed mainly of alluvial deposits, is the product of the main episode of volcanism. The presence of pumiceous fragments in material also classified as mudflow deposits, which crops out at an altitude of about 675 feet on the south side of the hill, suggests that the mudflow deposits may be in part of pyroclastic origin.

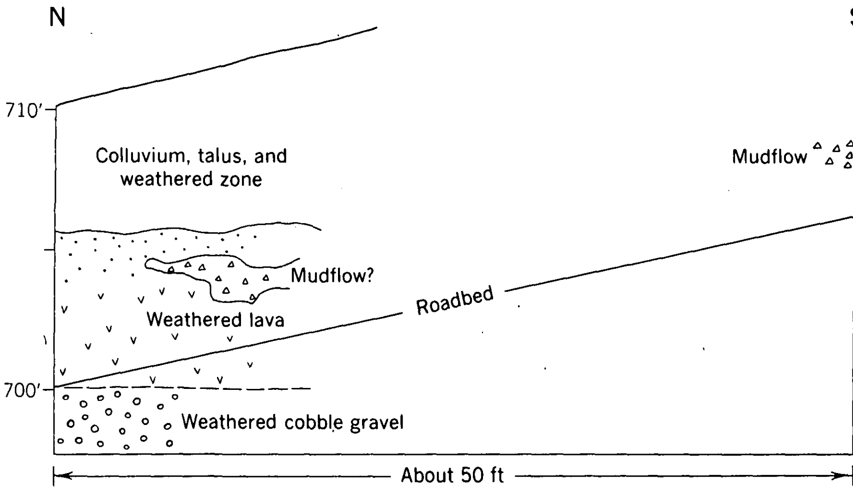

FIGURE 13.—Diagram of relations between mudflow deposit and lava on north side of hill in SE¼NE¼ sec. 26, T. 1 S., R. 3 E.

The age of the Walters Hill formation is not well established by its stratigraphic position, and the formation has yielded no fossils. The Walters Hill is underlain by the Boring lava, which ranges widely in age, and is overlain by loess of early(?) and middle(?) Pleistocene age. The loess also overlies the Springwater formation.

The superposition of most of the Walters Hill formation on the Boring lava is indicated by exposures and logs of wells on and near the hill northwest of Hillsview School. Boring lava crops out in a small exposure on the south side of the hill at an altitude of about 900 feet. Weathered gravel of the Walters Hill formation, capped by loessial silt, forms a terrace on the east side of the hill. Lava at a depth of 64 feet on a well to the northeast at the foot of the hill, in NE¼SE¼ sec. 22, T. 1 S., R. 3 E. (Griffin and others, 1956, p. 28), probably came from the hill vent, and underlies the Walters Hill formation in the terrace.

That the Walters Hill formation may not be a distinct unit, but perhaps represents erosional remnants of the Springwater formation, is suggested by similar altitudes of widely separated exposures of the two formations. Projection of the slope of the upper limits of the Walters Hill formation, however, suggests that the surface of the Walters Hill would be several hundred feet higher than the present surface of the Springwater formation where the altitude of the Springwater is equivalent to that of the highest Walters Hill. Because lithologic differences are not great enough to permit distinguishing between the two formations, this interpretation of the topographic relations is the best evidence for seperating them.

The Walters Hill formation, therefore, is considered older than the Springwater formation of early(?) Pleistocene age, and may be of either Pliocene or early Pleistocene age, or both.

QUATERNARY SYSTEM

Quaternary deposits mantle about 50 percent of the total map area, and most communities are underlain by them. The deposits are mostly water-transported and water-deposited sedimentary materials. The older ones are coarse gravels and mudflow deposits, but the Recent alluvium of the Columbia River flood plain and part of the deposits related to a late Pleistocene episode of flooding and ponding are fine grained. Loessial silt covers some of the older deposits.

Because the genesis, grain size, and lithologic character of many of the Quaternary deposits are similar, it would be difficult to identify them without some other distinguishing differences. The variations in the degree of weathering and topographic position have made it possible to identify and correlate units of the same stage of deposition.

The ages of the various deposits have not been determined accurately, but the units have been assigned relative ages based largely on comparative severity of weathering and relative topographic position.

PLEISTOCENE SERIES

SPRINGWATER FORMATION

Alluvial gravel and mudflow deposits of early(?) Pleistocene age are widely distributed beneath gently sloping surfaces adjacent to and between the Sandy and Clackamas River valleys. These deposits are here named the Springwater formation for the community of Springwater, about 2 miles south of Estacada. Treasher (1942b) included much of this unit in the underlying Troutdale formation.

Although the Springwater formation lies mainly east of the Willamette River, small deposits along the north side of the Tualatin Valley are included here in the Springwater formation. The formation mantles much of the broad interstream divide between the Sandy River and the Clackamas River. A small remnant of the unit is exposed on the east side of the Sandy River in sec. 23, T. 1 S., R. 4 E., between about 650 and 750 feet above sea level. South and west of the Clackamas River it caps the ridge, on which the community of Springwater is sited, between the Clackamas River and Clear Creek and also caps parts of two ridges west of Clear Creek. The western limit of the formation is near the west side of

R. 3 E., about 3 miles south of Gresham. The northern limit is near Gresham, and the hill about 425 feet above sea level west of the community is composed of weathered cobbly gravel that is probably Springwater formation, although the distinctive profile of weathering is lacking.

The upper surface of the Springwater formation in most places is slightly dissected. The altitude of the surface of the deposits ranges from more than 1,200 feet near the eastern border of the report area, between the Sandy and Clackamas Rivers, to less than 500 feet in the northern and western part of the Boring quadrangle. The deposits of the Springwater formation appear to be remnants of a formerly more continuous deposit, whose upper surface sloped westward or northwestward at about 50 feet per mile.

The formation is known to be more than 100 feet thick, and a maximum thickness of more than 200 feet has been inferred from indirect evidence at one locality. The base of the formation in SW¼SW¼ sec. 12, T. 2 S., R. 4 E., is at an altitude of about 650 feet, where cobble gravel overlies Boring lava. A crest less than a quarter of a mile to the southwest is about 875 feet above sea level. A thickness of about 225 feet is indicated at this locality, if the formation is horizontal and rests on a flat surface.

The Springwater formation is composed mainly of cobble gravel and bouldery cobble gravel, but interstratified mudflow deposits locally form a large part of the unit. The gravel is of fluvial origin, but is poorly sorted and lacks stratification. Most of the stones are rounded and are composed of mafic volcanic rocks presumably originating in the Cascade Mountains. Unweathered or slightly weathered gravel is only moderately well consolidated.

The mudflow deposits are known only along the walls of the Sandy River valley and in tributaries of Beaver Creek, except for a single exposure in the North Fork of Deep Creek at an altitude of about 500 feet along the road leading down to Siefer, about a mile southeast of the town of Boring.

The mudflow deposits are recognized by a number of characteristics, no one of which is identifying by itself. The deposits are composed of fragments of mafic volcanic rocks from the Cascade Mountains. Most of the stones are angular, but some, commonly of pebble size, are subangular to rounded. The deposits lack sorting and stratification, but have a poorly graded distribution of particle size with a relative concentration of larger stones, some as large as 7 feet in diameter, in the basal part. Many of the mudflow deposits also contain considerable amounts of noncarbonized wood.

Mudflow origin of deposits having many of these features is further suggested by the stratigraphic relations of two mudflow deposits, each about 50 feet thick, exposed in cuts along Dodge Park Boulevard, in SE¼ sec. 22 and SW¼SW¼ sec. 23, T. 1 S., R. 4 E. The lower one is separated from an underlying cobbly gravel by a few feet of stratified mudstone, and the mudflow deposits are separated from each other by an undisturbed thin layer of fat clay (fig. 14). If the deposits were till, the thin layer of clay probably would have been thoroughly disturbed, grooved, or removed by the overriding ice.

Weathering of the Springwater formation has been severe and most exposures are of either saprolite or of red clayey soil that has formed extensively at the surface. The red clayey soil is as much as 20 feet thick locally, and in much of the area it effectively conceals the character of the parent material. Maximum depth of weathering is probably about 75 feet. The upper part of this profile of weathering is well exposed in cuts along the new highway in the vicinity of Springwater, and in cuts along the highway between Sandy and Eagle Creek.

Similarity of the profiles of weathering on the Springwater formation and on the Troutdale formation has caused difficulty in identifying the units in some places. The formations can usually be distinguished, however, by the following differences: (1) Mudflow deposits, which are common in the Springwater formation, are not found in the Troutdale, (2) the Springwater does not contain the vitric sandstone that forms much of the Troutdale, and (3) the gravel or conglomerate beds of the two units generally differ in

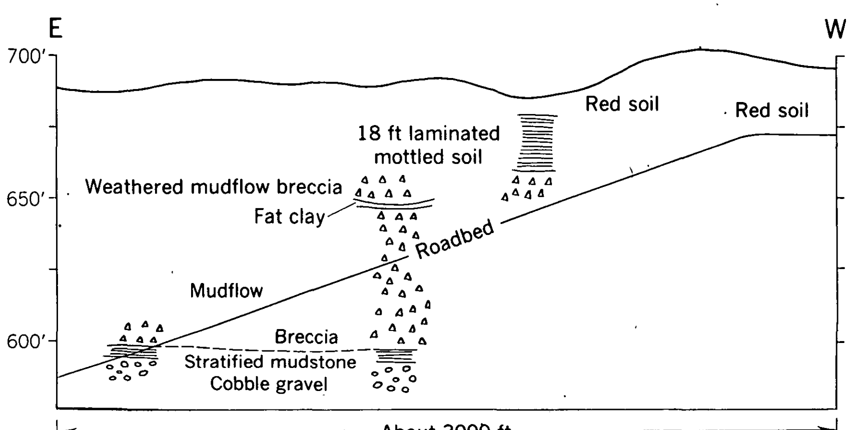

FIGURE 14.—Diagram of stratigraphic relations in the Dodge Park Boulevard exposure, secs. 22 and 23, T. 1 S., R. 4 E.

that the conglomerate of the Troutdale formation commonly is a stratified deposit of pebble-sized constituents and contains an abundance of well-rounded quartzite, whereas quartzite pebbles are rare in the Springwater formation, and the gravel is much coarser and poorly stratified. An unconformity between the two formations is exposed along the road between the communities of Sandy and Eagle Creek at an altitude of about 700 feet on the north side of Deep Creek, in the SW¼SE¼ sec. 21, T. 2 S., R. 4 E.

Deeply weathered sedimentary deposits that form terrace remnants between Jackson Creek and Rock Creek along the north side of the Tualatin Valley are assigned to the Springwater formation. The deposits crop out locally between the valley floor at an altitude of about 250 feet and an upper known limit of about 500 feet above sea level. The sediments are silt that locally is gritty or pebbly. The material exposed in the railroad cut east of Helvetia, in the SE¼SE¼ sec. 3, T. 1 N., R. 2 W., contained angular and subangular pebbles of granite and quartzite less than 1 inch in diameter as well as rounded pebbles of basalt as much as 1½ inches in diameter. The angularity of the foreign pebbles suggests ice rafting, rather than stream transport. A 3-inch bed of stratified very fine micaceous, quartzose sand is interbedded with nonstratified gritty silt that composes the bulk of the deposits in this exposure. The angular grit-sized particles are of basalt.

The Tualatin Valley deposits overlie Columbia River basalt, and probably locally overlie the Troutdale formation. They have been deeply weathered and commonly have a red soil capping. They are mantled in most places by loessial silt. The possibility of ice rafting of the angular pebbles suggests a Pleistocene age for the deposits. The similarity in topographic situation, relative degree of weathering, and stratigraphic relations suggest that these deposits are correlative with the high-level deposits of the Sandy River-Clackamas River area and should be included with them on the map.

Over much of the northern part of its extent in the Sandy River-Clackamas River area and in the Tualatin Valley, the Springwater formation is overlain by loess. The loess covers this unit and older formations locally but not younger deposits. The Springwater formation unconformably overlies the Troutdale formation and Boring lava, and as previously discussed, is probably younger than the Walters Hill formation. No fossils have been found that could be used to date the Springwater formation, but it is considered to be of early (?) Pleistocene age mainly on the basis of relative degree of weathering.

High-level weathered gravels along the east side of the Willamette Valley about 50 miles southwest of Portland have been named the Lacomb gravels by Allison (1953, p. 9). An early Pleistocene age was assigned to them also. The Lacomb gravels have a similar range in topographic position and the profile of weathering is markedly similar to that on the Springwater formation of this area. Probably the formation described here will be correlated with the Lacomb gravels when mapping of the intervening areas is completed.

The distribution, topographic expression, and lithologic character of the Springwater formation in the Sandy River-Clackamas River area indicates that it was laid as a piedmont deposit before the Sandy or the Clackamas River became entrenched. This stage of alluviation may have been caused partly by large-scale pyroclastic eruptions in the adjacent Cascade Mountains that overloaded the streams. Such activity may account for both the coarse gravel and the mudflow deposits. Alluviation during Pleistocene interglacial intervals in the Puget Sound lowland is thought to have resulted from intensive but intermittent volcanic activity at Mount Rainier (D. R. Crandell and D. R. Mullineaux, oral communication).

Terraces cut adjacent to the mouth of the Columbia River gorge at an altitude of about 550 feet may represent the floor of the ancestral Columbia River in early Pleistocene time and therefore may be of the same age as the lower(?) Pleistocene alluvial deposits.

LOESS

The mantle of yellowish-brown clayey, sandy silt that overlies the Springwater formation and older rocks south and west of the Columbia River is believed to be a loessial deposit. The loess caps ridges between the Columbia River and the Sandy River, mainly above an altitude of about 600 feet. It caps the Springwater formation southward to near the town of Boring, and veneers the older formations in the hills between Boring and Gresham. It also mantles the north side of the hills in the Mount Scott area, south to about the Clackamas County line. West of the Willamette River the loess forms an extensive cover on the Tualatin Mountains, extending to the floor of the Tualatin Valley on the west side, and occurs mainly above an altitude of about 600 feet on the east side, but extends down to 300 to 350 feet above sea level locally on the noses of some spurs. In places the surface of the loess conforms in a general way to the topography of the weathered surface of the underlying bedrock. It caps ridges and spurs and is absent on steeper slopes. The edge of the loess generally is at a sharp slope break. The loess occurs at altitudes of more than 1,600 feet in the northwestern part of the area.

The deposits thin away from the Columbia River flood plain. Tne greatest known thickness of the loess is 55 feet. This was determined from a deep auger hole at an altitude of about 1,090 feet on a crest of the Tualatin Mountains about a quarter of a mile north of the junction of Springville road and Skyline Boulevard in the SW¼NE¼ sec. 15, T. 1 N., R. 1 W., where the loess overlies clayey weathered basalt. Locally the loess may be thicker, and a thickness of more than 100 feet is inferred for the deposits along their northern limit south of the Sandy River. A thickness of 5 feet was arbitrarily selected as the limit of mappable loess and this limit is reached along the west edge of the report area. Reconnaissance of the area immediately to the west did not indicate the presence of loess more than 5 feet thick.

The loessial deposits are yellowish-brown clayey, sandy silt, which is homogeneous and structureless. No stratification has been abserved in this material by the author. Locally pebbles have been found near the base of the deposit, that are believed to represent colluvial contributions from adjacent conglomerate of the Troutdale formation during the accumulation of the loess. A size-distribution analysis of a typical sample from the upper loessial material at the Sylvan clay pit in the S½ sec. 6, T. 1 S., R. 1 E., indicated 19 percent sand by weight, 64 percent silt, and 17 percent clay. The clay mineral constituents of the loess, as determined by Gude, by X-ray diffraction methods, are kaolinite and illite, and an undetermined clay mineral, perhaps montmorillonite or chlorite, was also found in the sample. The silt and sand are mainly of quartz but contain conspicuous amounts of muscovite and lesser amounts of tourmaline, magnetite, and hornblende. These mineral fragments are mostly angular and unweathered. Atterberg limits determined for four samples of the loess are as follows: liquid limit, 29 to 32; plastic limit, 17 to 23; and plastic index, 9 to 12.

A podzolic soil profile, commonly 5 or 6 feet deep, is developed on the loess, although mottling and reticulation to depths of 8 feet or more are seen locally. The relative thinness of this profile probably is due to the quartzose character of the loess and the low permeability of the deposits. Shotlike concretions of iron oxide are abundant in the loessial soil. A blocky or polygonal structure is developed locally in the B horizon. Leaching along fractures bounding the blocks apparently has removed all constituents except quartz silt, which stands out as gray streaks about one-half inch wide that contrast with the moderate-yellowish-brown color of most of the deposit. The soil development aids in distinguishing the loess from some other silty deposits that are similar in appearance.

The loess mainly overlies Columbia River basalt west of the Willamette River, but it also mantles Troutdale formation, Boring lava, and Springwater(?) formation in this area. East of the Willamette River it mantles these same units, and also the Walters Hill formation in the hills northwest of Boring.

The Tertiary formations have been deeply weathered prior to the deposition of the loess, and commonly the loess overlies a red clayey soil developed on the underlying parent material. Locally it mantles saprolite that is not capped by the red soil. In fewer places the loess overlies unweathered rock that apparently represents an eroded surface.

The contact between the loess and the saprolite or red clayey soil commonly appears to be gradational. This anomalous relationship is probably a result of the downward infiltration of fine silt particles of the loess and the upward movement, perhaps by frost heaving, of fragments of weathered material into the overlying silt.

The youngest formation mantled by the loess is the Springwater formation. The Gresham formation of middle(?) Pleistocene age is not mantled by loess. The age of the loess then is early(?) and middle(?) Pleistocene. The loess is, in part, the same silt that was called the "Portland Hills silt member" by Lowry and Baldwin (1952, p. 10), who considered it to be the uppermost member of the Troutdale formation and of late Pliocene or early Pleistocene age.

The origin of the silt deposits has been a subject for conjecture in nearly all previous discussions of this area. They have been variously considered to be (1) water-laid (Diller, 1896, p. 485; Libbey, Lowry, and Mason, 1945, p. 10; Wilkinson and others, 1946, p. 26; Lowry and Baldwin, 1952, p. 11); (2) a product of residual weathering of basalt (Diller and others, 1915, p. 29); (3) a wind-transported deposit (Darton, 1909, p. 11; Libby and others, 1944, p. 5); and (4) a combination of all three (Williams, 1916, p. 14; Treasher, 1942a, p. 14). The quartzose character of the deposits indicates that they are not a product of weathering of basaltic parent materials. I believe that the silt deposit is a loess because of (1) the conformity of the silt mantle to preexisting topography, (2) the lack of stratification in the deposits, (3) the distribution of the deposits only south and west of the Columbia River flood plain, (4) the thinning of the silt away from the Columbia River flood plain, and (5) the general lack of widespread contemporaneous water-deposited sediments at equivalent altitudes. The distribution and pattern of variation in thickness strongly suggest the lower Columbia River valley as the source area for the loess.

GRESHAM FORMATION

Gravel and mudflow deposits in terraces along the Sandy River and correlative gravelly deposits in terraces along the Clackamas River represent alluviation of valleys cut into the Springwater formation. They are of middle(?) Pleistocene age and are here named the Gresham formation. The Gresham formation is present on both sides of the Sandy River and extends from the eastern edge of the mapped area to within about a mile of the town of Troutdale. Deposits assigned to this unit underlie the town of Gresham, from which the name is taken, and extend through Pleasant Valley to the Sunnyside district, north of the Clackamas River. Alluvial gravel deposits of this unit along the Clackamas River from the vicinity of Estacada to Oregon City are remnants of a former flood plain that had a maximum width of about 5 miles.

Weathered sedimentary beds underlying a late Pleistocene silt fill in the Willamette Valley are mapped with the Gresham formation and are probably correlative. Terrace sand deposits along the south side of the Columbia River up to about 450 feet above sea level east of Chamberlain Hill also are considered part of this unit, largely because of topographic position.

The Gresham formation occurs as terraces with surfaces commonly between 300 and 400 feet above present stream level and 200 feet or more below the surface of the adjacent Springwater formation along much of the Sandy and Clackamas Rivers (fig. 15). The surface of the Gresham ranges in altitude from about 650 feet along the upper parts of the streams in this area to less than 300 feet on the downstream terrace remnants. The thickness of the unit commonly is between 100 and 150 feet along the Sandy River. The thickness of the formation along the Clackamas River is probably about the same. The deposits on the terrace east of Chamberlain Hill are probably about 50 feet thick.

Cobble gravel and bouldery cobble gravel compose most of the Gresham formation but, as in the Springwater formation, mudflow rocks are important constituents along the Sandy River. The mudflow deposits range in thickness from about 10 feet to about 50 feet. A single mudflow deposit is present on the southwest side of Chamberlain Hill at an altitude of about 250 feet. It is underlain by silt, pebbly silt, and gravel and is overlain by silt. At other localities, the formation contains multiple mudflow layers as along the bluff above a logging road that follows the abandoned railroad grade to Dodge Park in sec. 25, T. 1 S., R. 4 E., where three separate mudflow breccias are present. The upper, middle, and lower mudflow deposits at this locality are about 10, 35, and 24 feet thick, respectively. The upper two are separated only by a soil profile, but the lower one is overlain by 30 feet of sand and gravel. Cobble gravel or bouldery cobble gravel, commonly more than 20 feet thick, composes the basal part of the formation in most places. A basal mudflow deposit is known at only one locality. Locally along the Sandy River the formation does not contain mudflow deposits.

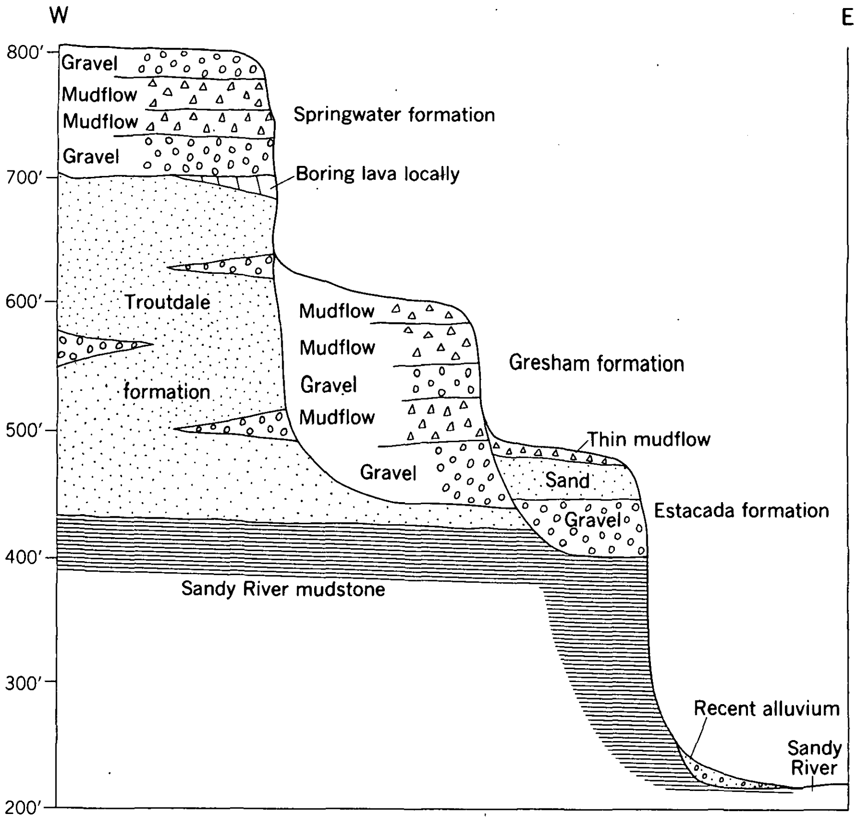

Figure 15.—Generalized section through the west bank of the Sandy River near Dodge Park showing relations of the Springwater, Gresham, and Estacada formations and the bedrock.

In the vicinity of Hurlburt School, in the SE¼SE¼ sec. 3, T. 1 S., R. 4 E., more than 25 feet of structureless clayey silty sand overlies bouldery cobble gravel of the middle(?) Pleistocene alluvial deposits. A size-distribution analysis of this material indicates about 49 percent sand by weight, 36 percent silt, and 15 percent clay. Similar material is widespread between this locality and the town of Springdale, and is exposed in all road cuts. Evenly stratified material that is similar in other respects to other fine-grained deposits in this vicinity is exposed in a road cut in the NE¼SW¼ sec. 3, T. 1 S., R. 4 E. That single exposure of stratified material indicates that these fine-grained sediments were deposited in water, perhaps in a pond or lake formed by local damming by a mudflow. This clayey silty sand was mapped with the Gresham formation. Stratified silty sandy clay overlies mudflow deposits of the Gresham formation at an altitude of about 440 feet in the NW¼NE¼ sec. 14, T. 1 S., R. 4 E., on the east side of the Sandy River south of Gordon

Creek. These stratified sediments are about 38 percent clay by weight, 30 percent silt, and 32 percent sand. They too are probably the result of local ponding and also are mapped as Gresham.

The coarser materials of the Gresham formation are composed entirely of basaltic and andesitic fragments derived from the Cascade Mountains. The gravel deposits are poorly sorted, poorly stratified coarse gravel, chiefly cobble gravel and bouldery cobble gravel. The mudflow deposits in the Gresham are similar to those in the Springwater formation. As the Gresham is similar lithologically in all respects to the Springwater, it must be distinguished from the Springwater on the basis of relative topographic position and degree of weathering.

The profile of weathering on the Gresham formation differs from that on the older Springwater formation in depth and lack of red soil. The Gresham is decomposed to depths of 25 to 35 feet. The resulting saprolite is similar in many respects to the saprolite beneath the red soil on the Springwater formation. Commonly, however, some larger pebbles, cobbles, and boulders have solid cores because of incomplete weathering. The weathering of these deposits has not progressed sufficiently to produce a red soil at any locality. The upper part of this profile of weathering is well exposed in a road cut about 1 mile north of Logan, in SE¼ sec. 27, T. 2 S., R. 3 E.

The similarity of weathering of sedimentary deposits underlying late Pleistocene silts along the north bank of the Willamette River north and west of Canby is the basis for including them with the Gresham formation. The sedimentary materials along the Willamette River are weathered conglomerate, sandstone, and mudstone with many interbedded peaty layers. No red soil is known on these deposits. They contain well preserved twigs, branches, and cones.

The terrace deposits east of Chamberlain Hill are mostly very fine sand and silt.

The age assignment of the Gresham formation also is relative. The Gresham occupies a position within valleys cut into the surface of the Springwater formation and is less weathered than the Springwater although the profile of weathering is still impressive. It is not capped by loess, and therefore, is younger than the Springwater formation. A pollen analysis of a peat sample from the north side of the Willamette River, almost directly across from the mouth of the Molalla River, was made by Estella Leopold of the U.S. Geological Survey, who concluded that the material probably was not of glacial origin. Mastodon teeth were obtained from beds along the Willamette River in the 1920's, but were not available for study. Mainly on the basis of relative topographic position and degree of weathering the Gresham formation is of middle(?) Pleistocene age.

Gravel deposits along the east side of the central Willamette Valley that occupy intravalley terrace positions at about the same altitude as the Gresham formation and that are deeply weathered have been named the Leffler gravels by Allison (1953, p. 9). The Gresham formation may be found to correlate with those gravel deposits when mapping of the intervening area is completed.

The entrenchment of the river valleys between early and middle Pleistocene time may have been due in part to lowering of sea level during a glacial stage. The deposition of the Gresham formation may then have been the result of change in base level owing to eustatic rise in sea level during an interglacial stage. Entrenchment of the stream valleys, however, may have been the result of normal re-establishment of drainage after a period of alluviation in which the Springwater formation was deposited, or it may have been caused by uplift of the Cascade Range.

Alluviation also may have been caused by some other means than eustatic rise in sea level. Glaciation probably did not cause deposition of the Gresham, because the pollen analysis of peat in material thought to be correlative with the main part of the formation indicates a nonglacial rather than a glacial climate. Large-scale pyroclastic eruptions, however, may have caused the alluviation as suggested for the Springwater formation.

ESTACADA FORMATION

Still another group of alluvial gravel and small mudflow deposits, of late(?) Pleistocene age, occur along the Sandy and Clackamas Rivers. They are here named the Estacada formation for the town of Estacada, part of which is sited on these deposits. Mapped with the Estacada formation are bedded deposits of sand in the lower part of the Sandy River that locally overlie the alluvial gravel and are overlain by thin mudflow deposits. The Estacada formation occurs in terraces along the Sandy River, the Clackamas River, and the lower part of Clear Creek. It caps several spurs bounded by entrenched meanders along the lower part of the Sandy River. The crests of the spurs range in altitude from about 550 feet to less than 200 feet. They generally are between 200 and 300 feet above stream level and about 100 feet below the surface of the adjacent Gresham formation. Along the Clackamas River the Estacada formation forms terrace remnants of a former flood-plain deposit that was nearly 3 miles wide at its widest point. The formation is present on both sides of the river from near Estacada to between Carver and Rock Creek. The surface of these deposits along the Clackamas River is generally between 100 and 150 feet above stream level and about 100 to 150 feet below the surface of the adjoining Gresham formation. The Estacada formation along Clear Creek is present only below the narrows downstream from Fischers Mill. The surface of the formation along Clear Creek is 50 to 100 feet above stream level and about 150 feet below the surface of the adjacent Gresham formation.

Locally along the Sandy River the Estacada formation is as much as 100 feet thick. Along the Clackamas River and Clear Creek it is generally between 30 and 50 feet thick.

Like the older alluvial deposits, the Estacada consists mainly of cobble gravel and bouldery cobble gravel. The gravel along the lower Sandy River for about 11 miles upstream from the town of Troutdale, however, commonly is overlain by a persistent stratum of evenly bedded sand that, locally, is between 50 and 100 feet thick. The surface of the bedded sand at a locality on the west side of the river in the SW¼SE¼ sec. 15, T. 1 S., R. 4 E., is slightly less than 400 feet above sea level. At this locality 30 to 40 feet of stratified sand overlies about 30 feet of bouldery cobble gravel at an altitude of about 350 feet. The contact between the two is abrupt, and the surface of the underlying gravel is apparently unweathered. The sand is overlain by 10 to 12 feet of angular material of less than one-quarter inch diameter. Some fragments however, are as much as 1 inch in diameter and some are subangular to subrounded. The upper material is believed to be a mudflow deposit and the same as that which overlies cobble gravel directly at localities farther upstream. The mudflow deposits of the Estacada formation are not present downstream from this point, but the alluvial gravel is mantled by bedded sand at all localities between here and Troutdale. Upstream the mudflow deposits are less than 25 feet thick and locally, particularly near the map boundary, are only 5 to 7 feet thick. Locally the mudflow material is poorly stratified. This mudflow material, unlike that in the older deposits, contains no large blocks. The largest fragment is less than 2 inches in diameter.

The Estacada formation in the Clackamas River and Clear Creek localities consists chiefly of pebble and cobble gravel, which is bouldery at many localities. Locally this gravel is capped by as much as 20 feet of very fine sand and silt, but at most places the silt is thinner or absent. Mudflow deposits are lacking in the Estacada formation in these valleys.

As in the older alluvial deposits, the materials composing the Estacada formation also originated in the Cascade Mountains. Mafic lava rocks, many of them porphyritic, are the dominant rock types in both the gravel and the mudflow deposits of the Sandy and Clackamas River areas. The bedded sand interstratified with these deposits along the lower Sandy River is loosely consolidated, very fine to very coarse sand, pebbly in part, but is chiefly of fine to medium grain size. It consists mainly of quartz grains, but the coarser fractions are largely composed of fragments of mafic volcanic rock.

The capping mudflow deposits along the Sandy River are weathered to a depth of about 6 feet, with partial decomposition in the upper 3 feet. Along the Clackamas River the profile of weathering on the silt is only about 4 feet deep and includes "shot," mottling, and soil structure. The profile of weathering on the gravel, however, is as much as 10 feet deep. It is characterized by partial decomposition with the formation of weathering rinds, one-quarter inch or less in thickness. A good exposure of this profile of weathering is in a road cut in SE¼NW¼ sec. 26, T. 2 S., R. 3 E.

The relative topographic position and degree of weathering of the deposits suggest a late Pleistocene age for the Estacada formation. It is younger than the Gresham formation as is established by its lower terrace position and considerably lesser degree of weathering. The Estacada formation, however, is higher topographically and is much more weathered than younger deposits.

The Estacada formation of the Sandy River and Clackamas River valleys probably will be found to correlate with the Linn gravels of Allison (1953, p. 11) in the central Willamette Valley when mapping of the intervening areas is completed. Similarity in degree of weathering of the two deposits strongly suggests this correlation.

LACUSTRINE DEPOSITS

The floors of the valley of the lower Columbia River and Tualatin and Willamette Valleys are almost completely covered by unconsolidated gravel, sand, silt, and clay that are interpreted as lacustrine deposits of late(?) Pleistocene age. They include the Portland delta deposits of Bretz (1925, p. 252–257; 1928, p. 697–700), the Portland and Tualatin terrace gravels and the Willamette terrace deposits of Treasher (1942b), the Portland gravels of Lowry and Baldwin (1952, p. 17–19), and the Willamette silts of Allison (1953, p. 12, 13). Bretz proposed that these water-laid deposits all were emplaced by a flood of far greater proportions than any in historic time. The present writer agrees fully with these concepts but differs with Bretz mainly in the details of the mechanics of deposition. Because the sediments of this stage of alluviation include far more than the deltaic deposits and because much of the alluviation was in slack water, the more inclusive genetic term lacustrine deposits is applied in this paper. This change in terminology does not imply any radical departure from the original concepts of Bretz in regard to the map unit in the immediate Portland-Vancouver area.

The lacustrine deposits are distributed widely in the area up to altitudes of 350 to 400 feet. Their surface has been dissected and terraced, and the original surface probably has been largely destroyed. Terraces at altitudes of about 275 and 200 feet are especially prominent in the Portland-Vancouver area. The lacustrine deposits north of the Columbia River overlie a weathered erosional surface of the Troutdale formation that slopes westward about 10 feet per mile to a northwestward-trending bluff line, which extends from Vancouver Junction on the northwest to about the point of intersection of the township line with the flood plain 3 miles east of Vancouver. This bluff line marks the top of a cliff about 150 feet high that is marginal to a former Columbia River flood plain. The lacustrine deposits have buried this former topography, and east of the bluff line they commonly are from 50 to 150 feet thick. West of the bluff line, in Vancouver, they are as much as 250 feet thick. At most localities east of Portland the thickness of the deposits is less than 100 feet, although locally it is as much as 150 feet. The silt deposits at the north end of the Willamette Valley, south of Petes Mountain, are as much as 75 feet thick, but most commonly are about 30 feet thick.

The lacustrine deposits have been mapped in some detail using grain size as the criterion for differentiating units. Three units are distinguished: a gravelly phase, a sandy phase, and a silty and clayey phase. North of the Columbia River the sediments are zoned in a roughly lobate pattern at the mouth of the Lackamas Lake channel. This channel carried part of the Pleistocene flood waters that deposited the lacustrine deposits, and the coarsest material was dropped nearest the mouth of the channel. South of the river the transition from coarse to fine material is not as abrupt. Nearly all the deposits in the vicinity of Portland and east of Portland are gravelly, but in the University Park district of north Portland they are sandy. The deposits of the Willamette and Tualatin Valleys are sand and silt, except locally, as west of Oswego Lake and south of Canby, where the material is gravel. Angular erratic boulders, as much as 7 feet in maximum size, most of which are granitic in composition, are widely distributed on and in all the lacustrine deposits. They also are found resting on bedrock at altitudes as high as 350 feet.

GRAVELLY PHASE

The gravel deposits composing the easternmost band of the zonate sediments north of the Columbia River and most of the deposits in the lower Columbia River valley south of the river constitute the gravelly phase of the lacustrine deposits. The gravelly phase is also found locally in the Tualatin and Willamette Valleys. It varies widely in grain size. In most places it consists of bouldery pebble

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and cobble gravel with a sandy matrix. Some boulders incorporated in the gravel near Gresham are more than 15 feet in greatest dimension, but commonly they are less than 8 feet in maximum size. They are subangular to rounded and are mainly distributed along foreset beds in the gravel to a depth of at least 50 feet, but some are in upper, possibly reworked, parts of the gravel. They appear to be limited in their distribution to areas at the discharge ends of channelways once occupied by flood waters (fig. 16). Locally the gravelly phase consists of an open-work pebble or cobble gravel that contains little or no sandy matrix, although commonly it is bonded by clayey silt coatings on the gravel. Near the western and northwestern margin of the gravelly phase the deposits grade to pebbly sand. The gravel in the eastern part of the area generally is continuous downward to the contact with the underlying bedrock. Westward, however, north of the Columbia River, the gravelly deposits overlap sandy deposits. Locally near the western limit of the gravelly phase in Portland, as along Greeley Avenue, gravel showing cut-and-fill structure overlies about 20 feet of sand that in turn overlies coarse bouldery gravel. Deltaic foreset bedding with dips as steep as 27° is common in the deposits of the gravelly phase. Direction of dip changes abruptly within relatively short distances laterally. For example, less than a mile northwest of Gresham the beds that apparently represent an eddy deposit (Bretz, 1928, p. 697) dip to the southwest, but about a mile northeast of Gresham, they dip southeastward.

Nearly 60 percent of the pebbles are of Columbia River basalt, and about 30 percent are of other mafic volcanic rock types. The rest consist of quartzite, tuff, granitic types, and sandstone. Cobbles and boulders are primarily of Columbia River basalt and Boring lava, but many other rock types are represented. In the lower Columbia River valley the boulders are dominantly rounded to subrounded, but the boulders larger than 6 feet in diameter are angular to subangular. Although most of the boulders were derived locally, some may have been derived from the Columbia River gorge. These boulders differ from the erratic boulders in lithologic character, shape, and distribution. The gravel is composed mainly of well-rounded pebbles and cobbles. The Tualatin Valley deposits west of Oswego Lake, however, are dominantly angular, bouldery gravels, and are generally poorly sorted and lack stratification. They grade laterally into sorted and stratified, foreset-bedded, well-rounded gravel deposits that dip to the northwest near the western margin of the Oregon City quadrangle. The sandy matrix of the deposits of the gravelly phase is composed mainly of fragments of mafic volcanic rocks, but it also contains quartz, muscovite, and other constituents.

Deposits of the gravelly phase, as much as 12 or 15 feet thick, that mantle the Troutdale formation locally between Wilkes School and the town of Troutdale were not mapped because the Troutdale formation crops out abundantly in this area.

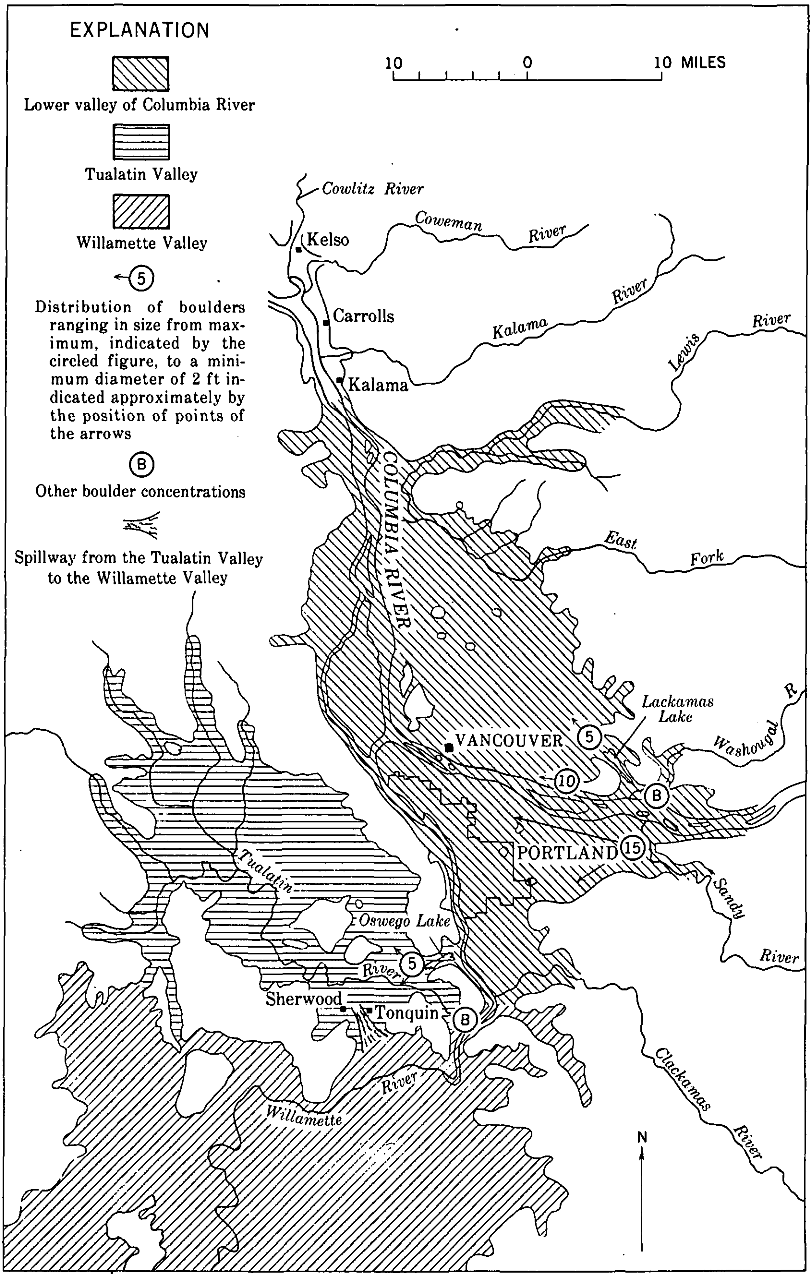

FIGURE 16.—Ponded valley system in the vicinity of Portland, Oreg.

SANDY PHASE

The sandy phase of the lacustrine deposits is widely distributed in an irregular belt 2 to 4 miles wide that extends generally northeastward from Vancouver. Its boundaries are gradational. It grades from coarse and very coarse sand along the boundary with the gravelly phase to fine sand along the boundary with the silty and clayey phase. Sandy material in the University Park district of north Portland shows a similar gradation from coarse to fine. Stratified deposits of fine sand and silt as much as 50 feet thick overlie bouldery gravel at many places adjacent to the Willamette River between Canby and Oswego and are considered to be part of the sandy phase of the lacustrine deposits. Quartz is the dominant constituent of the fine fractions of the sandy phase, but most of the coarser fraction consists of fragments of mafic volcanic rock.

Dunelike forms northeast of Vancouver near Hidden, which Bretz called "river bars" (1925, p. 253–254), were considered by Allison (1933, p. 718) to be erosional features. Allison, however, believed them to be erosional remnants of a preflood terrace. They are probably erosional features cut mainly from the sandy phase of the lacustrine deposits. Their composition ranges from fine to coarse sand. Exposures reveal stratification ranging from nearly horizontal (SW¼SW¼ sec. 12, T. 2 N., R. 1 E.) to steeply inclined (spur NE¼NE¼ sec. 10, T. 2 N., R. 1 E.). The configuration of some of the features (NW¼NE¼ sec. 14, T. 1 N., R. 1 E.) suggests that channeling or scouring was an active agent in their formation. Near Lake Shore School a large granite erratic rests on a small mound that is probably genetically related to larger ridges in the vicinity of Hidden. Although the form and distribution of some of the prominences suggest that they are dunes, other features, such as the wide range in sand-grain size and the horizontal stratification, are more properly related to water-laid deposits. The fan-shaped alinement of lesser features to the north, but south of Salmon Creek, and the position of this area of prominences between two channels cut in the lacustrine deposits are also suggestive of water rather than wind as the dominant agent of deposition. The flat bedding noted in one of the larger features is not typical of bar structure. These forms therefore are considered to be erosional remnants of water-laid beds of the sandy phase of the lacustrine deposits. The dunelike feature in sec. 33, T. 3 N., R. 1 E., may be of windblown origin, but its internal structure is not known. It is composed mainly of fine and medium sand. Because of the similarity in form and alinement to the features in the vicinity of Hidden, this dunelike feature too is probably an erosion remnant. Perhaps the sandy phase overlapped the silty and clayey phase in this locality, and these sandy prominences are all that remain.

SILTY AND CLAYEY PHASE

The belt of sand north of the Columbia River grades almost imperceptibly northwestward into a belt of very fine sand, silt, and clay that covers much of the area north and south of Salmon Creek and mostly west of U.S. Highway 99. These fine-grained sediments are more than 100 feet thick in places. Thin silty and clayey phase has been mapped with the Troutdale formation north of Salmon Creek where the silt and clay were considered too thin to map separately.

Similar deposits mantle the floor of the Tualatin Valley and part of the Willamette Valley. Along the lower reaches of the Tualatin River the silty and clayey phase occurs up to altitudes of 225 to 250 feet. This same general upper limit also applies to deposits in the Willamette Valley north of the Willamette River. In the wider upper part of the Tualatin Valley the deposits occur at more than 300 feet in altitude. Although these beds locally are stratified, in most places they show no stratification. Stratification in the deposits is present in both the Tualatin and Willamette Valleys, but is not known in the silty and clayey phase north of the Columbia River. The very fine sand and silt fraction consists mainly of quartz but contains muscovite in appreciable quantities.

The silty and clayey phase of the lacustrine deposits is probably equivalent to the Willamette silts of Allison (1953, p. 12) and is a part of the same fill to which he applied that name.

AGE AND MODE OF DEPOSITION

The lacustrine deposits contain abundant evidence that they were deposited in a vast lake that formerly occupied simultaneously the lower valley of the Columbia River, and the Tualatin and Willamette Valleys (fig. 16). The deposits appear to have been emplaced in the ponded region by flood waters of great volume and energy, in late(?) Pleistocene time.

The condition of ponding is evident from the occurrence and distribution of erratic boulders, from the wide distribution of the deposits themselves, and from the apparent rapid loss in transporting power of the flood waters entering the region. Allison (1935) has shown that the erratics are widely distributed throughout the entire area of the indicated lake, and that their distribution, shape, size, and lithologic character indicate probable ice rafting from a distant source. Rapid loss in transporting power of the flood waters that emplaced the deposits is indicated by the zonate pattern of grain-size distribution, by the deltaic bedding, and by the rapid decrease in size of boulders downstream from the mouth of the Columbia River gorge (fig. 16).

The extent of the inundation is indicated by the distribution of sediments and erratics, and from an upper limit inferred from divide areas that the waters apparently did not transgress. Erratics are widely distributed in all three valleys up to an altitude of about 350 feet. The top of the gravelly phase of the deposits, about 1.5 miles northeast of Gresham, is about 375 feet above sea level. There is no evidence, however, that the waters crossed divides that have altitudes of only a little more than 400 feet. Thus, the maximum lake level must have been between 375 and 400 feet above sea level.

The concept of ponding of this region is not new. Condon first suggested that this area was submerged by what he called the "Willamette Sound" (1871). Bretz (1919, p. 506) briefly supported a modified "Willamette Sound" hypothesis but later (Bretz, 1925, p. 252; 1928, p. 697) abandoned it in favor of nonponded flood waters of spectacular proportions. He considered the deposits, which he called "the Portland delta," to be wholly subfluvial. Treasher (1942a, p. 13) is a recent proponent of ponding.

The existence of such a body of water requires some mechanism or agency of ponding the Columbia River downstream from the Portland region. Several possible means of accomplishing the ponding were considered: damming by (*a*) valley glaciers, (*b*) intracanyon lava flows, (*c*) landslides, (*d*) ice jams, or (*e*) aggradation; eustatic change in sea level; crustal movement; or hydraulic damming. Reconnaissance of the valley of the Columbia River and tributary valleys downstream from this area has revealed that the Columbia River was not dammed by either valley glaciers or intracanyon lava flows. Evidence of landslides, massive enough to have accomplished the damming, also is lacking. Blocking or impeding the drainage of the Columbia River downstream from Portland by ice jams was proposed by Allison (1935, p. 626). The narrowest constriction in the channel below Portland, near Kalama and Carrolls, Wash., is more than 1.5 miles wide, so that a dam formed by the jamming of icebergs would be of large dimensions. The lack of any concentration of berg-rafted erratics in this vicinity suggests that this type of damming did not occur. The character of the mass of sediments indicates that they were deposited in a ponded body of water and could not themselves have been responsible for the ponding, a possibility that was suggested by Treasher (1942a, p. 13). Late Pleistocene eustatic rise in sea level of the order of magnitude required has not been reported from other parts of the world and there is no direct evidence of it on the Pacific coast west of Portland. Furthermore, the time of ponding (p. 68) probably was coincident with a near maximum extent of continental ice sheets, a time when sea level was low rather than high. No evidence of crustal movement that could have been responsible for submergence of the area has been found. Both crustal movement and eustatic change in sea level probably would result in a gradual change in base level, with which aggradation would perhaps keep pace, rather than in conditions of ponding.

Evidence of flood waters of great volume and energy consists of the distribution of the boulders other than erratics, the erosional features in the Oswego Lake channel, and an unusual channeled spillway that led from the Tualatin Valley into the Willamette Valley. This evidence has led to an hypothesis of hydraulic damming, whereby more water entered the valley system than was able to escape through the restricted channel downstream. The excess water therefore accumulated in a widespread but short-lived lake.

The boulders have been previously described, but the following aspects of their distribution and character are pertinent:

1. They are present at the discharge end of not only the Columbia River gorge but also the Lackamas Lake channel and the Oswego Lake channel.
2. They decrease abruptly in size from maximum to 2 feet or less within 2 or 3 miles of the discharge end of the channel (fig. 16).
3. The rounded to subrounded shape of many boulders indicates that they were stream borne.
4. Their lithologic character implies that many of the boulders, particularly the larger angular to subangular ones, were derived within 1 or 2 miles of their site.
5. Their large size indicates that waters of extremely high energy were responsible for their transport.

Many of the boulders rest on terrace levels, which suggests that they have been let down vertically by removal of the fine material in which they formerly were incorporated. The distribution and abrupt decrease in size of the boulders at the discharge ends of channel constrictions suggest that these channels, large as they are, acted as venturi tubes, increasing velocity and therefore competency of the water passing through them. Total occupation of such large channels would require water of considerable volume.

One of the channel constrictions from which boulders were discharged is the Oswego Lake channel between the lower valley of the Columbia River and the Tualatin Valley. The depressions on the north side of the lake, in sec. 9, T. 2 S., R. 1 E., are interpreted as gigantic potholes and channel scours. West of Oswego Lake, the direction of foresetting and the size of material in deposits in the railroad cut west of Cook suggests westward-flowing water of high energy with a later reversal of flow to the east by low-energy water.

Four or five miles southwest of the western end of the Oswego Lake channel is a low drainage divide area between the Tualatin Valley and the Willamette Valley (fig. 16). This area is well shown on the Sherwood, Oreg., 7½-minute topographic quadrangle map (U.S. Geological Survey, 1954 edition, scale, 1:24,000). The town of Sherwood is just northwest of this drainage divide and the small community of Tonquin is near the east edge of the area. Most of the area below an altitude of about 300 feet is rough, bare basalt that has been channeled and scoured, and the floor of the main channel at the drainage divide area is about 150 feet in altitude. There are several closed depressions and many isolated hummocks of bedrock. The configuration of the channels suggests that they were formed by flood waters pouring from the Tualatin Valley into the Willamette Valley. The vertical range of the eroded rock and the character of the channeling indicate that large volumes of water of great erosive power must have acted here.

Transportation of the sediments by high-magnitude flood water was suggested by Bretz (1925, p. 252). This hypothesis was later supported by Allison (1932). Treasher (1942a, p. 13) and Lowry and Baldwin (1952, p. 20) concluded that there was no evidence that these deposits were the result of unusually large flood stages. The results of the present field investigation supplement Bretz's finding and confirm his hypothesis of emplacement of the deposits by high-magnitude flood waters.

It seems apparent that ponding of the Portland region did occur and that flood waters of almost unbelievable proportions were active. This ponding could have resulted from the inability of the constricted channel at the north end of the lower valley of the Columbia River to discharge the total volume of the flood at the same rate that it entered the valley system without a rise in water level at the constriction. The channel constrictions in the vicinity of Kalama and Carrolls are constrictions in a relative sense only, for they are more than 1.5 miles wide at the narrowest point between the 350-foot contours on opposite sides of the river at Carrolls. The amount of water required to pond a region of this extent by piling up the water to a depth of 350 feet or more in a channel 1.8 miles wide is of spectacular proportions.

A probable source of such a vast flood is known. A lobe of the continental ice sheet advancing down the Purcell Trench in the Idaho panhandle acted as a valve and impounded all of the drainage in Montana west of the continental divide and south of the ice front (fig. 17). This area is drained by the Clark Fork River, and its tributaries, which emerges from its narrow valley at Pend Oreille Lake in northern Idaho. The drainage system was ponded to an altitude of 4,150 to 4,200 feet, and the lake thus formed contained more than 500 cubic miles of water (Pardee, 1942, p. 1594). This lake was named Glacial Lake Missoula by Pardee (1910). He later

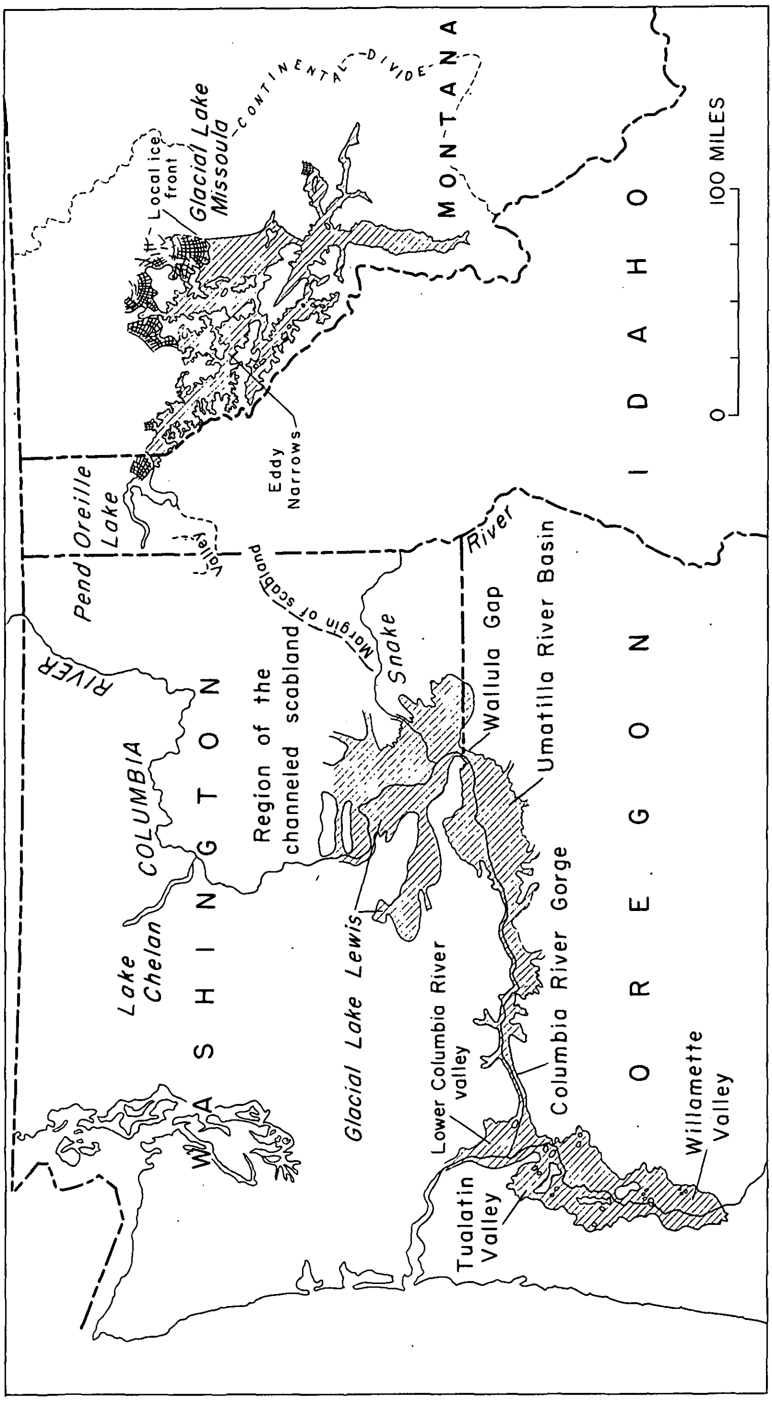

FIGURE 17.—Glacial Lake Missoula and the ponded valley system.

postulated sudden release of the lake water with a peak discharge of about 2.5 cubic miles of water per hour (Pardee, 1942, p. 1597) at the Eddy Narrows, above which about 380 cubic miles of water was impounded.

This flood of water must have crossed the channeled scabland and formed the features of that area as suggested by Bretz (1930, p. 92). The rush of water, however, was checked at Wallula Gap, where the Columbia River cuts through the Horse Heaven Hills. A computed rate of discharge for this flood through Wallula Gap, of 66,132,000 second feet or about 39 cubic miles of water per day was given by Bretz (1925, p. 258). This is more than 50 times the maximum historic flood stage (1,240,000 second-feet) of the Columbia River, measured at The Dalles, Oreg. (Church and Schalbert, 1949, p. 81), but is only one-sixth the rate of peak discharge of Glacial Lake Missoula.

The distribution of erratics in the Pasco Basin and the Yakima Valley in southeastern Washington indicates that the excess water formed a lake behind Wallula Gap with an upper limit of about 1,100 or 1,150 feet above sea level. The existence of this lake was first recognized by Lt. Symons (1882), who named it Lake Lewis. The importance of Wallula Gap in the formation of this lake was first recognized by Bretz (1925, p. 240). Such hydraulic damming is probably analogous to what happened in the Portland region. The existence of other high-water areas between Portland and Wallula Gap also is indicated by the distribution of erratics (Bretz, 1919, p. 496–497) and all are probably part of one great hydraulic system.

The flooding and the deposition of the lacustrine deposits, which are only slightly weathered, probably occurred in late Pleistocene time during a glacial rather than an interglacial stage.

UPPER(?) PLEISTOCENE SAND AND SILT DEPOSITS

Water-laid deposits of sand and silt disconformably overlie the lacustrine deposits through a wide range in altitude along the Columbia River and the lower part of the Willamette River, and in areas east of Portland. These sediments were referred to as "Pleistocene alluvium" in an earlier report (Trimble, 1957). Because this term is not specific, a more definitive informal term is used in this report. The distribution and physical character of the sand and silt beds have genetic implications that are puzzling and incompletely known. Although these fine-grained deposits are probably about correlative with the lacustrine deposits and probably are part of the same episode of deposition, a separate description seems warranted.

Stratified fine-grained sediments overlie the lacustrine deposits along the south side of the Columbia River almost continuously from St. Johns to near the town of Troutdale between flood-plain level and an upper altitude of about 125 feet. Locally the fine-grained materials contain boulders. Similar deposits containing large boulders, perhaps let down from adjacent bouldery gravels, are present north of the Columbia River for less than a mile west from Fisher, at altitudes between 125 and 150 feet. Remnants of sand deposits are also on the south side of Prune Hill and in the city of Camas at similar altitudes. Bedded sand assigned to this unit is exposed east of Washougal and in the town of Troutdale south of the Columbia River up to 250 feet or more in altitude. East of Corbett Station, south of the Columbia River, more than 50 feet of very fine sand mantles a terrace surface at altitudes as high as 250 feet. The largest area of this unit is in the city of Portland, where stratified silt and sand disconformably overlie the gravelly phase of the lacustrine deposits between the Willamette River and Mount Tabor. The fine-grained sediments occur up to about 300 feet above sea level. Similar and related beds occur west of the Willamette River to an altitude of about 200 feet. The deposits in east Portland extend southward to remnant areas near Clackamas. Thin deposits of silt and sand, locally stratified, mantle two segments of a terrace riser between Rocky Butte and Kelly Butte to an altitude of about 300 feet. A northward-facing terrace riser along Halsey Street is similarly veneered from about NE 126th Avenue to just east of NE 162nd Avenue, but these deposits lack stratification.

The deposits range in thickness from a thin veneer to a maximum thickness of 100 feet, inferred from the log of the Ladd well in east Portland (Griffin and others, 1956, p. 27).

This map unit consists of unconsolidated sand and silt, stratified in most places and locally crossbedded. Crossbedding is mainly in the deposits marginal to the Columbia River flood plain and at the margins of the deposits in east Portland. The sand ranges in size from very coarse to very fine, but is chiefly fine and very fine sand. The coarse sand is limited mostly to the margins of the deposits in east Portland, west of Mount Tabor. Locally pebbles and boulders are present in the deposits and may have been ice rafted to their positions; or they may have been let down from adjacent gravel deposits in which they were incorporated.

An exposure of stratified sand and silt at NE 42nd Avenue and NE Ainsworth Street contains pebbles and angular blocks of mafic volcanic rock more than 12 inches long. These were probably ice rafted to their site.

The stratification and crossbedding and the presence of erratic blocks prove that these deposits were water laid. The nonstratified deposits may include some colluvial and windblown materials, but, because of similarity in all respects except stratification and the recognized presence of pebbles and boulders, most of the nonstratified material seems to have the same general origin as the stratified sediments. The sand and silt are only slightly weathered. Staining and soil structure extends only to a depth of 6 or 7 feet. This weathering is similar to that on the lacustrine deposits, indicating near contemporaneity.

In many places the fine-grained sediments of this unit lie at the base of a scarp or low bluff, locally more than 50 feet high, cut in the gravelly phase of the lacustrine deposits. This sharp topographic break is emphasized by the abrupt change in grain size from coarse pebble gravel to very fine sand and silt. Near the break in slope, the fine-grained deposits are known to be of considerable thickness. These relations indicate disconformity between the gravel and the fine-grained sediments. The total height of the bluff cut in the gravelly phase of the lacustrine deposits is probably locally as much as 150 feet. Total depth of cutting of the gravelly phase was probably about 300 feet. The floor along the Willamette River in Portland was about 20 feet above sea level, and probably was about the same along the Columbia River. In east Portland the floor rises to about 100 feet at Laurelhurst. The floor east of Milwaukie has an altitude of about 150 feet. The lacustrine deposits along the main channel of the Columbia River were eroded or scoured to depth of about 300 feet, or nearly to present river level. In the vicinity of Rocky Butte and Mount Tabor they also were scoured by currents that apparently flowed across the surface of the lacustrine deposits in now-abandoned channels. The floors of these abandoned channels are about 200 feet above sea level, but the depth of erosion west of Rocky Butte and Mount Tabor was nearly to present river level.

The deposits filling the excavated areas are water laid, locally crossbedded, uniformly fine grained sediments. They occur up to an altitude of 300 feet, disconformably overlying lacustrine deposits. A hypothetical explanation of the lake responsible for the lacustrine deposits has been discussed. Normal means of achieving that ponding have been discounted, and the lack of evidence of means of damming the Columbia River would apply similarly to all subsequent episodes. A second episode of ponding that would produce only fine-grained materials in such local situations is extremely unlikely. Although any explanation of the origin of the deposits beyond this point is pure conjecture, the relations discussed above suggest that the scouring of the lacustrine deposits, and, at least in large part, the deposition of the upper(?) Pleistocene sand and silt deposits, must have been accomplished while the lake in which the lacustrine deposits were laid down existed. The early stages of the flood waters formed the lake and these early waters must have carried an extremely heavy load. The main body of the lacustrine deposits was probably emplaced quite rapidly upon formation of the lake. Less load was available for transport by later flood waters and as a result, more energy was available for erosion. This may have permitted subsequent scouring along the main channel and on the west of Rocky Butte and Mount Tabor, as a result of turbulence in this area produced by the presence of these prominences. With slackening of the flood waters, the fine-grained deposits partly filled the scoured areas. How this was accomplished can only be guessed. Cessation of the flood waters produced rapid and uniform decline of the lake and re-establishment of drainage. The scoured areas may have been filled by normal drainage courses of the area, which were re-established at high level on the fill. Perhaps there was continued deposition of flood-plain sediments locally, marginal to the deepening channel. These may be the deposits between the present flood-plain level and the 125- to 150-foot contour. This unit then may be partly lacustrine and partly fluviatile. It may also include minor amounts of colluvial and windblown materials.

RECENT SERIES

RECENT(?) TERRACE DEPOSITS

Alluvial deposits of sand, silt, and gravel, probably of Recent age, occur along the Clackamas River and in an abandoned channel extending from Clackamas to Milwaukie, Oreg., and northward to east Portland. The deposits are present on both sides of the Clackamas River from near Estacada to within a mile of Gladstone. They form terraces that occur at as many as three levels. One group of multiple terrace levels is in the SW¼ sec. 18, T. 3 S., R. 4 E., and the SE¼ sec. 13, T. 3 S., R. 3 E. The surfaces of the terraces of this group range from about 40 to 110 feet above river level. The surface of the Recent(?) terrace deposits along the Clackamas River ranges in altitude from more than 550 feet near Faraday to less than 200 feet near Carver, and about 100 feet near Clackamas. The terrace surface is commonly about 75 to 100 feet above river level. From Clackamas northwest to Milwaukie and northward to east Portland these deposits mantle the floor of a channel cut in the upper(?) Pleistocene sand and silt deposits. The surface of the Recent(?) terrace deposits in this channel is generally less than 100 feet above sea level. In Portland these deposits are mapped above the 50-foot contour, which is the extrapolated upper limit of the Recent alluvium.

The Recent(?) terrace deposits above Carver commonly are less than 30 feet thick. Locally they are as little as 6 to 8 feet thick. Between Carver and Clackamas the deposits are generally more than 50 feet thick.

The terrace deposits above Carver consist of cobble gravel or bouldery cobble gravel. They are mantled by finer grained material at only one place, in the NW¼ sec. 26, T. 2 S., R. 3 E., where 10 feet of sand overlies the gravel. Below Carver the deposits consist generally of 30 to 50 feet of cobble gravel overlain by as much as 25 feet of very fine sand and silt. Probably similar relations exist in the abandoned channel between Clackamas and east Portland, where only the finer grained sediments are known to be present. The gravel of the Recent(?) terrace deposits is composed of mafic volcanic rock types and is similar lithologically to the older alluvial gravel deposits of the Clackamas River valley. The fine-grained deposits are similar in composition to the Recent alluvium of the lower Willamette River. The surface materials of the Recent(?) terrace deposits, however, have been so slightly weathered that a profile of weathering is not apparent in most places and only an incipient soil development is present.

The disposition of these deposits in an abandoned channel cut into the upper(?) Pleistocene sand and silt deposits and as terrace deposits topographically below the Estacada formation, and their slight degree of weathering are the basis for assigning them to the Recent epoch. They are younger than deposits of probable late Pleistocene age, and are less weathered than sediments thought to be Pleistocene.

Similar deposits are lacking in the Sandy River valley, perhaps because of the narrowness of that valley and the greater amount of downcutting in Recent time. Any deposits of this unit that may have been there have been completely removed. Nor are correlative deposits known in the Columbia River valley. The Columbia River, however, as the master stream in the area, probably achieved grade while the tributary streams were still cutting at much higher levels. The former course of the Clackamas River that extends northwest from the town of Clackamas was abandoned, as a result of capture by a lesser tributary of the Willamette. The abandoned channel is now 75 feet above present river level near the town of Clackamas.

LANDSLIDE DEPOSITS

Landslide deposits have been mapped only where they form large and discrete masses of landslide debris. In many localities landsliding has occurred on such a grand scale that entire valley walls are of slide materials and map-unit boundaries have not been drawn for these areas. Many small landslides have not been mapped. The landslide area along the Washougal River is the largest one mapped. An old stabilized landslide area in west Portland is shown on the map. South of the Columbia River, near the eastern edge of the map area is a prominent slide area. A discrete slide area on the north side of Chamberlain Hill was mapped, as were some areas adjacent to the Sandy River and one fairly recent slide about a mile southwest of Estacada. Other smaller slide areas were mapped along the Clackamas River valley.

The landslide deposits consists of displaced debris resulting from the dislocation of adjoining formations. Large blocks of disoriented material compose much of the deposits. In some places sliding has been of the slump type, and stratigraphic relations within the slide mass have not been thoroughly disturbed. Most of the landslide deposits, however, are composed of thoroughly disarranged blocks in a matrix of finer material. Most of the areas mapped as landslide deposits contain Boring lava and the underlying Troutdale formation, which has failed. South of the Columbia River most of the landslides also involve the Sandy River mudstone. A few involve other materials.

Some landslides, such as the Washougal River landslide area, are quite old and probably date back to Pleistocene time. Others, such as the one southwest of Estacada, have occurred since cultivation of the land. Landslide deposits of wide age range are grouped in this unit because of the difficulty in dating most slides.

Landsliding in this area will be further discussed in a separate section.

BOG DEPOSITS

Bog deposits, referred to locally as beaver dam soils, underlie the valley floor of the upper part of Burntbridge Creek east of Orchards, Wash., and extend eastward into the Lackamas Creek flood plain. The deposits form a belt about half a mile wide and about 3 miles long. Estimated maximum thickness is about 10 feet. They are mucks composed of organic-rich muds containing probably 50 percent or more of fragmental plant matter. Below a depth of about 12 inches they are completely saturated with water. In the Lackamas Creek drainage, the bog deposits are overlapped by clayey alluvium along their margins.

The local name of beaver dam soil is perhaps appropriately applied, for these deposits may have accumulated in a ponded area behind a beaver dam or series of such beaver dams. They also may have accumulated in a shallow scour in the lacustrine deposits, possibly aided by beaver dams.

RECENT ALLUVIUM

Recent alluvium covers the flood plain areas of the Columbia and Willamette Rivers and some of their tributaries. The upper limit of the Recent alluvium along the major streams in the vicinity of Portland is at an altitude of approximately 50 feet. Sharp topographic breaks at the margin of the Columbia River flood plain occur repeatedly at about 50 feet in altitude and the contact is extrapolated along this contour where the margin is not so obvious. Upstream the upper altitude at which the Recent alluvium occurs is much higher. Along the Willamette River near the southwest corner of the map area, the Recent alluvium is deposited up to an altitude of about 100 feet, which is also about the upper limit along the Pudding and Molalla Rivers. Along the Clackamas River and Eagle Creek it occurs at altitudes above 300 feet, and in the Sandy River valley, near the east edge of the map area, Recent alluvium is present at more than 400 feet above sea level. Along the upper part of Clear Creek it occurs at altitudes between 500 and 600 feet. The alluvium is probably less than 50 feet thick in most places, but locally may be nearly 100 feet thick. Well logs suggest that the Recent alluvium reaches this greater thickness along the Columbia River flood plain west of Vancouver.

The Recent alluvium of the Columbia River and Willamette River flood plains is composed chiefly of sand and silt. In the major tributary valleys it is mostly sand and gravel. Along the Sandy River, the higher deposits are more sandy. The alluvium near stream level is sandy along the lower reaches and consists of coarse gravel along the upper parts of the Sandy River in the map area. The deposits along the Clackamas River are mainly coarse cobble gravel, as are the deposits along the Pudding and Molalla Rivers. Some of the lesser tributary streams have finer alluvial deposits. The area mapped as Recent alluvium includes many areas of artificial fill, such as the Guild Lake locality and part of Swan Island in Portland, for which alluvial sediments were used as filling materials.

TERTIARY INTRUSIVE ROCKS

SILVER STAR GRANODIORITE

The Skamania volcanic series was intruded by a granodiorite stock named the Silver Star granodiorite by Felts (1939a, p. 302), who mapped the major part of the stock in the adjoining Bridal Veil and Lookout Mountain quadrangles to the east and northeast, respectively, of the Camas quadrangle. J. E. Allen, in an unpublished thesis (1932, Contributions to the structure, stratigraphy, and paleontology of the lower Columbia River gorge: Oregon Univ.), had previously called the mass the Silver Star formation. The name is taken from Silver Star Mountain in the northwest corner of the Bridal Veil quadrangle, less than a mile east of the area of this report. An extension of the stock and a small cupola are mapped in the northeastern part of the Camas quadrangle (fig. 18).

That part of the stock in the Camas quadrangle covers an area of about 4 to 5 square miles. The cupola is less than half a square mile in extent, and is traversed by Rock Creek. The drainage area of Hagen Creek within the Camas quadrangle is almost entirely within the boundaries of the stock. Cold Creek and Grouse Creek head in the north side of the stock, and most of the Grouse Creek

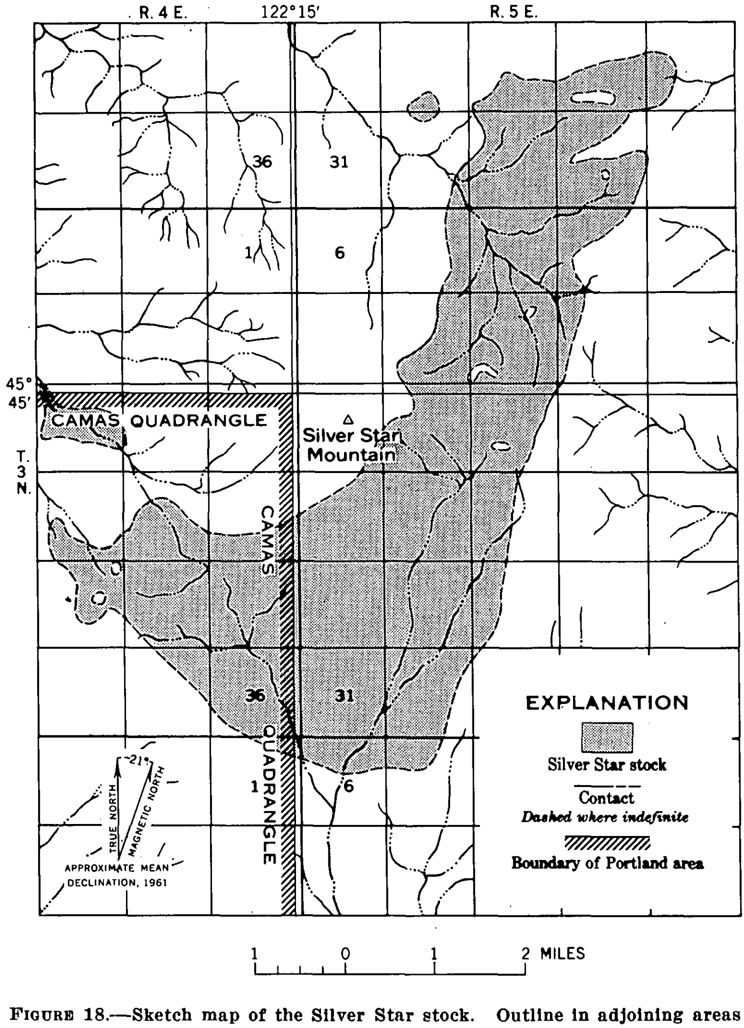

FIGURE 18.—Sketch map of the Silver Star stock. Outline in adjoining areas modified after W. M. Felts (1939a).

drainage is within the stock. The intrusive rocks obviously are less resistant to erosion than are the adjoining volcanic rocks, and most of the area of intrusive rocks is deeply dissected. The top of Larch Mountain and the associated crest just northeast of the Larch Mountain crest are underlain by roof pendants of older volcanic rock.

Felts (1939a, p. 302, 306) described the stock as granodiorite with subordinate amounts of augite diorite and quartz diorite near its border. The granodiorite is commonly light greenish gray and coarse grained. It has a mottled or salt-and-pepper appearance owing to the light color of the feldspar and the dark green of the pyroxene or amphibole. The texture of the rock is granitic. The plagioclase commonly is zoned, with basic andesine cores and less basic rims. Many of the feldspar crystals are corroded. Felts (1939a, p. 307) said that the granodiorite is about 55 percent plagioclase, 10 to 25 percent orthoclase, 10 to 25 percent quartz, and about 10 percent dark mineral.

Microscopic examination of the border phases of the stock in the Portland area verifies Felts' statement that the border of the stock is diorite or quartz diorite. The more basic phases of the stock along its borders contain little or no quartz or orthoclase but contain larger amounts of pyroxene, commonly augite. One sample of the stock from the actual contact with the country rock, however, contained euhedral andesine floating in a eutectic mass of vermicular and graphic intergrowths of quartz and feldspar.

The granodiorite was intruded into the lower part of the Skamania volcanic series. The walls of the intrusive apparently are steep and sharp, and the granodiorite contains swarms of zenoliths near the contact. The Skamania volcanic series has been metamorphosed to a siliceous hornfels near the contact, and thin veinlets of quartz, hornblende, calcite, epidote, and zeolite along joints in the Skamania are thought to be related to the intrusion of the stock. The Columbia River basalt is not altered, nor does it contain similar veinlets. The upper flows of the Skamania volcanic series do not appear to have been affected by the intrusion. These relations indicate that the Silver Star was intruded before the extrusion of both the upper flows of the Skamania and the middle Miocene Columbia River basalt, and during or after the deformation of the lower part of the Skamania volcanic series, possibly in late Oligocene time.

The Silver Star is similar to many other intrusions of comparable petrographic character, stratigraphic relations, and age that have been described from the Cascade Range of Washington and Oregon. Prominent among these is the Snoqualmie granodiorite, originally described from the Snoqualmie quadrangle by Smith and Calkins

(1906). These rocks were further described by Coombs (1936), from the Mount Rainier area, and by Warren (1941) from the Mount Aix quadrangle in Washington. Verhoogen (1937) briefly described a quartz diorite intrusive body northwest of Mount St. Helens, between the Toutle and the Green Rivers in Washington. Sixteen dioritic intrusive bodies in the Cascade Mountains in Oregon, including the Halls intrusive of Thayer (1936, p. 714; 1939, p. 10) and the granite at Nimrod, the largest of the group, were described by Buddington and Callaghan (1936). Felts (1939a, p. 309–311) compared the Silver Star granodiorite with several other intrusive bodies in the Cascade Range and found that chemical-variation diagrams for the several intrusive bodies were markedly similar. The investigations of Felts were more extensive and covered a much greater part of the stock than this study, and for that reason his conclusions are relevant. He believed that the stock was intruded along a line trending approximately N. 20° E., and that stoping was the major process of emplacement (Felts, 1939a, p. 316). The swarms of zenoliths observed during this study and by Felts are direct evidence of stoping and assimilation.

STRUCTURAL GEOLOGY

The geologic structure of the region is simple. Broad synclinal folds or basins are separated by equally broad anticlines. Faulting is minor.

The structure of the rocks older than the Columbia River basalt is obscure. Some of the beds of the Scappoose formation dip as steeply as 25°, but most dips are considered unreliable because of large-scale landsliding. The few attitudes that were measured on the rocks of the Skamania volcanic series suggest a general southeastward dip, locally as high as 37°. This is true only of the lower part of the formation. The upper part does not appear to have been deformed. The Columbia River basalt probably overlies the older rocks in this region nonconformably.

The valleys or basins formed by the folding of the Columbia River basalt were partly filled, and the formations that constitute the Tertiary valley fill all have been deformed to a greater or lesser degree. The valley of the lower Columbia River, and the Tualatin and Willamette Valleys are structurally simple. Locally, in adjoining areas, small auxiliary folds interrupt the major structure. The greatest known depth of the Columbia River basalt surface in the Tualatin Valley, at Hillsboro, is about 1,300 feet below sea level, and the top of basalt in the lower valley of the Columbia River in east Portland is about 1,000 feet below sea level. The lowest part of this structural feature is probably much deeper. Dips within the basins and near the margins are low, commonly only a few degrees, although dips as high as 15° have been measured along the east slope of the Tualatin Mountains. These dips decrease downslope, however, and have been measured at 7° near the east base of the Tualatin Mountains. Beneath the city of Portland, the buried basalt surface slopes rather uniformly about 4° NW. This buried surface has probably been somewhat modified by erosion and may not represent the true dip of the formation. The decrease in dip downslope, however, was probably progressive and undoubtedly the true dip is less than 7°. The beds dip into the valley in most instances.

The Tertiary sedimentary formations have been warped, and the beds of the Troutdale formation apparently continue into the Cascade Mountains adjacent to the Columbia River gorge and have been folded with the basalt. The Boring lava and succeeding Quaternary deposits, however, nonconformably overlie the Troutdale formation but show no evidence of warping, or other tectonic deformation. Slight deformation of the Boring lava however, would be difficult to determine.

The anticlines separating the valleys in this area trend generally northwestward. The Tualatin Mountains appear to broaden in the northwestern part of the area and extend beyond the northern boundary of the Hillsboro quadrangle. The Columbia River basalt just north of the map area is part of the northeastern limb of a broad anticline, whose opposite limb dips beneath the Tualatin Valley in this area (Wilkinson and others, 1946, p. 33). The hill southeast of Oswego Lake between the Willamette and Tualatin Rivers apparently is along the axis of a syncline. Petes Mountain is part of an anticline with the structural axis probably about coincident with the topographic crestline.

No evidence of major faulting is exposed in the mapped area. Small-scale normal faulting of the Columbia River basalt along the north side of the Tualatin Valley with less than 50 feet of displacement is inferred from bore-hole records (J. H. MacWilliams, Alcoa Mining Co., oral communication, July 1951). Faulting with large-scale displacement has occurred along the south side of the Tualatin Valley outside of the area of this report (Warren and others, 1945). Discontinuity of ridge crestlines about 1 mile southeast of Cornelius Pass suggests faulting of the Tualatin Mountains along a northwestward-trending line following generally down the valley to the northwest. Examination of the general locality of the possible fault line, however, yielded no evidence to substantiate such a fault. Differential erosion, owing to more rapid cutting of the exposed marine beds north of Logie Trail, and headward cutting by the northwestward-flowing creek in the valley along the Cornelius Pass highway, may have created the offset crestline. A fault is not mapped in this locality because of the lack of conclusive physical evidence.

Deformation of the region apparently ended in early Pliocene time as the Troutdale formation is the youngest one involved in the warping. The undeformed Boring lava overlies an erosional surface of considerable relief cut on the Troutdale. Post-Troutdale crustal movements, if any, have consisted only of vertical movement of regional extent.

LANDSLIDES

Landslides are common in this region of heavy rainfall. They range from small slips, flows, and sand runs that damage highway cuts, and locally cause damage to private property, to large slide areas that are miles in extent. Most of the large landslides in the region are slumps. Included in the slump category is the complex type of landslide with multiple slump unit blocks and earthflow or debris flow in the lower part of the slide.

The unconsolidated materials, exclusive of the loess, are subject mainly to small scale landsliding. Landslides in the unconsolidated materials are of many types, but soil falls, sand runs, and flows probably exceed the slumps in large number. Steepness of slope, lithologic character of the landslide terrain, vegetation, and degree of saturation are all factors that determine the kind of failure. Saturation appears to be a significant factor in causing slump and earthflow, and small failures are noted in many highway cuts after heavy rains.

During the winter of 1955–56 an estimated $100,000 damage to the main water-supply system of the city of Portland was caused by landslides, and slides caused an additional $100,000 damage to the city parks and streets (Schlicker, 1956, p. 39). These figures do not include the cost of damage to private property.

In the city of Portland the most damaging recent landslides have been comparatively small slump or slump-earthflow types that mainly involved thin loessial deposits near their lower margin along the steep east-facing slope of the Tualatin Mountains. Conditions are favorable for landsliding in this type of material wherever the surficial mantle is appreciable and the slopes are steep. Contributing factors causing landslides in this material include removal of vegetation, disturbing the equilibrium of the slope by excavating or by loading, and saturation. Other landslides, mainly slumps and sand runs, occur in the loosely consolidated materials along the west-facing bluff along the Willamette River.

The largest and certainly the most thoroughly investigated landslide in the city of Portland occurred in 1894. This slide has been described in detail by Clarke (1904; 1918). Excavations for city reservoirs near the east foot of the Tualatin Mountains in west Portland, just north of Tanner Creek, apparently triggered a landslide involving about 30 acres of land in what is now Washington Park. The slide area is shown on the geologic map for this report (pl. 1). The estimated volume of ground involved was 3.4 million cubic yards, and the depth to the base of the slide near its center ranged from 46 to 112 feet. Comparison of Weather Bureau records with the monthly movement of the slide indicated that the rate of movement of the slide depended on the volume of rainfall during any series of months. The landslide subsequently was stabilized by a system of drainage tunnels and the reservoirs are still in use.

Damaging as they are, the landslides involving the surficial materials are commonly of relatively small scale, and most have not been plotted on the geologic map. In many localities in this region, however, landslides of gigantic proportions have resulted from special conditions. Ironically, the larger landslides have probably not resulted in as great an economic loss as was caused by the smaller slides, mainly because most of the large ones either were prehistoric or occurred in unsettled areas of high relief. Most of the landslide deposits shown as discrete areas on the map are of this category. Significantly most of these areas of large-magnitude landslides are localized where lava rock overlies sedimentary units.

As previously discussed, most of the area of exposure of the Scappoose formation is a landslide complex. There the Columbia River basalt overlies the Scappoose formation. Where the basalt has been cut through and the underlying marine beds exposed in steep slopes, sliding almost invariably has taken place.

Similar landsliding on a grand scale has occurred in localities where the Troutdale formation or the Sandy River mudstone is overlain by the Boring lava, as in the Washougal River area or along the Sandy River. Slides of considerable proportions, however, also have resulted from failure of the Troutdale formation or Sandy River mudstone capped by Pleistocene alluvial deposits. The Sandy River mudstone, especially, is extremely susceptible to landsliding along steep valley walls, and locally, as along the Mosier Creek tributary of Clear Creek, nearly the entire area along the valley wall is a landslide complex.

The following conditions seem to be common to most of these areas: Weakness of sedimentary formations, presence of overlying lava flows or Pleistocene alluvial gravel or mudflow deposits, and exposure along bluffs or steep slopes. Perhaps load is partly responsible for the great magnitude of these landslides, and migration of ground water through the underlying sedimentary rocks undoubtedly is an important factor in causing the slides. Oversteepening of slopes, however, may be responsible in large part.

Landslides of this character are neither unique nor limited to this general area or set of stratigraphic conditions. Landslides in the plateaus of southwestern Colorado are of similar nature where Mancos shale is overlain by unconsolidated gravel, or by hard beds such as sandstone or lava rock (Varnes, 1949, p. 3). The greater number of landslides in the San Juan Mountains of Colorado have occurred at localities where hard, massive beds resting upon soft, unyielding beds were exposed on fairly steep slopes (Atwood and Mather, 1932, p. 160). The resistant caprock is responsible for oversteepening of slopes, which promotes slope failure of intermittent nature but in large units.

Recurrent movement on old landslides resulting from similar stratigraphic conditions along the Columbia River gorge has been troublesome to both highways and railroads in the gorge section. This indicates that recurrent movement is possible in areas that now appear to be stabilized.

WEATHERING

Weathering is a continuing process affecting the rocks at the surface of the earth. The intensity of weathering is determined largely by climate, although other factors contribute, and increases in temperature and precipitation will produce intensified weathering. The depth to which the rocks have been affected and the degree of alteration, however, may be a rough measure of the length of time that earth materials have been subjected to the processes of weathering. Within a region of broadly similar climate, lithologically similar deposits of different ages will have markedly different profiles of weathering.

Progressive weathering of deposits in northwestern Oregon, which range in age from middle Miocene to Recent, has produced a series of profiles that appear to represent successive stages of chemical change. Notable differences in these profiles have been used as a means of identifying and distinguishing several map units in the Portland area. Furthermore, the amount of time required to produce each of a number of different profiles has been estimated. The estimates are based on the assumption that the relative age assignments of the Quaternary units are nearly correct; therefore these estimates are subject to rather broad limits of error. Nevertheless, they emphasize the importance of the time factor in weathering, and particularly in the formation of laterite.

The profile of weathering on the younger deposits is thin and contains practically unaltered material. The depth of the profile and the degree of alteration on successively older rocks is progressively greater. The Columbia River basalt of Miocene age, which has been continuously weathered for the longest period of time, has a deep profile capped by a low-silica laterite crust. Laterite also was formed on the Rhododendron formation of late Miocene age. Weathering of the Rhododendron, however, was stopped by the deposition of the Sandy River mudstone of probable early Pliocene age, and the laterite on the Rhododendron contains more silica than most of the laterite on the Columbia River basalt.

The many different profiles preserved in this area provide a record of changes effected at successive intervals of time by weathering of mafic volcanic rocks under conditions of temperate climate with moderately heavy rainfall, good drainage, and abundant vegetation. The total length of time covered by this record is probably tens of millions of years.

QUATERNARY PROFILES OF WEATHERING

Four distinct profiles of weathering of Quaternary alluvial deposits, preserved in part as terrace deposits, are recognized along the Sandy and Clackamas River valleys (fig. 19). These include the profiles developed on the Recent deposits, and on the Estacada, Gresham, and Springwater formations, all of similar lithologic character.

Recent alluvium and lower terraces of probable Recent age along the streams have been weathered so little that there is no apparent decomposition of the constituent particles and the soil profile is at most a few feet thick.

The Estacada formation of late(?) Pleistocene age occupies higher terrace positions along the streams. It has been weathered to as much as 10 feet in depth. The profile of weathering is characterized by partial decomposition and the formation of weathered rinds as much as one-quarter inch thick but more commonly about one-eighth inch thick. Oxidation and resultant iron staining are other evidences of weathering in this profile.

The Gresham formation, of middle(?) Pleistocene age, forms still higher terraces along the valleys. The profile of weathering on the Gresham formation is much more pronounced than that of any of the lower terrace deposits. The total depth of alteration is as much as 35 feet, and the gravels are almost entirely decomposed throughout the vertical extent of the profile. Most of the boulders and larger cobbles have hard cores, but the pebbles and small cobbles have been completely altered to clay and can be cut with a shovel

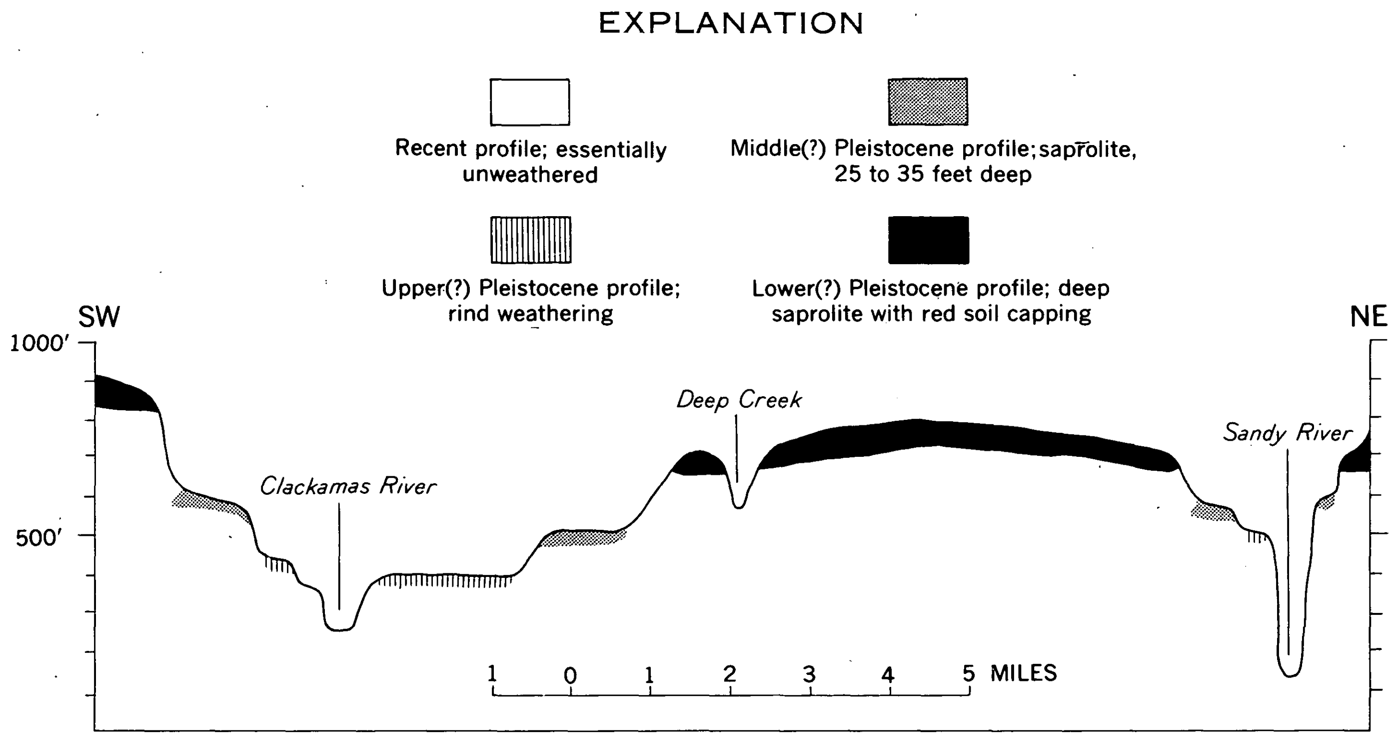

FIGURE 19.—Diagrammatic section across the Clackamas and Sandy River valleys showing the relative topographic position of the Quaternary profiles of weathering.

or a knife. The chemical changes have not disturbed the original textures and structural features of the parent material. Consequently the saprolite not only retains the outlines of the original pebbles and cobbles, but it also preserves the mineralogic textures of the rock in remarkable detail. The sharp outline of former feldspar laths and phenocrysts is retained although the minerals have been completely altered to clay. No apparent change in volume accompanied the process. Similar occurrences of thoroughly altered gravel have been described from other localities in northwestern Oregon and southwestern Washington (Wilson and Treasher, 1938, p. 19–23; Allen and Nichols, 1946). Petrographic and X-ray determinations show that halloysite and kaolinite are the main clay minerals produced in this type of alteration, but lesser amounts of beidellite-nontronite and montmorillonite also are formed (Allen and Nichols, 1946).

The Springwater formation mantles the surface of the broad interstream divide between the Sandy River and the Clackamas River and caps ridges adjacent to the two major streams. These deposits are remnants of a once-continuous piedmont alluvial plain of early(?) Pleistocene age. The profile of weathering on the Springwater formation is as much as 75 feet deep, and a red soil as much as 20 feet thick has formed over much of its surface. Most of the profile is a saprolite that retains relict textures and structural features and is virtually indistinguishable from that on the Gresham formation. The bright-red clayey soil on the surface, however, is homogeneous and retains none of the original structural features and textures of the parent material. This red soil locally is separated from the underlying saprolite by a mottled red and gray zone with a laminated structure. The red soil was not formed on the Springwater formation in areas where the weathering was stopped by the deposition of capping loess in early(?) and middle(?) Pleistocene time.

Similar profiles of weathering capped by red soil are also present on several formations older than the Springwater, but in most cases these profiles are formed on erosional surfaces of the older units. The Boring lava has this type of profile on its surface rather widely. In many places it is overlain by loess. The eroded surface of the Troutdale formation locally has been weathered to a deep saprolite that is capped by red clayey soil. An example is in the area marginal to the highlands in the Camas quadrangle north of the Columbia River. In most places, however, the weathered surface of the Troutdale was eroded prior to mantling by Pleistocene or other material. The profile of weathering probably was formed and then removed in some places. At one locality, along the south edge of Bear Prairie east of the report area, the Troutdale surface apparently was weathered to a saprolite before it was covered by Boring lava.

The red soil also has formed locally on the Columbia River basalt, and it is extensively mantled by loess. In places, the Columbia River basalt has been deeply weathered and a laterite crust has been formed. If the laterite profile ever was formed in the localities where the red soil profile now exists, it must have been at least partly eroded before the red soil profile was superimposed on the eroded surface.

The presence of the loess overlying the red soil on both the Boring lava and the Columbia River basalt is in contrast with the loess-soil stratigraphy on the Springwater formation. The red soil was formed on the surface of the Springwater formation almost everywhere that it is free of loess. There is no red soil on the Springwater, however, where it is overlain by loess. A partly weathered mudflow deposit that lacked a red soil cap was found in an auger hole drilled through 25 feet of loessial silt into the Springwater formation, on the east side of a small drainage in the SW¼SW¼ sec. 17, T. 1 S., R. 4 E. Apparently the silt deposit halted weathering at an early stage in the development of the profile, because the Springwater formation here is less weathered than some younger formations. Deep weathering with the formation of a red soil cap took place only at localities where the surface of the Springwater was exposed for most of Quaternary time. Furthermore, at no place has the red soil formed on a formation younger than Springwater. This indicates that most of Quaternary time was required to produce a profile with a red soil capping. Therefore the surfaces of the Boring lava and the eroded Columbia River basalt were exposed to weathering for an interval of time about equivalent to that of the Quaternary period before deposition of the loess at localities where loess overlies red soil on these formations.

The profiles of weathering capped by red clayey soil, therefore, represent a time span equivalent to most of the Quaternary period and locally perhaps part of the Pliocene epoch, or a period of time on the order of about a million years. This profile could not develop in much less time than that in this climatic region, because the next younger profile of weathering is only about half as deep and has no red soil capping. It took perhaps half as long to form. Late Pleistocene deposits that have been subjected to weathering for only tens of thousands of years are slightly weathered with only weathering rinds. Deposits less than about 10,000 years old are virtually unweathered.

LATERIZATION

Products of rock weathering in Oregon that contain a high content of alumina and iron oxide are called ferruginous bauxite (Libbey and others, 1945, p. 3). They are formed locally on the Columbia River basalt and on the Rhododendron formation. The ferruginous bauxite on the Columbia River basalt was known prior to this investigation and has been described in detail by Libbey, Lowry, and Mason (1944 and 1945); Allen (1948); and Corcoran and Libbey (1956). The stratigraphic relations of the ferruginous bauxite on the Rhododendron formation were discovered during this investigation, although some occurrences were known previously (Oregon Dept. Geology and Mineral Industries, 1948, p. 63–65).

The ferruginous bauxite is a laterite. The term "laterite" and the process of laterization have been subjects of much debate, which has been reviewed adequately by others (DuPreez, 1949; Harder, 1949; Prescott and Pendleton, 1952). The process of laterization is considered here to be one of desilication in which the alkalies and alkaline earths are eliminated with the silica by leaching (Mohr and Van Baren, 1954, p. 353; Corcoran and Libbey, 1956, p. 9). Laterite is the silica-deficient residual deposit, composed primarily of the oxides and hydroxides of aluminum and iron, that is the end product of the process of laterization. It commonly forms a hard crust of massive, vesicular, or concretionary character. A typical profile of lateritic weathering includes an upper laterite crust, an intermediate mottled zone, and a lower saprolitic or kaolinitic pallid zone that overlies unweathered parent rock (Whitehouse, 1940, p. 8; Prescott and Pendleton, 1952, p. 45). The thickness of the profile and of the component zones ranges from the thin profile of Hawaii (Sherman, 1950) to nearly 170 feet in the Oregon occurrences (Allen, 1948, p. 621).

LATERITE PROFILE ON COLUMBIA RIVER BASALT

The ferruginous bauxite that formed on the Columbia River basalt is distributed rather widely on preserved crests on the Tualatin Mountains, as described by Libbey, Lowry, and Mason (1945). A similar laterite was found on the Columbia River basalt in the eastern part of the present map area at only one locality, in the SW¼SE¼ sec. 25, T. 1 N., R. 4 E., but the stratigraphic relations there are obscured by a landslide. Similar laterite also occurs on the Stayton lavas, thought to be the equivalent of the Columbia River basalt, in the Salem area to the south (Corcoran and Libbey, 1956).

A continuous series of samples from a hole drilled by Alcoa Mining Company into one ferruginous bauxite deposit on the Columbia River basalt was reported by Allen (1948). The samples from this drill hole probably provide one of the most complete records of chemical and mineralogic changes effected in a laterite profile as the result of weathering (fig. 20). The profile illustrated by the drill hole samples is probably characteristic of most of the laterite formed on the Columbia River basalt. The thickness of the laterite crust on the Columbia River basalt in the drill hole cited by Allen is apparently more than 20 feet. The upper 6 feet of the crust is enriched in silica apparently by downward infiltration of the overlying loessial silt (Allen, 1948, p. 625). The mottled intermediate zone of earthy laterite is about 35 feet thick. The thickness of the saprolitic pallid zone is more than 110 feet. Except where contaminated in the upper few feet, the laterite crust in this drill hole averages less than 5 percent silica. The sample with the highest alumina content (47 percent) was from near the interpreted base of the crust. The highest ferric oxide content (about 49 percent) was from the top of the uncontaminated part of the crust (fig. 21). The predominant mineral form of Al_2O_3 is gibbsite, although traces of boehmite were noted. Gibbsite is limited to the upper 68 feet of the drill hole (Allen, 1948, p. 625). Only traces of kaolinite or halloysite are in the material above the middle part of the mottled zone (Allen, 1948, p. 625). The pallid zone is saprolite composed of halloysite and kaolinite (Allen, 1948, p. 622). It retains the textures and structural features of the parent basalt (Allen, 1952, p. 657).

Several textural varieties of laterite from this general area have been described. These include a bright-red hard oolitic or pisolitic type, which is characteristic of the crust; a softer earthy variety with hard porous nodules or angular fragments, which is more characteristic of the mottled zone; and a hard porous granular type (Libbey and others, 1945, p. 15). The porous granular type is found largely as float and is probably also crust material. The oolitic or pisolitic crust is commonly 10 to 20 feet thick.

A standard rock analysis of a sample of pisolitic laterite crust (U.S.G.S. No. C–948) from a test pit excavated by the Alcoa Mining Company, in the NW¼SW¼ sec. 5, T. 3 N., R. 2 W., is shown on table 1. This crust is markedly deficient in silica, but alumina, iron oxide, and titania have been concentrated. The iron is predominantly ferric iron. This analysis differs from the arithmetic average of analyses of auger-hole samples in Washington County of 9.49 percent silica, 34.68 percent alumina, 23.2 percent iron,

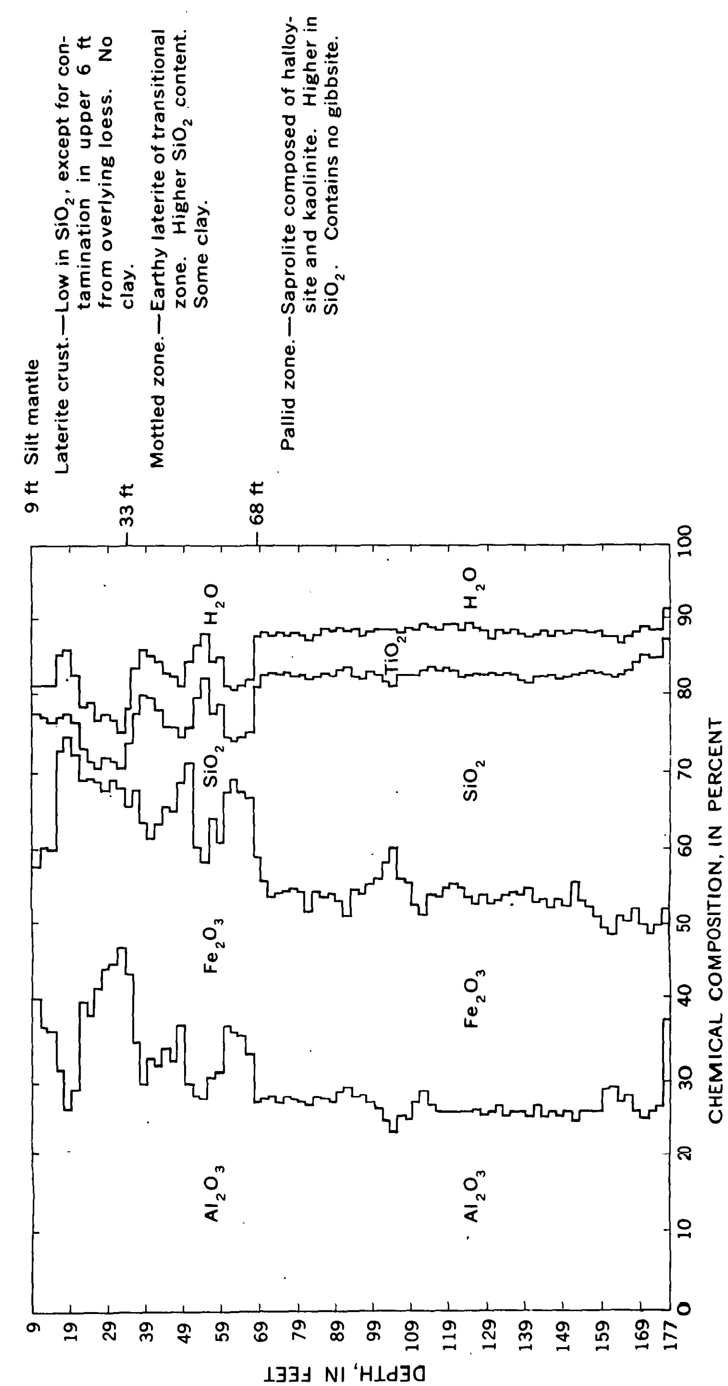

FIGURE 20.—Diagram showing variations in chemical composition with depth in a ferruginous bauxite deposit in Oregon (from Allen, 1948, p. 621).

4.85 percent titania, and 0.176 percent phosphorous (Libbey and others, 1945, p. 1) in large part because the latter analysis is an average of the crust and of much of the mottled zone, whereas the test-pit sample is a selected sample of the crust material.

LATERITE PROFILE ON THE RHODODENDRON FORMATION

The laterite on the Rhododendron formation has been found along the valleys of Eagle Creek and the Clackamas River in the southeastern part of the map area. It is present at the contact with the overlying Sandy River mudstone in the valley of Eagle Creek. The exposure near River Mill Dam on the Clackamas River has been described briefly. Other localities are, (1) just east of Estacada in a road cut at an altitude of about 600 feet in the NE¼SW¼ sec. 21, T. 3 S., R. 4 E.; (2) the Kiggins locality in the NW¼ sec. 3 and the NE¼ sec. 4, T. 4 S., R. 4 E. (Oregon Dept. Geology and Mineral Industries, 1948); and (3) at about 925 feet in altitude in a small draw in the SE¼NW¼ sec. 33, T. 3 S., R. 4 E., above the forebay at Faraday.

The laterite crust on the Rhododendron formation is a brown pisolitic ferruginous bauxite from 6 to 10 feet thick. The mottled zone is of undetermined thickness, but at least 50 feet of weathered

TABLE 1.—*Analyses of laterite crusts formed on the Columbia River basalt and on the Rhododendron formation, and approximate chemical composition of parent rocks*

	Columbia River basalt	C–948	C–947	C–945	C–946	Cascade Range, andesite complex
SiO_2	52.31	1.77	26.02	17.34	28.71	54.04
Al_2O_3	14.38	30.79	24.03	37.94	39.54	17.02
Fe_2O_3	2.47	42.32	27.80	9.39	8.25	2.82
FeO	9.95	0.80	1.76	7.49	.18	6.31
TiO_2	2.10	5.16	5.72	2.40	1.77	1.35
MgO	4.46	.03	.11	.27	.13	4.12
CaO	8.37	.01	.02	.52	.14	8.16
Na_2O	2.94	.02	.03	.10	.04	3.07
K_2O	1.26	.01	.04	.06	.05	1.27
H_2O-	.39	1.66	2.62	2.58	3.01	.32
H_2O+	.74	16.27	11.14	18.02	17.63	1.36
CO_2	-----------	.13	.07	2.90	.03	-----------
P_2O_5	.36	.22	.44	.40	.24	.22
S	-----------	.04	.18	.05	.02	-----------
MnO	.21	.02	.05	.10	.04	.14
Total	-----------	99.25	100.03	99.56	99.78	-----------
Less O	-----------	.02	.09	.03	.01	-----------
Total	-----------	99.23	99.94	99.53	99.77	-----------

Columbia River basalt.—Average of 13 analyses from the Pacific Northwest (from Waters, 1955, p. 705).
C–948.—Laterite crust on Columbia River basalt from Alcoa Mining Co. test pit, NW¼SW¼ sec. 5, T. 3 N., R. 2 W. Analyst, Faye H. Neuerburg, 1957.
C–947.—Laterite crust on Columbia River basalt where overlain by Troutdale formation, SW¼SE¼ sec. 25, T. 1 N., R. 4 E. Analyst, Faye H. Neuerburg, 1957.
C–945.—Laterite crust on Rhododendron formation near River Mill Dam, NW¼NE¼ sec. 19, T. 3 S., R. 4 E. Analyst, Faye H. Neuerburg, 1957.
C–946.—Leached(?) laterite crust on Rhododendron formation above forebay at Faraday, SE¼NW¼ sec. 33, T. 3 S., R. 4 E., Analyst, Faye H. Neuerburg, 1957.
Andesite complex, Cascade Range.—Average of seven analyses (from Waters, 1955, p. 705).

rock underlies the pisolitic crust at the River Mill Dam locality. Gibbsite is the important alumina mineral in this laterite also (Oregon Dept. Geology and Mineral Industries, 1948, p. 63). The laterite is overlain by the Sandy River mudstone. The analyses C–945 and C–946 shown on table 1 indicate that the Rhododendron laterite has a higher percentage of alumina and silica and a lower iron and titania content than the laterite formed on the Columbia River basalt in the northwestern part of the map area.

The River Mill sample (U.S.G.S. No. C–945) is normal brown laterite of the Rhododendron formation. The Faraday sample (U.S.G.S. No. C–946) is light orange and is more earthy in appearance. It has probably been modified in some way by ground water, perhaps resilicated and leached, but both Rhododendron samples have relatively high percentages of silica as compared with normal laterite of Columbia River basalt. The smaller percentage of ferric iron and the relatively high ferrous iron content probably account for the darker color of the laterite on the Rhododendron formation in the River Mill sample.

GENESIS OF LATERITE

The laterite on both the Columbia River basalt and the Rhododendron formation is separated from unweathered parent rock by a thick section of saprolite composed of halloysite and kaolinite. Studies of laterite deposits in widely separated areas in the world have shown that this type of profile is common (Allen, 1948, 1952; Carroll and Woof, 1951; Harder, 1952; Eyles, 1952).

Allen (1948, p. 625; 1952, p. 658) concluded that the bauxitization of the Columbia River basalt in northwestern Oregon was the result of a two-stage process. The basalt first weathered to clay, from which the bauxite then was formed. Eyles (1952) reached the same conclusion in his studies of laterite developed on basalt in Antrim, Northern Ireland. He said, "It is shown everywhere in Northern Ireland the formation of laterite is preceded by kaolinization of the parent rock" (Eyles, 1952, p. 3). Studies of laterization in Hawaii also indicate that the formation of clay minerals preceded the formation of laterite (Sherman, 1949, 1950).

Formation of the laterite from the saprolite seems well established for the Oregon occurrences. These changes are evident from field relations, but no single exposure shows all components of the profile, and nowhere in this area is the base of the laterite crust known to be exposed. Allen's studies of drill-hole samples from a deep hole drilled through the laterite profile of the Columbia River basalt, therefore, provide the best information on this profile. He found that not only are the textures and structural features of the parent rock faithfully preserved in the saprolite of the pallid zone (Allen, 1952, p. 657), but that halloysite pseudomorphs after plagioclase have been partly altered to gibbsite along their edges near the base of the mottled zone (Allen, 1948, p. 623). Others have observed that the original texture of the basalt is preserved in much of the gibbsitic laterite in northwestern Oregon (Libbey and others, 1945, pl. II; Corcoran and Libbey, 1956, p. 24). It is evident, therefore, that the laterite was formed from the saprolite.

Factors that influence or determine the character of the weathering are lithology, topography, drainage, climate, biologic factors, and time. Laterite profiles are formed on a wide variety of lithologic types (Harder, 1952), although some parent materials, mainly those composed predominantly of quartz, are not susceptible to laterization (White, 1954, p. 15). Topography influences laterization in two ways. It influences drainage and erosion. Relief must not be so great that weathering products are removed as rapidly as they are produced. Some generalizations concerning the influence of drainage on weathering processes have been formulated as a result of observations of geologic occurrences. Hosking (1940) found that in Australia montmorillonite clay minerals form from basalt under conditions of poor drainage, but that kaolinite forms from basalt under conditions of good drainage. The requirement of good drainage, as well as neutral to slightly acid conditions, for the formation of kaolinite was also determined by others (Allen, 1952, p. 656; Mohr and Van Baren, 1954).

The influence of climate on weathering processes in general and laterization in particular has long been known. Most laterites occur in tropical climates, and all appear to have formed in areas of considerable precipitation. A tropical climate, however, evidently is not required for the formation of laterite, for the Miocene and Pliocene flora of the area of this report are temperate zone flora. Sherman (1949) has shown that laterites are produced under conditions of both continuously wet and alternating wet and dry seasons. Under a continuously wet profile alumina tends to be the stabilized free oxide, but in an alternating wet-and-dry-season climate iron becomes the stabilized free oxide. The biologic factors affecting weathering solutions will be determined largely by the climate.

An adequate explanation of the chemistry of weathering that is in accord with the conclusions based on geologic observations is provided by Keller (1958). He points out that weathering of aluminum silicate minerals is primarily a result of hydrolysis, augmented by oxidation and carbonation. The character of the weathering product is determined mainly by the relative concentrations of

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hydrogen and metal cations in the hydrolizing solutions and by the relative solubilities of alumina and silica in these solutions. The pH of the hydrolizing solutions is determined in part by the abrasion pH of the minerals of the parent rock but is modified by climate, drainage, and biologic factors.

Clay minerals form as a result of the relative insolubility of alumina and silica under certain conditions of pH. Kaolinite or halloysite form in neutral to slightly acid hydrolizing solutions. Such solutions result from conditions of good drainage that permit removal of the metal cations and concentration of the hydrogen cations. Poor drainage is conducive to the formation of montmorillonite because of concentration of the metal cations by either evaporation or waterlogging.

The formation of laterite from the clayey alteration product is also discussed briefly by Keller (1958, p. 243), who points out that the structural change from clay minerals to gibbsite involves only stripping of the silica sheets in the clay mineral and reconstitution of the gibbsite sheets into crystalline gibbsite. He believes that this change is accomplished by further dialysis and hydrolysis of the clay structure. This is accomplished under conditions of profuse quantities of renewed fresh water, excellent drainage, and the presence of organic material. Because the energy drive toward this process is low, a large amount of time may be inferred as a further requirement.

TIME OF FORMATION OF LATERITE

The importance of the time factor in the formation of laterite has been pointed out by Mohr and Van Baren (1954, p. 356), and Allen (1952, p. 658) has concluded that ferruginous bauxite deposits were formed by continuation of the same process of weathering and thorough leaching that formed the kaolin minerals. Despite the importance of the time factor in the development of a profile of weathering, few quantitative data of even general nature are available on this subject. The several profiles of weathering in this area provide some quantitative data of rather broad limits.

It has been shown previously in this report that laterite was not produced by a period of time encompassing all of the Quaternary period. An evaluation of the chemical analyses and of the geologic relations of the laterite zones on the Rhododendron formation and the Columbia River basalt gives an approximation of the amount of time required for the development of a laterite in this climatic region. The Miocene and Pliocene flora indicate a temperate climate with rainfall broadly similar to that of the present but with somewhat greater amounts of summer rainfall (Chaney, 1944, p. 334).

The high silica content of the laterite on the Rhododendron formation as compared with the low percentage of silica in most of the laterite on the Columbia River basalt is perhaps explained by the difference in the amount of time that the two formations were subjected to weathering. The laterization of the Rhododendron formation was stopped by the deposition of the overlying Sandy River mudstone in early Pliocene time. The Columbia River basalt in the northwestern part of the area, however, continued to be laterized until it was mantled by loessial silt, probably in early to middle Pleistocene time. The high silica content shown in the analysis (C–947 on table 1) of pisolitic ferruginous bauxite developed on the Columbia River basalt where it is overlain by lower Pliocene Troutdale formation in the SW¼SE¼ sec. 25, T. 1 N., R. 4 E., seems to support this inference.

The time required for the laterization of these rocks, then, may be inferred from their stratigraphic relations. It has been suggested that the laterization of the Columbia River basalt of Miocene age was effected prior to the folding of the basalt, which was assigned to the Pliocene epoch (Libbey and others, 1945, p. 21). This inference seems doubtful, for although the Columbia River basalt was partly laterized prior to the deposition of the Troutdale formation, the process of laterization evidently continued as long as the laterized surface was exposed. The upper Miocene Rhododendron formation, therefore, was subjected to weathering from the time of its deposition some time in late Miocene until weathering was halted in early Pliocene time.

The laterite on the Columbia River basalt is known only at those localities where the surface of the basalt was exposed at least until early Pliocene time. The Columbia River basalt does not appear to have been laterized at localities where it is overlain by the upper Miocene Rhododendron formation, such as in the valleys of the Bull Run River, the Little Sandy River, the Sandy River, and the Clackamas River to the east of the map area. The Columbia River basalt, however, was partly laterized before the deposition of the lower Pliocene Troutdale formation. A period of time greater than the interval between the extrusion of the Columbia River basalt and the Rhododendron formation, therefore, was required for the production of a laterite crust.

A laterite crust containing much silica was formed during the time between the deposition of the Columbia River basalt or the Rhododendron formation in Miocene time and the deposition of the Sandy River mudstone and the Troutdale formation in early Pliocene time, a period of probably several millions of years. The low silica content, which indicates greater leaching, of the laterite on the Columbia River basalt in the northwestern part of the area suggests that it is a product of total weathering from the time of extrusion of the basalt until the weathering was stopped by the deposition of the mantling loess in Pleistocene time. This is a time span including all of the Pliocene, nearly half of the Miocene, and part of the Pleistocene epochs, a period of perhaps tens of millions of years.

CONCLUSIONS ON LATERITE ORIGIN

Profiles of progressive weathering on the Quaternary deposits of this area indicate that saprolitic decomposition has required perhaps hundreds of thousands of years of continuous weathering, and that Quaternary time was not sufficient to produce a laterite. The laterite, however, has a profile similar to the thickest Quaternary profile of weathering except for the formation of the laterite crust and the depth of the profile.

The laterites have significant differences in silica content in the crusts that can be related to the amount of time the formation was exposed to surface weathering. High-silica laterite crusts on the Rhododendron formation and at one locality on the Columbia River basalt are overlain by lower Pliocene sedimentary formations, whose deposition terminated the laterization of the underlying surfaces after perhaps several million years of weathering. The low-silica laterite on the Columbia River basalt in the northwestern part of the area is on a surface subjected to weathering, at least locally, until early or middle Pleistocene, a period of probably between 15 and 20 millions of years.

The parent rocks for all of these profiles of weathering are mafic and intermediate volcanic types. The topographic and climatic conditions affecting the multiple profiles were probably broadly similar, and they all probably developed under conditions of good drainage. Time was the significant variable, and these profiles seem to represent successive stages in progressive weathering to a mature laterite profile with a low-silica crust (fig. 21).

A laterite profile is the product of a relatively long period of weathering of a stable land surface. A laterite, as pointed out by Harder (1949, p. 888), is a geological horizon marker representing a long interval of nondeposition and nonerosion.

GEOLOGIC HISTORY

The geologic history of this area is perhaps typical of the history of much of northwestern Oregon. The entire Cenozoic era in the middle Cascade Mountains is characterized by volcanism. The known geologic history of the Portland area began late in the Eocene epoch with volcanic eruptions in the eastern part of the area. This activity was probably quite general throughout the Pacific Northwest, but is represented in the area of this report only by the Skamania volcanic series. In later Eocene time the region was invaded by marine waters that probably did not reach the Portland area. With continued subsidence in Oligocene time the seas reached farther inland, and in later Oligocene and early Miocene time the western part of the report area was submerged. Volcanism that had been continuous throughout the Oligocene epoch in the eastern part of the area continued, and ash falls provided significant amounts of pyroclastic debris that is seen in the tuffaceous sandstone and shale beds of the Scappoose formation.

The region then was uplifted and deformed, probably in late Oligocene or early Miocene time, and the seas retreated from the area. Probably contemporaneous with this orogeny, the volcanic rocks in the eastern part of the mapped area were intruded by the

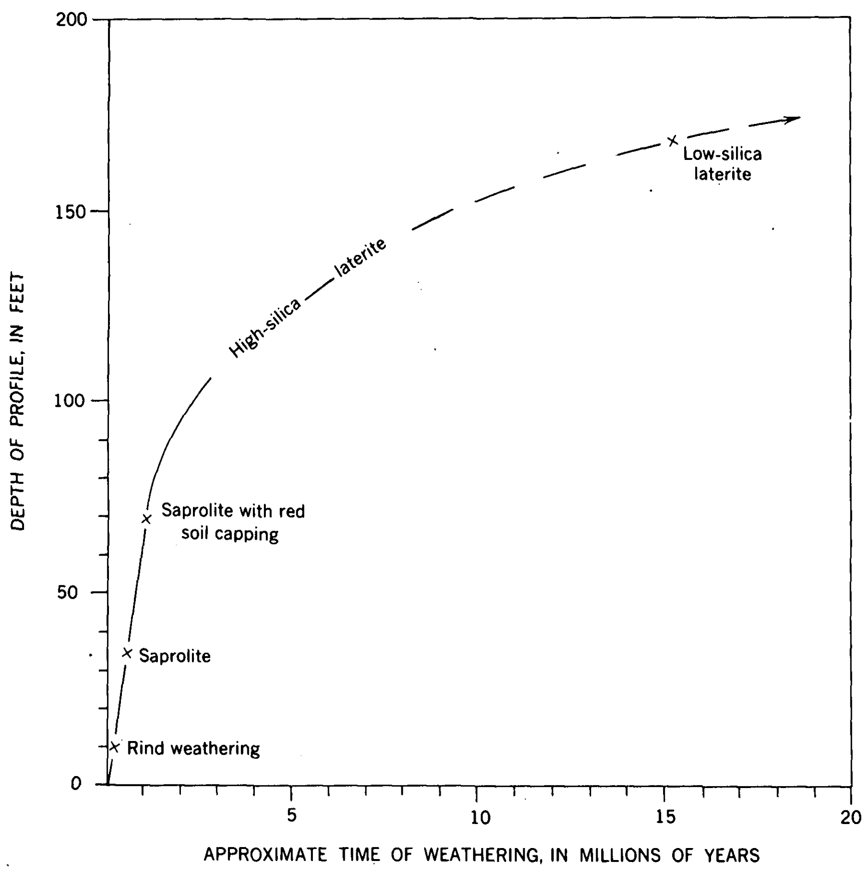

FIGURE 21.—Graph of progressive weathering leading to a low-silica laterite, based on profiles in the Portland area.

Silver Star granodiorite, which silicified and metamorphosed the surrounding rocks. This was followed by a period of stability and erosion. The deformed marine beds were truncated and partly eroded, but the volcanic rocks in the northeastern part of the area were more resistant and formed a highland area north of the Columbia River. Some later volcanism is represented by the upper flows of the Skamania volcanic series.

Fissure eruptions of flood basalt during middle Miocene produced great plains of Columbia River basalt to the east of the Portland area. Lavas of this stage of volcanism flowed into the map area through a wide gap between highlands to the north and south of the site of present Columbia River, and covered the eroded surface at lower altitudes. In late Miocene time the present Cascade Range to the east began to be uplifted as a result of deformation of the Columbia River basalt. Volcanism was renewed along the western flank of this newly formed range, and flows of the upper Miocene Rhododendron formation were extruded. Mudflows, probably originating as saturated pyroclastic debris, ran beyond the flow rocks and built up a mudflow deposit several hundred feet thick, overlying Columbia River basalt.

During later Miocene and very early Pliocene time, weathering processes attacked the exposed rocks and partly changed them to clay. An extensive laterite crust was formed on the exposed Columbia River basalt and Rhododendron formation.

Continuing diastrophism in early Pliocene time further developed the structural features and in some cases closed basins apparently were formed. The Sandy River mudstone was deposited in the quiet water of a vast lake in at least one of these basins, locally burying the laterized surface. Probably there was contemporaneous deposition in similar adjacent structural basins.

As the basins were filled, or when the outlets had been breached to the level of the surface of the sedimentary accumulations, conditions were changed suddenly to an environment of stream deposition. The course of the Columbia River, through the Cascade Mountains was practically in its present position. The river brought in its load of coarse gravel and sand of foreign origin and deposited it in the gradually subsiding basin. These gravel deposits of the early Pliocene Columbia River form an important part of the Troutdale formation. The Cascade Mountains continued to be a center of intermittent volcanism, and basaltic flows poured into the Columbia River at intervals. Glassy particles were borne downstream and deposited as the vitric or sideromelane sandstone phases of the Troutdale formation. Perhaps as a result of accelerated folding, conditions reverted to a closed-basin environment for a short period during

Troutdale time when fine-grained materials were again deposited. Later fluvial deposition was resumed. The sediments of the Troutdale formation continued to accumulate while folding progressed, but after folding ceased in early Pliocene time the surface of the Troutdale formation was extensively eroded.

The post-Troutdale Pliocene was a time of renewed small-scale discontinuous volcanic activity. Boring volcanoes dotted the land surface in the vicinity of Portland. The lavas were viscous and in most cases did not flow far from their source vent, but a few vents were explosive. In some areas, notably along the foothills of the Cascade Mountains east of the Sandy River and in the area southeast of Oregon City, several vents furnished enough lava to form a lava plain. The lavas southeast of Oregon City displaced the ancestral Willamette River to the west, where it cut its present gorge. Most of the volcanoes that produced Boring lava were in or near the map area, except for their equivalents to the east in the Cascade Mountains. This fourth episode of Tertiary volcanism continued into the early or middle part of the Quaternary.

Piedmont alluviation began in the latter part of the Pliocene, and continued perhaps into the Pleistocene. Coarse gravel and mudflow deposits accumulated in considerable thickness and partly buried some of the Boring volcanoes. This may have been caused by volcanism in the mountains supplying increased load to the streams.

The land surface in the lowland areas was extensively eroded during the early part of the Quaternary period and the piedmont plain had little relief except for isolated erosional buttes and the Boring volcanoes. Again increased volcanism, or perhaps interglacial rise in sea level, caused extensive alluviation of the piedmont plain. Vast mudflows poured down the mountain valley of the Sandy River from the vicinity of Mount Hood and spread out on the plain at the foot of the mountains. These mudflows may represent, in part, the early eruptive activity of Mount Hood. They were buried by more gravel or successive mudflows. The Clackamas River, in the Cascade Mountains farther south, contributed its load of coarse gravel to the wide plain of alluviation.

In the early to middle part of the Pleistocene epoch the Sandy and Clackamas Rivers cut valleys locally more than 200 feet deep into the piedmont plain. The rivers continued to occupy and modify these valleys.

The Columbia River by this time had cut a wide valley and the winds whipped silt from its flood plain and deposited it to the south and west of the flood plain. The silt thinned away from the flood plain to a thin edge less than 10 miles away. This silt mantled the weathered and laterized surface of the Columbia River basalt in the Tualatin Mountains.

The valleys of the Sandy and Clackamas Rivers were partly filled with fluvial gravel and mudflow deposits, probably in middle Pleistocene time. These fills were incised and the inner valley was partly filled with fluvial deposits probably in late Pleistocene time. The deposition and renewed cutting may have been controlled in part by eustatic changes in sea level, or may have been in response to changes in load owing to changes in climate or volcanism.

Sometime after the third period of Pleistocene fluvial deposition, the area was suddenly flooded by glacial melt water that backed up as a vast lake in the lower valley of the Columbia River and in the Willamette and the Tualatin Valleys.

A lobe of ice in the Purcell Trench in northern Idaho had acted as a dam shutting off the drainage of the Clark Fork River and forming a large lake in western Montana. Upon recession of the ice lobe, the ice dam suddenly failed, releasing 500 cubic miles of glacial melt water and draining the entire lake in a matter of days. This tremendous flood of water was diverted across the Columbia Plateau, creating the fantastic topography of the scabland and being checked by the narrows of Wallula Gap. Only one-sixth of the water arriving at this point could pass through the gap, and as a result much of the flood backed up to form a lake in the Pasco Basin and the Yakima Valley in southeastern Washington. Wallula Gap, however, was discharging about 40 cubic miles of water daily, part of which was again impounded in the Umatilla Basin. The amount of flood water that finally arrived in the lower Columbia River valley, however, was too great to pass through the relatively constricted channel downstream, and the excess water was ponded. The maximum lake level was between 350 and 400 feet above sea level. The deposits of this lake are evidence of the tremendous volume and energy of the flood water responsible for the lake. The floors of the valley of the lower Columbia River and Tualatin and Willamette Valleys were mantled with extensive lacustrine deposits of gravel, sand, silt, and clay.

Reduction in the amount of load carried to the Portland area by the flood waters allowed erosion of channels in the lacustrine deposits and the creation of great scours on the down-current (west) side of obstacles that caused turbulence. With slackening of the flood, these scours were filled with bedded sand and silt. As the flood waters diminished, the level of the lake declined rapidly, and drainage was re-established in the area. The rivers then began to cut down through the unconsolidated deposits left by the flood and locally deposited slack-water sediments.

In late Pleistocene time and early Recent time there was further downcutting and intermittent alluviation. The slight degree of weathering of the surface of the late deposits indicates their youth. The Clackamas River flowed into the Willamette River through a channel between Clackamas and Milwaukie until the channel was abandoned owing to capture.

Recent entrenchment of about 150 feet in the valley of the Clackamas River, and locally of more than 300 feet in the valley of the Sandy River, may represent normal lowering of the stream profile along its lower course, or it may be in part the result of regional uplift.

The climate of the region throughout late Tertiary and Quaternary time has been a temperate one characterized by at least moderately heavy rainfall, with perhaps decreasing amounts of summer rainfall. Continuous exposure of the surfaces of successively younger deposits to climatic conditions probably much like those of the present has produced a series of profiles of weathering that are successively thinner and less severely weathered with decreasing age of the deposits.

Landslides have occurred probably throughout the late Tertiary and all of Quaternary time, and have modified slopes over large areas in some places.

Recent alluviation of the modern flood plains, and locally the accumulation of bogs of high organic content have modified the surface only slightly during the late history of the area.

DRAINAGE CHANGES OF THE WILLAMETTE RIVER AND TUALATIN RIVER

The geomorphic development of the Willamette River-Tualatin River-Oswego Lake system of channels may be interpreted in part from the geologic evidence. The evidence is not complete for all the history, however, and the gaps must be filled by speculation.

The pre-Troutdale course of the Willamette River can be approximated from fragmentary evidence. The best control for any point on this channel perhaps is provided by drill-hole information from a well drilled for water for the Willamette National Cemetery on Mount Scott, in NE¼NE¼ sec. 27, T. 1 S., R. 2 E. This well apparently was drilled into the channel of the ancestral Willamette River because fine-grained sediments typical of the Sandy River mudstone were not penetrated at a depth of 250 feet below sea level although a map of the configuration of the top of the Sandy River mudstone (fig. 7) indicates that the uneroded top of the mudstone would have been at an altitude of nearly 100 feet above sea level at that locality. This condition suggests that a channel at least 350 feet deep was cut into the Sandy River mudstone at this point. The east edge of the channel farther south must have been west of exposures of the Sandy River mudstone along the Clackamas River and Abernethy Creek, which requires that the channel must arc westward south of the Clackamas River.

The present lower valley of the Tualatin River was a pre-Troutdale tributary channel of the ancestral Willamette River. This is established by the Troutdale-filled channel cut in Columbia River basalt on the east side of the Willamette River opposite the mouth of the Tualatin River. A second tributary a few miles to the northeast, paralleling the Tualatin channel, is suggested by the linear distribution of outcrops of the Troutdale formation in the vicinity of Mount Sylvania. The Troutdale formation there is largely concealed by the mantling Boring lava and loessial deposits, but the linear alinement of the three areas of exposure is suggestive of a Troutdale-filled channel that extended southeastward and followed the present Willamette channel from Oswego to Oregon City.

If the ancestral Willamette River flowed northward, the tributary drainage was barbed, owing perhaps to structural control. The Columbia River, however, may have flowed southward in pre-Troutdale time, draining westward to the ocean through some Miocene valley far to the south.

Incision of these tributary valleys may have been accentuated by the warping of the Columbia River basalt that produced the basin of deposition in which the Sandy River mudstone and the Troutdale formation were deposited. The depositional basin was aggraded with Troutdale sediments to an altitude of more than 700 feet in this part of the map area, probably almost completely burying the Columbia River basalt prominences south of Hillsdale.

The Willamette drainage established on the Troutdale surface must have flowed northward. If the Columbia River did flow southward in pre-Troutdale time, the Columbia now established itself with an outlet to the north, joining the Cowlitz River. This may have been due to superposition on a Troutdale surface that had a slight initial slope to the north or northwest. Perhaps the Kalama-Carrolls narrows was cut at this time.

The position of the post-Troutdale Willamette River south of Oregon City, however, was still east of its present course, and the river planed the Troutdale surface over a broad area, generally between the present course and the Cascade Highway, to an altitude of about 350 or 400 feet. This amounts to 300 feet or more of downcutting.

The Willamette River north of Oregon City may have followed approximately its present course or may have taken a course to the north or northeast, perhaps even flowing out through Pleasant Valley where the Troutdale surface was channeled deeply.

The Tualatin River in the meantime must have been superposed on the Troutdale surface in the present position of the Oswego Lake channel, flowing northeast to join the Willamette near Oswego or farther to the northeast. In any event, the segment of the present Willamette channel between Oswego and Milwaukie, Oreg., also probably was initiated at this time by either the Tualatin River drainage or the combined drainage.

When the Willamette had cut down to the 350- or 400-foot level south of Oregon City, it was displaced westward by the Boring lava flows from the southeast. The river was displaced against the basalt of Petes Mountain and the hill north of the present Tualatin, and it began entrenching itself in its present gorge between New Era and Oregon City. The displacement occurred before the Springwater formation of early(?) Pleistocene age was deposited, because this formation, at localities south and west of Estacada, mantles Boring lava that probably came from the same vents as the lava that displaced the Willamette drainage.

The history of the drainage changes becomes largely speculative at this point. Baldwin (1957, p. 113) has suggested that the displaced Willamette River flowed westward through the lower Tualatin River valley to join the Tualatin River, which then flowed eastward through the Oswego Lake channel. It is more likely, however, that the Tualatin joined the Willamette River at or beyond Oswego until long after displacement by the Boring lava.

During the time of planation before displacement of the Willamette River, the lower part of the Tualatin channel probably was partly re-excavated, because sedimentary fill is more easily eroded than the basalt on either side. The former tributary became a lesser tributary of the Willamette River graded to the level of the Willamette River of that time. When the Willamette River was displaced to the west, however, the western part of the Tualatin channel was probably unexcavated and would have been blocked by Troutdale sediments. Furthermore, the cutting of the gorge between the mouth of the Tualatin River and Oregon City must have been accomplished at this time. It seems unlikely that the drainage was ever superposed at any later time at an altitude high enough to accomplish the cutting of the gorge. It also is doubtful that tributary retreat across this basaltic nose could have been great enough to capture the Willamette River.

The Tualatin River probably continued to occupy the Oswego Lake channel until downcutting reached an altitude of about 200 feet at Oswego. The excavation of the lower Tualatin tributary perhaps was great enough at that time to capture the main Tualatin River, leaving the Oswego Lake channel abandoned. The pre-

Recent extension of the Oswego Lake channel cut in the Columbia River basalt along the west bank of the Willamette River at Oswego is comparable in size to the Tryon Creek channel just north of it, which suggests that both channels were cut by minor tributary drainage.

Although the Willamette River north of Oregon City may have occupied a post-Troutdale course east of its present course, the amount of lateral planation of the Columbia River basalt adjacent to the channel between Oswego and Milwaukie suggests that the cutting could not have been done by the relatively small Tualatin River. Probably the segment of the former tributary between Oswego and Oregon City was re-excavated, and the Tualatin River captured the Willamette River when the stream was cutting at an altitude of more than 200 feet in the vicinity of Oswego. The Willamette-Tualatin drainage pattern almost certainly was established in practically its present form when the Oswego Lake channel was abandoned. Later modification resulted only in deepening the Willamette and Tualatin channels by normal stream lowering, and by enlargement and deep scouring of the Oswego Lake channel by late Pleistocene flood waters.

The falls on the Willamette River may represent merely retreat of a falls that was started by differential erosion at the northern margin of the basalt at West Linn-Oregon City. However, it may represent retreat from an initial position of the falls near Sellwood, where the river leaves the basalt. The falls apparently was cut since deposition of the deposits of probable late Pleistocene age.

ECONOMIC RESOURCES

This area contains abundant reserves of earth materials used by the construction industry. In 1954 the four counties in Oregon partly covered by the area of this report yielded mineral resources, mainly construction materials, valued at nearly $9 million which was more than 25 percent of the total value of mineral resources produced by the State. Except for the potential of the ferruginous bauxite as a source of aluminum and iron, however, the area is deficient in metallic mineral resources. Exploratory drilling for petroleum in the marine sedimentary rocks of the area has been unsuccessful to date.

METALS

The potential metallic mineral resources of the area include aluminum, copper, and iron. Exploratory and mining operations have been undertaken in the search for and development of these three minerals in this area.

ALUMINUM

The ferruginous bauxite deposits of the laterite on the Columbia River basalt and on the Rhododendron formation constitute potential sources of aluminum and iron. Because of their high silica and iron content, they presently are not of ore grade. With improved metallurgical processes, however, they may become aluminum ore at some future date. They constitute large reserves of this strategic metal in the event of national emergency.

The ferruginous bauxite on the Columbia River basalt is low in silica and alumina and high in iron and titania as compared with that on the Rhododendron formation. Its economic potential has been discussed in some detail in the bulletin publication of the Oregon Department of Geology and Mineral Industries (Libbey and others, 1945, p. 83–86; Corcoran and Libbey, 1956, p. 30–36). The ferruginous bauxite of the Rhododendron commonly contains a greater amount of alumina than the Columbia River basalt, but it is also much higher in silica, containing as much as 20 percent or more. The alumina content, however, is commonly near 40 percent.

Another possible use of the ferruginous bauxite is in quick-setting aluminous cement. Experimental work has indicated that despite its high iron content, a suitable mixture of ferruginous bauxite and lime or limestone will produce a good aluminous cement (Every and Hagen, 1949, p. 31).

COPPER

Two abandoned prospects along the margin of the Silver Star granodiorite contain minor amounts of sulphide minerals and some secondary copper minerals. The Silver Star mine, in the SW¼SW¼ sec. 14, T. 3 N., R. 4 E., and the unnamed prospect about half a mile south of the Silver Star mine, in the SE¼NW¼ sec. 23, T. 3 N., R. 4 E., were examined and show only slight signs of mineralization. Traces of secondary copper minerals were noted in other places as well. Some malachite staining of quartz veins cutting jointed rocks of the Skamania volcanic series was noted on the northeast tip of Lady Island.

The Silver Star mine is in weathered rock of the Skamania volcanic series near the contact with a small cupola of Silver Star granodiorite. The abandoned mine consists of a drift about 140 feet long, and a crosscut about 45 feet long that follows a minor fault of small displacement about 15 feet from the end of the drift. A quartz vein, about 5 feet wide at the end of the crosscut, is intruded along the fault. Chalcopyrite, bornite, pyrite, galena, and sphalerite are associated with the quartz vein. Specular hematite is present in small amounts. Malachite is the only secondary copper mineral recognized at this locality. The mineralization is of the vein type and metallic minerals occur in only small amounts. The main drift cuts other minor quartz veins between the adit and the crosscut.

The unnamed prospect to the south is in a silicified contact phase of the Skamania volcanic series, very close to the contact with the main stock of the Silver Star granodiorite. A drift about 115 feet long has been driven along a small fault. The drift cuts several small quartz veins and most are slightly mineralized. Metallic minerals contained by the veins include chalcopyrite, pyrite, sphalerite, specular hematite, and malachite.

The amount and type of mineralization are inadequate for commercial exploitation.

IRON

Iron occurs as hematite in the ferruginous bauxite deposits and as limonitic bog iron in interbasalt deposits.

The ferruginous bauxite deposits formed on the Columbia River basalt locally contain more than 25 percent metallic iron, but more commonly the iron content is less than 20 percent. If these deposits are utilized as a source of aluminum, iron will be an important byproduct of the process.

Limonitic bog iron deposits have been known in the region for nearly 100 years. The limonite beds are interlayered with the flows of the Columbia River basalt. Deposits near Oswego Lake were mined from 1865 to 1894 and were described by Diller (1896, p. 508–511). The important ore body, known as the Prosser bed, is on Iron Mountain on the north side of Oswego Lake, in the NE¼NE¼ sec. 8 and the NW¼NW¼ sec. 9, T. 2 S., R. 1 E., about 2 miles west of the town of Oswego. The bed crops out at an altitude of about 325 feet at its western end. It is about 400 feet above sea level at the eastern end. The greatest thickness of the bog iron on the present outcrop is about 4 feet, but the bed thins and pinches out within a short distance to the east. According to Diller (1896, p. 508, 509) the bed is about 1 mile long and half a mile wide, and ranges in thickness from 2 to 20 feet. The ore averaged from 38 to 45 percent metallic iron. A similar bed is on the south side of Oswego Lake (Diller, 1896, p. 511). Similar deposits a few miles north of the area of this report, west and northwest of the town of Scappoose, Oreg., have estimated reserves of approximately 4 million long tons of iron ore (Hotz, 1953, p. 92).

A thin bed of limonite about 1 foot thick is reported from a locality on the flank of a low knob about 1 mile northeast of Helvetia, in the NW¼ sec. 2, T. 1 N., R. 2 W. (Oregon Dept. Geology and Mineral Industries, 1953, p. 7).

The economic possibilities of the limonitic deposits have been discussed by Miller (1940) and Hotz (1953), who cite limited reserves and high phosphorous content of the deposits as a deterrent to their economic development.

MERCURY

Traces of mercury were found in seams and agglomeratic interbeds in the Columbia River basalt in an old tunnel in the Tualatin Mountains (Oregon Dept. Geology and Mineral Industries, 1951, p. 141). The east tunnel adit was found at an altitude of about 650 feet on the south side of the bottom of a deep draw in the SW¼SE¼ sec. 30, T. 1 N., R. 1 E. The tunnel is reported to have extended due west for a distance of 960 feet. The adit was caved at the time of the present investigation, and only oxidized vesicular basalt was found on the dump. A ditch that nearly followed the 650-foot contour line was traced northward along the hillside from the tunnel adit for almost a mile. A similar ditch was found on the opposite side of the ridge, on the north side of Balch Canyon, at about the same altitude suggesting that the tunnel was part of an aqueduct system of some sort.

Mercury is also reportedly produced from the Skamania volcanic series in sec. 16, T. 2 N., R. 4 E. (Huntting, 1956, p. 264).

NONMETALS

The nonmetallic mineral resources of the area consist mainly of earth materials used by the construction industry. The importance of these materials in the Oregon mineral industry is illustrated by the production figures for 1954 when the value of sand and gravel, stone, and clay produced in the State was $21,694,933, or about two-thirds of the total for the entire industry (Oregon Dept. Geology and Mineral Industries, 1955, p. 65). More than 40 percent was produced from the four counties partly covered by the area of this report. Clark County, Wash., also produces large amounts of stone and sand and gravel.

BRICK CLAY

The brick and tile industry is an important element of the construction industry of this area. Red-burning clayey materials with wide ranges in composition are used in three producing plants, two in Oregon, and one in Washington.

Nearly two-thirds of the brick produced in Oregon is manufactured at the two plants in this area: The Sylvan Brick Co., near Sylvan in sec. 6, T. 1 S., R. 1 E., and the Columbia Brick Works at Hogan Station, about 1.5 miles southeast of Gresham (Allen, 1949, fig. 3). Both plants utilize loessial clayey silt as a source material, and produce face brick, common brick, and tile.

The Hidden Brick Co., at 2610 Kauffman Avenue, Vancouver, Wash., uses a loamy alluvial silt that overlies the gravelly phase of the lacustrine deposits. Only the upper few feet of the surface materials is used for raw material at this plant. It is probably an alluvial silt deposited during the downcutting of the lacustrine deposits, with perhaps some admixed colluvium. Similar deposits were used during the early history of brickmaking near Portland (Darton, 1909, p. 18).

The major constituent of deeply weathered saprolite on the basaltic rocks of the area is halloysite, a kaolinlike clay mineral that may prove useful in the ceramic industry. Other weathered materials also are high in clay content. The Sandy River mudstone is chiefly a clayey silt, and locally may be utilized as a source of clay for brickmaking.

Clay from the Troutdale formation near Russell Landing formerly was used in the manufacture of brick and terra cotta (Darton, 1909, p. 18). This pit has long been abandoned and has been filled in for a new highway grade.

SAND AND GRAVEL

Sand and gravel, suitable for use as road metal or as concrete aggregate, is available in the Portland-Vancouver area in large quantities. The largest single source of these materials is the gravelly phase of the lacustrine deposits. Bar and channel gravel of the Willamette River is also an important source of supply, and the alluvial gravel deposits of the Molalla, the Washougal, and the Sandy Rivers are each utilized by a single operator in the area. Conglomerate of the Troutdale formation is obtained locally for use as road metal, but it is not acceptable for concrete aggregate (Bailey Tremper, Materials and Research Engineer, Washington State Dept. of Highways, written communication, 1948). At one time most of the gravel used for concrete in the region was obtained by dredging, mainly in the Willamette River channel (Darton, 1909, p. 13). In more recent years, however, the bulk of this material has been dug from pits. Bar and channel gravel, however, is still an important source of supply.

STONE

Stone is quarried from the Skamania volcanic series, the Columbia River basalt, and the Boring lava for many different purposes. The largest use is as crushed stone for road metal, but these volcanic rocks are also utilized for building stone, rock gardens and rock walls, riprap, and ballast.

Crushed rock from the Skamania volcanic series, the Columbia River basalt, and the Boring lava has been used satisfactorily for surfacing material. Quarries in the Columbia River basalt in the city of Portland have been closed for years because of legal restrictions, but quarries in this formation at other localities in the Tualatin Mountains and to the south still provide crushed rock. The Skamania volcanic series is the source of most of the crushed rock in Clark County, Wash., but the Boring lava also provides important amounts of crushed stone. The flow rocks of the Rhododendron formation are a source of crushed rock in other areas. Larger sizes of crushed rock from these sources are used as riprap and ballast.

The volcanic rocks of this region are used to some extent as building stone. The Columbia River basalt has been used to a very minor extent as building stone, but apparently its dark color makes it objectionable for general use. Boring lava, because of its lighter color, has been used to a greater extent, but is probably used most in masonry retaining walls, garden walls, and rock gardens. Oxidized and scoriaceous phases of the lavas appear to be especially desirable for rock garden construction, and a quarry on the south side of Prune Hill, west of Camas, Wash., provides a red scoriaceous phase of the Boring lava that is much in demand. Two quarries in the Oregon part of the area, the Rocky Butte Quarry in east Portland and Faoro and Sons Quarry near Carver, are in Boring lava and provide building stone.

The Silver Star granodiorite has some undeveloped possibilities as a source of building stone. The unweathered rock is attractive and joints commonly are widely spaced. The area of exposure is relatively inaccessible, however, and good quarry sites may be difficult to locate.

LIGHTWEIGHT AGGREGATE

Tuffaceous marine shale of the upper Eocene and lower Oligocene Keasey formation is obtained in the Coast Ranges west of this area and expanded or bloated in rotary kilns to produce lightweight aggregate. As the Scappoose formation is largely tuffaceous in character and similar to the Keasey, parts of this formation may provide material that can be bloated to produce a similar product.

MOLDING SAND

Molding sand for use in foundry operations is obtained at a locality in the SW¼SW¼ sec. 7, T. 2 N., R. 2 E., about half a mile west of Walnut School, northeast of Vancouver. The source material is clayey fine sand of the sandy phase of the lacustrine deposits. This is the only source of molding sand that is being exploited in the region.

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VOLCANIC ASH

A small amount of volcanic ash was mined during the period 1916 to 1924 from the Terrill "silica" property in the NW¼SE¼ sec. 32, T. 2 S., R. 2 E., just east of Oregon City. The ash bed is part of the Troutdale formation. It is not exposed now, but it is described as being 3.5 to 5 feet thick, and composed of about 90 percent volcanic glass. The size of the average particle is 0.02 mm (Oregon Dept. Geology and Mineral Industries, 1951, p. 23, 24). The ash was used as filler in asphalt pavements, as molding sand, and for the base of tooth powder.

A volcanic ash of similar character was noted during this investigation at an altitude of about 300 feet at the south end of a cut on an abandoned railroad grade on the east side of Abernethy Creek, in the NW¼NW¼ sec. 4, T. 3 S., R. 2 E. This bed of ash is about 1.5 to 2 feet thick and is interstratified with siltstone and sandstone of the Troutdale formation. If the two localities are on the same bed, as seems probable, the bed dips at a low angle (about 3° or 4°) to the north. This dip was observed at the Terrill locality (Oregon Dept. Geology and Mineral Industries, 1951, p. 24).

OIL AND GAS

The presence of sedimentary rock of marine origin in this area has resulted in some exploratory drilling for petroleum. The exploration has not been successful to date. The first prospect well, known to have been drilled in the area, was drilled in 1910. It was abandoned at a depth of about 1,200 feet (Washburne, 1914, p. 79). This well was located in the NW¼SW¼ sec. 24, T. 2 S., R. 2 E., at an altitude between 575 to 600 feet. It was collared in Troutdale formation and probably also penetrated the Sandy River mudstone, both of terrestrial origin. Later, prior to 1927, a test well was drilled in Dutch Canyon, on South Scappoose Creek, in the SE¼NW¼ sec. 17, T. 3 N., R. 2 W. This well, drilled to a depth of 4,426 feet, yielded salt water and some gas (Warren and others, 1945); it is artesian and is still flowing salt water. The brine contains 25,200 parts per million total dissolved solids, mostly sodium and calcium chloride (H. A. Swenson, U.S. Geol. Survey, written communication, 1955). In 1946, the Richfield Oil Co., drilled a well at an altitude of about 1,055 feet in the NW¼SE¼ sec. 23, T. 1 N., R. 1 W., near the crest of the Tualatin Mountains. This well was drilled to a depth of 7,885 feet through the Columbia River basalt, underlying marine beds, and older volcanic rock (Hart and Newcomb, 1956, p. 281). In 1947 a well was drilled by The Texas Co. to a depth of 9,263 feet in the NE¼SE¼ sec. 25, T. 1 S.,

R. 2 W., on Cooper Mountain just outside the area of this report (Hart and Newcomb, 1956, p. 292).

A permit to drill five stratigraphic core holes in secs. 2, 11, and 12, T. 2 N., R. 2 W., was granted to the Sunray Mid-Continent Oil Company in 1956 (Oregon Dept. Geology and Mineral Industries, 1956, p. 78).

GROUND WATER

The occurrence, quality, and yield of ground water in this area have been rather fully described in other reports (Piper, 1942; Griffin and others, 1956; Hart and Newcomb, 1956). The following summary was prepared largely from data given in U.S. Geological Survey Circular 372, by W. C. Griffin, F. A. Watkins, and H. A. Swenson (1956).

The water supply available to the Portland-Vancouver area exceeds requirements for any foreseeable industrial expansion. Vancouver is the largest user of ground water in the area. Ground water supplies about one-third of the irrigation water used in the area.

Most of the ground water is obtained from the Columbia River basalt, the Troutdale formation, and from the unconsolidated Quaternary deposits. Formations older than the Columbia River basalt are mostly nonpermeable and do not transmit much fresh water. Water from these formations is mineralized and commonly is high in calcium and sodium chloride. The Columbia River basalt contains moderate amounts of ground water, mostly in permeable zones along interflow contacts. At some places yields of 500 to 1,000 gallons per minute are obtained from 12-inch wells drilled through several hundred feet of the basalt. The Troutdale formation yields water to 12-inch wells at rates as high as 1,000 gallons per minute near large rivers; elsewhere few wells yield more than 900 gallons per minute. The Boring lava contains only small amounts of perched water.

Large quantities of recoverable ground water are contained in the older alluvial materials and the younger alluvial sand and gravel deposits beneath the flood plains of the Willamette and Columbia Rivers. The fill deposits of the Tualatin Valley are largely silt and clay of low permeability but contain some fine-grained sand zones that yield small amounts of water. Some wells have been drilled through these deposits to obtain ground water from the Columbia River basalt.

Ground-water supplies are generally of good quality, although harder and more mineralized than the surface water. Some of the ground water contains objectionable quantities of iron.

RELATION OF GEOLOGY TO ENGINEERING CONSTRUCTION PROBLEMS

The great variety of geologic materials in the Portland-Vancouver area makes a complete synthesis of their engineering properties impractical in a report of this scope, but some generalizations may be drawn from successful use of these materials and from obvious failures. Furthermore, by limiting the discussion to those materials of common occurrence in the areas where major construction activity is concentrated, the number of geologic materials to be considered is greatly reduced.

Much of the cities of Portland and Vancouver has been built on upper(?) Pleistocene unconsolidated deposits of gravel, sand, and silt. These materials are well drained, and generally provide adequate bearing strength for the structures sited upon them. Locally, along steep bluffs, they are subject to failure by landslide, but where they underlie broad relatively flat terraced levels they do not present problems in foundation design. The finer-grained materials of the flood plains of the Columbia River and the Willamette River are also unconsolidated deposits but have lower bearing strength. The coarser-grained phases of the upper(?) Pleistocene and flood-plain deposits provide most of the concrete aggregate and road metal used in this area. The unconsolidated materials are readily excavated by hand or power tools.

The Tualatin Mountains to the west of the Portland business section provide desirable "view property" sites, but their geologic character increases construction problems. The underlying bedrock of much of these hills is Columbia River basalt, which in an unweathered state is a hard, strong rock and an excellent foundation material for the heaviest structure.

Much of the basalt, however, is capped by a layer of loess—a clayey silt of wind-transported origin. The loess in this area is 18 to 25 percent sand (+0.05 mm), 44 to 68 percent silt (0.05 to 0.005 mm), and 13 to 31 percent clay size (−0.005 mm). Atterberg limits determined from four samples of the loess are: liquid limit, 29 to 32; plastic limit, 17 to 23; and plastic index, 9 to 12. Loessial deposits in other parts of the country with similar size-distribution characteristics and a similar range of Atterberg limits, but containing appreciable amounts of calcium carbonate, have been found to have certain performance characteristics that are significant in an evaluation of loess as a construction material. Although loess may have moderately good dry strength, it is unstable when wet (Bollen, 1945, p. 291). As the Portland area is one of relatively high seasonal rainfall, landslides in the loessial silt, though commonly not large, have caused considerable damage to property. These small landslides are concentrated mainly along the lower limits of the loess, but all steep slopes underlain by loess are subject to landsliding if sufficiently wetted.

Loessial deposits commonly develop either columnar jointing or prismatic structure, and these structural features influence the stability of the deposits in cuts. The loess of this area develops prismatic structure but does not develop columnar jointing. Columnar jointing has been considered a characteristic feature of loessial deposits, but Thorp (1936, p. 120–121) believes the columnar jointing is present only in the lime-rich deposits. The lack of lime in the loess of the Portland area may explain the lack of columnar jointing. Loessial deposits with vertical columnar structure stand well in vertical cuts, but slopes cut on the same loess erode readily (Bollen, 1945, p. 291). The lack of columnar jointing in the loess in the area of this report may make vertical cuts impractical. No history of this type of cut is known for this area, but some vertical slump scarps have stood for a few years without failure.

Loess, because of its high silt content, is susceptible to frost heaving (Bollen, 1945, p. 291), but the mild winters of this area make problems of this type unlikely.

The loessial materials are generally poor foundation soils because of low bearing ratio and are a poor wearing surface. They are generally impermeable and have poor compaction characteristics. Loessial deposits are considered to be fair to poor subgrade material; loess with a high clay content and a minimum silt content is more suitable for this purpose. The higher clay content reduces the rate of water intake, produces more cohesion, and decreases the elastic characteristics. The higher clay content also maintains a more uniform content of water during wet and dry cycles (Bollen, 1945, p. 291).

Loess with a high clay content is useful as a soil binder; that with a low clay content may be used as mineral filler (Bollen, 1945, p. 291–292).

The upper part of the Columbia River basalt beneath the loess is deeply weathered locally. In many cases it is completely decomposed to clay, which is also unstable as a foundation material under wet conditions although it may have considerable dry strength. The loessial deposits and the weathered Columbia River basalt are readily excavated by hand or power equipment. Excavation of the Columbia River basalt in an unweathered state requires the use of explosives.

Because of the lesser strength of the surficial materials, some buildings founded partly on surficial materials and partly on stronger bedrock have failed, largely by differential settling. Whenever economically possible, buildings in this area should have footings on sound basalt rather than on the weaker surficial deposits. This has been accomplished for smaller buildings by drilling churn-drill holes to basalt and installing concrete piles for foundation support.

Areas underlain by deeply weathered materials, either middle or early Pleistocene or older, are generally poorly drained. The area between Gresham and Sandy and the high plain south of Oregon City typify such areas. The clayey weathered material is impervious, and presents drainage problems in all types of construction and in agricultural land use. These materials are unstable when wet and are subject to landsliding on steep slopes, but they commonly underlie broad areas of low relief, which greatly lessens the danger of landslides except in excavation.

Because of their decomposed and clayey character, the weathered materials are readily excavated with hand or power equipment.

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