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Geology of the St. Helens Quadrangle, Oregon

By

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FOREWORD

The St. Helens quadrangle is a key area for the study of Tertiary formations of northwestern Oregon. In this quadrangle the stratigraphic relationship between the Columbia River basalt and the older Goble volcanic series is clearly shown. Also the area reveals evidence that led the authors to assign most of the widespread silt cover to the upper part of the Troutdale formation.

Especially after the greatly increased study of oil and gas possibilities of northwestern Oregon began in 1944 and 1945 by the major oil companies, the Department felt that all the geological information which it had gathered on this area should be made available. Therefore mapping of the quadrangle was completed as promptly as possible and the map published.

The quadrangle and the area adjacent to the west contain most of the limonite deposits known in the State. Although these deposits have drawbacks for steel making, they are of value for foundry iron and will some day be put into production. A few have been mined at times for paint pigment. Originally mapping of the quadrangle was centered especially on a restudy of limonite occurrences. A report of a much earlier survey made by the Oregon Bureau of Mines and Geology was published in 1923.

From the standpoint of economic geology, the area is most important because of the widespread lateritic deposits of ferruginous bauxite. These, together with the known deposits in other counties, may very well prove to be the most valuable mineral deposits ever found in the State. From a national standpoint they are doubly important because of the need for increasing domestic reserves of low-silica aluminum ore.

F. W. Libbey
Director

October 1, 1946.

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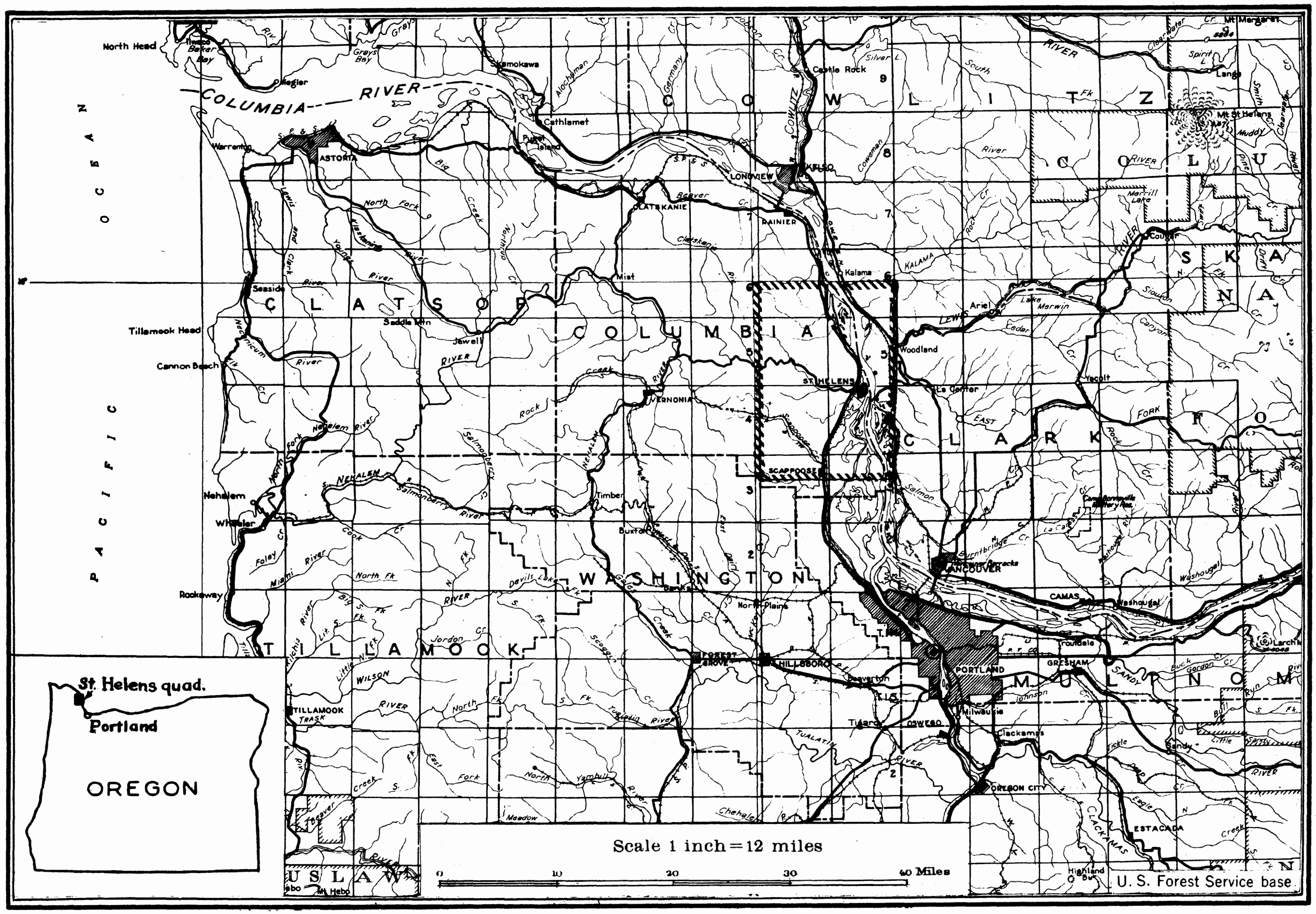

Index Map of Northwestern Oregon and Southwestern Washington Showing Location of St. Helens Quadrangle

GEOLOGY OF THE ST. HELENS QUADRANGLE, OREGON-WASHINGTON

Introduction

In 1941 the Oregon Department of Geology and Mineral Industries began a mapping project in the St. Helens quadrangle in Columbia County of northwestern Oregon as a part of the State geological survey. Dr. W. D. Wilkinson of Oregon State College was placed in charge of the survey and he was assisted by Messrs. R. K. Meade, H. D. Wolfe, and J. P. Martin. Completion of the project was prevented by the war, as all of the men named entered the armed services in 1942. Moreover, the Department discontinued the State geological survey in order to give full attention to war mineral work.

In 1945, while Dr. Wilkinson was still in the Army, several large oil companies became active in studying northwestern Oregon for oil and gas possibilities. Therefore the Department felt that the project should be completed and the map made available as promptly as possible. Drs. W. D. Lowry and E. M. Baldwin of the Oregon Department spent about a month early in 1945 completing the mapping of the volcanic rocks in the northern part of the quadrangle and in tracing the extent of the sediments tentatively assigned by them to the Troutdale formation. The accompanying geological quadrangle map (in pocket) was published in November 1945.

The area within the St. Helens quadrangle, like much of western Oregon, is covered by a thick mantle of soil and dense underbrush. Most of the outcrops are deeply weathered and recent slumping has obscured some of the evidence. Therefore there are likely to be inaccuracies in the location of the contacts, particularly of the silty sediments tentatively assigned to the Troutdale formation, especially where they lie upon the Columbia River basalt and the Goble volcanic series.

Acknowledgments

The writers wish to acknowledge the assistance rendered by Mr. E. K. Nixon, former director of the Oregon Department of Geology and Mineral Industries, and by Messrs. R. K. Meade, H. D. Wolfe, and J. P. Martin, who composed the first mapping party under the supervision of the senior author.

Dr. H. E. Culver, former supervisor of the Washington Division of Geology, and Mr. S. L. Glover, supervisor of the Washington Division of Mines and Geology, gave valuable help, as did Mr. W. C. Warren, Dr. H. E. Vokes, and Mr. Hans Norbisrath, all of the U.S. Geological Survey. Grateful acknowledgment is made to Dr. Ethel I. Sanborn of Oregon State College for identification of fossil leaves.

The cooperation of many individuals in Columbia County is also acknowledged. Especial mention should be made of Mr. G. A. Nelson, County Agricultural Agent, and Mr. J. W. Hunt, County Clerk.

Mr. F. W. Libbey, director of the Oregon Department of Geology and Mineral Industries, aided greatly by suggestions during the field study and by criticism of the manuscript. Dr. J. E. Allen, department geologist, contributed to the study by his knowledge of the area, especially the limonite deposits. The writers wish to thank Mrs. Lillian Owen for her care in the multigraphing of the bulletin.

The 29th Engineers, U.S. Army, furnished the base map and aerial photographs.

Location

The greater part of the St. Helens quadrangle is in northwestern Oregon; the northeast corner lies across the Columbia River in Washington. Location of the quadrangle is shown on the index map opposite page 1. It lies between latitudes 45° 45' and 46° 00' north, and longitudes 122° 45' and 123° 00' west, and is about 220 square miles in area. General reconnaissance of the areas lying just outside the quadrangle was necessary in order to interpret the stratigraphy.

The region is easily accessible via U.S. Highway 30 which follows the Oregon side of the Columbia River. Many county and logging roads extend laterally from this main highway, and most parts of the area are within 1 or 2 miles of a passable road. The Washington side is accessible via the Pacific Highway (U.S. 99) which follows the east bank of the Columbia River.

Relief and drainage

Most of the St. Helens quadrangle lies on the east side of the Coast Range of northwestern Oregon. The area is drained by the Columbia River, which follows a northerly course along the eastern edge of the quadrangle. Within less than a mile of the Columbia River at tide level there is an abrupt rise to 400 feet above mean sea level. West of this abrupt rise elevations increase gradually toward the western boundary of the quadrangle where a series of north-trending ridges known locally as the Clatskanie divide reach an elevation of about 1500 feet. Tide, Milton, and North Scappoose creeks have their headwaters along the Clatskanie divide and flow easterly or southeasterly to the Columbia River. The small part of the area west of the divide drains northwestward into the Columbia by way of the Clatskanie River.

Stream gradients are high near their headwaters along the Clatskanie divide; Tide Creek has a gradient of 14 percent in the first half-mile of its course. Other streams, near their headwaters, have gradients of from 7 to 10 percent. The average gradient is less than 1 percent except for that part of the stream course near the headwaters.

The valley profiles are V-shaped with little bottom land. Many of the divides on Columbia River basalt terrane are relatively flat and undissected. The ratio of slopeland to topland is about equal. Thus the character of the stream gradients, valley profiles, and divides indicates a youthful stage in the cycle of erosion. The area on the Washington side of the Columbia River is somewhat more dissected and suggests a slightly more advanced stage in the cycle of erosion. There the maximum elevation is a little more than 1800 feet. However, the maximum elevation within the quadrangle is in the southwest corner where the Columbia River basalt rises to more than 2000 feet.

In the southern two-thirds of the quadrangle, the drainage pattern has been developed as a series of consequent streams on the warped and probably somewhat faulted Columbia River basalt surface. Those streams which have cut through the lava have been superimposed on the underlying sediments. Merrill Creek in the northern third of the quadrangle appears to be a subsequent stream developed near the contact of Columbia River basalt with the underlying Oligocene sandstone. Apparently the Alder Creek-North Scappoose Creek drainage evolved along a fault. The lower part of the courses of Tide Creek, in the northern part of the quadrangle, and Milton Creek, west of St. Helens, appears to have been superimposed from a silt filling onto the underlying volcanic rock.

Stratigraphy

Introduction

All the rocks exposed in the St. Helens quadrangle are of Cenozoic age. They include both marine and terrestrial sediments and volcanic rocks. The oldest rocks exposed consist of a thick series of upper Eocene basaltic flows, pyroclastics, and associated sediments which are widespread in parts of northwestern Oregon and southwestern Washington. Sediments derived in part from the erosion of this upper Eocene series were deposited in an advancing Oligocene sea.

Accompanying or following the retreat of the Oligocene sea these marine sediments and the upper Eocene rocks were folded and eroded to form eventually an area of moderately low, rounded hills with rather wide intervening valleys. Subsequently, during Miocene time, Columbia River basaltic lavas poured over this surface and buried much of it to depths of as much as 700 feet in places. These extrusions occurred intermittently, for at several localities soil layers several feet in thickness were developed and buried by subsequent flows. A major interruption in the outpouring of these lavas is shown by the presence of at least one horizon of bog-iron deposits within the basaltic series.

The present drainage may have begun to develop with the cessation of the Miocene basaltic eruptions. However, a long period of laterization produced an extensive cover of laterite on the Miocene basalt terrane before it was warped and dissected and before the deposition of Troutdale sediments in the Pliocene. Both the Columbia River basalt and the Troutdale sediments have been folded. Where the lava sheets were thin over the crests of older sandstone ridges, erosion removed them and the former sites of ridges became valleys. Changes in base-level during and since the Pleistocene have resulted in considerable erosion and terrace deposition.

Goble volcanic series

The name Goble volcanic series is herein proposed by Lowry and Baldwin for a thick section of basaltic flows, pyroclastics, and minor amounts of sediments all of which are well exposed in the vicinity of Goble, Oregon, just north of the St. Helens quadrangle as well as elsewhere along both the Oregon and Washington sides of the Columbia River. The platy basalt in the county quarry near Goble is shown in figure 1, opposite page 4. Studies of the faunas in the sediments underlying and overlying Goble volcanic rocks indicate that the series is interfingered with the marine Cowlitz formation of upper Eocene age and is unconformably overlain by beds tentatively correlated with the Gries Ranch stage of the lower Oligocene.

Culver (1919) mapped basalts near Kelso, Washington, which he states are apparently interbedded with sediments assigned by him to the Eocene. The writers are indebted to H. S. McQueen who suggested that basalts on the Washington side of the St. Helens quadrangle were older than the Miocene Columbia River basalt to which they had been generally assigned. It is understood that S.L.Glover had earlier suggested the probable Eocene age of these rocks.

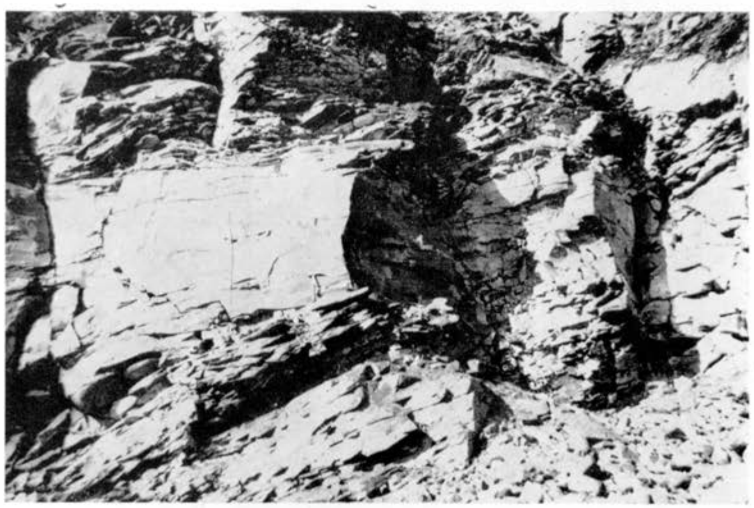

Fig. 1. Platy basalt in the Goble quarry, just north of the St. Helens quadrangle. The platy jointing is characteristic of some of the denser flows of the Goble volcanic series.

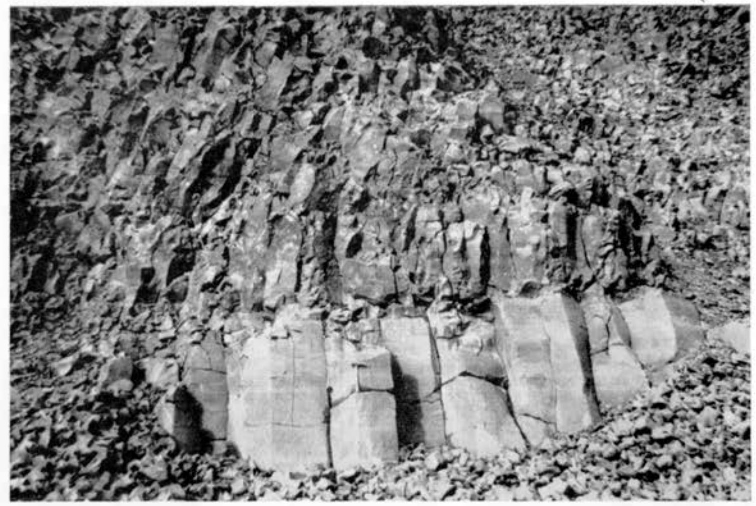

Fig. 2. Columnar jointing in Columbia River basalt exposed in a quarry just north of St. Helens.

Fig. 3. Basaltic conglomerate capped by Columbia River basalt occurring at or near the base of the basalt series, exposed near the junction of Meissner and Canaan roads.

Fig. 4. Moderately indurated Troutdale conglomerate along Canaan Road west of Deer Island. Some of the pebbles, such as the one indicated above hammer, are completely decomposed. A characteristic well-rounded quartzite pebble is shown to the right of the hammer.

On the Washington side, the Goble volcanic series extends almost continuously northward from the mouth of the East Fork of the Lewis River to the Kelso-Longview road junction; on the Oregon side they extend from the town of Deer Island to Walker Island several miles down the Columbia River from Rainier. A section of more than 5000 feet of flows, pyroclastics, and associated sediments along the Pacific Highway (U.S. 99) between Kelso and Woodland, Washington, is given in figure 5, opposite page 7, along with other occurrences.

The lower part of the series appears to be made up predominantly of basaltic flows with associated flow breccia, although tuff breccias occur in apparently the lowest part interbedded with marine sandstones of Cowlitz age. The upper part of the series is comprised of basaltic lavas with associated pyroclastic rocks in significant, if not predominant, amounts. Marine sediments have not been found in the upper part of the series. Some of the marine sandstones interbedded with the lower part of the series show large contributions from volcanic sources, whereas others are massive light-colored micaceous sandstones which contain no appreciable additions of volcanic materials. Along the Pacific Highway less than a mile north of the Kelso-Longview junction, about 25 feet of massive yellow sandstone made up of quartz, plagioclase, and mica, is overlain by about 30 feet of volcanic breccia containing some vesicular boulders as much as $1\frac{1}{2}$ feet in diameter. The breccia appears to be disconformable upon the massive sandstone, but no significant break is indicated as the breccia grades upward into tuffaceous grit and sandstone. The lava fragments in the breccia are basaltic and loose grains of plagioclase have a composition slightly more basic than Ab_5An_5. Although marked lithologic differences and erosional breaks occur elsewhere in the Goble series, no important stratigraphic breaks could be determined. The evidence indicates volcanic activity contemporaneous with marine deposition.

All of the Goble flow rocks and the one breccia examined in thin section are basaltic. The locations of rocks sectioned are indicated in figure 5, opposite page 7, by a "P" number.

Of the 14 basalts examined microscopically, eight show about 5 percent or less altered olivine present as phenocrysts, and they may be referred to as olivine basalts. All the basalts are hemicrystalline and have a slightly to markedly porphyritic texture with a groundmass ranging from intergranular through intersertal to hyalopilitic. A few have a glomeroporphyritic or cumulophyric texture. Phenocrysts include plagioclase, augite, olivine, and magnetite, and constitute from 5 to 35 percent of the basalts, averaging about 20 percent.

Labradorite or bytownite is the predominant phenocryst and together with the laths in the groundmass makes up about 55 percent of most of the basalts. The average length of the plagioclase phenocrysts is about 0.5 mm but some are as long as 4 mm. They have euhedral to subhedral outlines and most are somewhat corroded. All phenocrysts show albite twinning, and combined Carlsbad-albite twinning is common. Poor to well-developed zoning is also common. One phenocryst has a core with a composition of Ab_2An_8 and a rim with a composition of Ab_4An_6. The composition of these phenocrysts ranges from slightly more basic than Ab_4An_6 to more basic than Ab_2An_8; most of them are a little more basic than Ab_3An_7. The plagioclase in the groundmass ranges in composition from Ab_5An_5 to slightly more basic than Ab_3An_7, averaging about $Ab_{35}An_{65}$, labradorite.

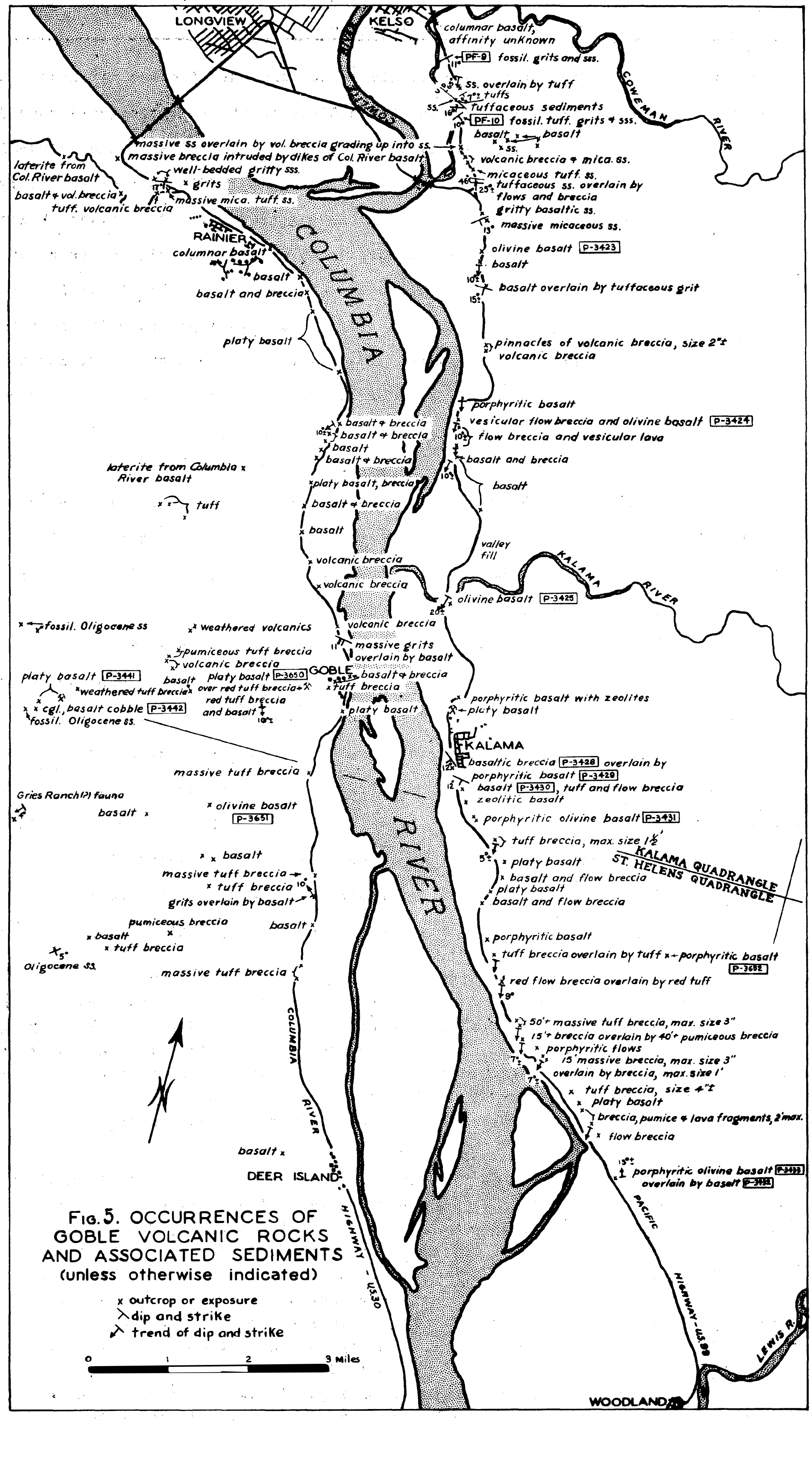

Fig. 5. OCCURRENCES OF GOBLE VOLCANIC ROCKS AND ASSOCIATED SEDIMENTS (unless otherwise indicated)

The plagioclase phenocrysts in two of the sections are arranged in clusters. Others contain fractures which do not extend into the groundmass. Inclusions of magnetite and glass occur in some but the glass is believed to be present as fillings in corrosion embayments. One thin section shows the plagioclase phenocrysts partially altered to calcite and to an unidentified zeolite.

Augite occurs as phenocrysts in 11 of the 14 basalts examined, making up from 1 to 20 percent (average about 5 percent) of the rocks. Together with the pyroxene in the groundmass they constitute 15 to 20 percent of most of the basalts. The average length of the augite phenocrysts is less than 1 mm, although a few crystals are as long as 4 mm. Most of them have a partially corroded euhedral to anhedral outline. All of the 11 sections with augite phenocrysts contain some twinned augite and one section contains an augite phenocryst which shows both zoning and twinning. In some thin sections part of the augite phenocrysts are arranged in clusters. Some crystals contain included magnetite and a few show fracturing prior to crystallization of the groundmass. The groundmass of all the sections contains grains of augite or minute grains of an unidentified pyroxene. Most of the augite grains in the matrix have subhedral or anhedral outlines although a few are euhedral. Some contain inclusions of magnetite.

Olivine phenocrysts were previously noted as being present in eight of the sections in amount of 5 percent or less. Most of the olivine grains are less than 1 mm in length; the maximum length is 1.5 mm. Their shape is euhedral or subhedral and some grains are somewhat corroded. All are altered, mostly to antigorite and magnetite although one grain was altered to chrysotile and serpophite (?)* and two contain altered iddingsite.

Magnetite occurs as inclusions in phenocrysts and is an important constituent in the groundmass, forming from 2 to more than 10 percent of the sections. The grains may be euhedral to anhedral in outline and skeletal crystals are common in several of the sections. Dust-size particles are profusely distributed throughout the groundmass of some sections.

The glass in the groundmass of the basalts constitutes between 5 and 35 percent of the sections, averaging 15 to 20 percent. It is either clear or brownish in color and in several of the basalts it is partly devitrified.

The order of crystallization of the phenocrysts was magnetite, olivine, augite, and plagioclase. Magnetite was also first to crystallize in the groundmass and was followed by plagioclase and augite.

The one volcanic breccia sectioned (see P-3428, fig. 5 opposite page 7) is basaltic and made up of irregularly shaped pieces of augite and plagioclase together with lithic fragments. The plagioclase grains, which are bytownite with a composition of $Ab_{25}An_{75}$, are about 1 mm in size and corroded. Some of them have been altered to spherulitic aggregates of an unidentified zeolite and opaline material. The augite shows twinning and contains inclusions of magnetite and glass. The lithic fragments are angular and as much as 2 mm in diameter. They are basaltic and most are made up of magnetite grains and plagioclase laths in a glassy matrix. However some contain small grains of an unidentified pyribole and others are largely glass. Although one fragment contains an altered plagioclase phenocryst, most of them are not porphyritic.

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*Rogers, A.F., and Kerr, P.F., <u>Optical Mineralogy</u>, p. 362, McGraw-Hill Book Co., New York, 1942.

The chemical composition of the Goble basalt is indicated by the following spectrographic analyses* of the platy basalt from the Goble and Kalama quarries:

Percentage	Goble, Oregon	Kalama, Washington
More than 10%	silicon aluminum calcium	silicon aluminum calcium
1 - 10%	iron magnesium	iron magnesium sodium
0.1 - 1%	sodium manganese titanium strontium	 manganese titanium strontium
0.01 - 0.1%	chromium vanadium barium	chromium vanadium barium
0.001 - 0.01%	zirconium copper cobalt nickel	zirconium copper cobalt nickel

Many of the more massive flow rocks are dark gray and characterized by platy jointing. The range in the thickness of individual flows is not known but some appear to be more than 50 feet thick.

A wide variety of zeolitic minerals and calcite are present in some of the Goble lavas. The presence of zeolites, the platy jointing of some of the basalts, and the associated pyroclastic rocks help to distinguish the lavas of the Goble volcanic series from similar appearing rocks belonging to the Columbia River basalt series which lack these characteristics in most places (compare figures 1 and 2, opposite page 4).

The greater part of the pyroclastic rocks of the Goble series in the St. Helens quadrangle are quite massive and uniform in texture. Most of them do not show the effects of water sorting and apparently were deposited directly from the air. However, along U.S. Highway 30, half a mile north of Goble, just north of the St. Helens quadrangle, a massive well-indurated grit contains a number of well-rounded pebbles and cobbles. Massive, jointed flows of basalt both underlie and overlie the grit, and the overlying flow baked the upper part of the grit to a red color. Some of the tuffaceous grits and sandstones north of Tide Creek also have been somewhat water sorted and some of the volcanic breccia along U.S. Highway 99 north of Woodland, Washington, is possibly of mudflow origin. The locations and character of a few of the pyroclastic rocks are indicated in figure 5, opposite page 7.

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*Made by Esther W. Miller, Spectroscopist, Oregon Department of Geology and Mineral Industries.

More than 50 feet of massive, brown volcanic breccia, or lapilli tuff, is exposed along U.S. Highway 30 just north of Tide Creek. The fragments are angular and most of them are less than an inch in longest dimension. The plagioclase phenocrysts in one lithic fragment were determined to be labradorite, $Ab_{45}An_{55}$.

The tuff breccia along the road east of the Goble quarry is stratigraphically below the platy basalt in the quarry. This breccia contains pieces of pumice and angular basaltic fragments, some nearly a foot in diameter. Large pieces of fossil wood are also present. Less than a mile north of the Beaver Homes School just north of the St. Helens quadrangle and about 2 miles west of Goble, volcanic breccias with basaltic blocks as much as 2 feet in diameter underlie a pumiceous breccia which is very similar in appearance to that exposed along U.S. Highway 99 at Martin Bluff, Washington. About three-fourths of the Beaver Homes breccia is made up of pumice fragments altered to montmorillonite, and the remainder is composed of angular dark gray lithic fragments as much as three-fourths of an inch in diameter. The Martin Bluff breccia consists largely of pumice fragments altered to montmorillonite. Other constituents include dark gray lithic fragments as much as half an inch in size, and loose grains of plagioclase with a composition of basic andesine.

At least 25 feet of tuff was encountered in a well about 1½ miles west-southwest of the Beaver Homes School and near the boundary of the St. Helens and Kalama quadrangles. It has been altered to a light greenish buff clay. The relatively rapid alteration of the glass in the Goble pyroclastic rocks to clay is believed responsible for most of the landslides which are common north of Tide Creek. One of these slides just below the road about 1½ miles nearly due west of the mouth of Tide Creek has exposed tuff breccia with pumice fragments as much as 14 inches in length.

As shown in figure 5, opposite page 7, the rocks of the Goble volcanic series and associated sediments have a southerly regional dip. There is a reversal in the dip along the Pacific Highway about 3 miles north of Woodland, Washington, and another along U.S. Highway 30 about 3½ miles north of the town of Deer Island. The terrane of the Goble volcanic series is thoroughly dissected and is in a stage of late youth or early maturity in the erosion cycle.

The Goble volcanic series is upper Eocene in age and possibly in part lower Oligocene. The Cowlitz fauna (PF-9) listed below and identified by E. M. Baldwin occurs in tuffaceous sediments on the east side of the Pacific Highway, 0.6 mile south of the Coweman River bridge (see figure 5, opposite page 7, for location). The sediments dip southward about 10 degrees and contain lenses of grit and decomposed fragments of cinders and pumice. They are stratigraphically a little below sandstones that are interbedded with the basal pyroclastics and flows of the Goble volcanic series.

Nuculana cowlitzensis (Weaver and Palmer)
Pteria clarki Weaver and Palmer
Ostrea sp.
Volsella (Brachidontes) cowlitzensis (Weaver and Palmer)
Crassatellites stillwaterensis Weaver and Palmer
Pitar californiana (Conrad)
P. eocenica (Weaver and Palmer)
Pachydesma cf. crowderi Weaver
Gari cowlitzensis (Weaver and Palmer)
G. columbiana (Weaver and Palmer)
Solena columbiana (Weaver and Palmer)
Spisula cf. packardi var. yokamensis Turner
Corbula sp.
Dentalium sp.
cf. Cymatium sp.
cf. Polinices hornii (Gabb)
Ficopsis sp.

The fauna at locality PF-9 seems to be closely related to the Cowlitz fauna from the Coal Creek section northwest of Longview, Washington, described by Weaver and Palmer (1922). Tuffaceous sandstones and tuff breccia along the hill road about 2 miles north of Longview and about three-fourths of a mile east from the crest of the Lone Oak Road contain Turritella uvasana subsp. Conrad and Acila decisa (Conrad). The sandstone of this locality, which is midway between the Coal Creek section and locality PF-9, is probably a connection between the Cowlitz strata exposed in Coal Creek and that in the section south of Kelso.

Another fossil locality (PF-10), near the junction of a county road with the Pacific Highway, 1.5 miles south of the Coweman River bridge (see figure 5, opposite page 7, for location), and stratigraphically higher in the section than PF-9 yielded the following fauna:

Nuculana cf. cowlitzensis (Weaver and Palmer)
Volsella (Brachidontes) cowlitzensis (Weaver and Palmer)
Pachydesma crowderi Weaver
Tellina cf. cowlitzensis Weaver
cf. Bonellitia paucivaricata (Gabb)
Polinices sp.

By far the greater part of the fauna (PF-10) is composed of numerous shells of Pachydesma crowderi Weaver. This species was named and described by Weaver (1942:190, pl. 46, fig. 8) who assigned it to the Cowlitz formation. His type locality is 2 miles south of Kelso and is probably the same as fossil locality PF-10. The single specimen figured by Weaver is slightly smaller than the average. The shells range from a few millimeters to more than 43 mm in length and 34 mm in height - the largest specimen measured.

The Goble volcanic series in the St. Helens quadrangle is overlain unconformably by tuffaceous sandstone containing a fauna tentatively correlated with the Gries Ranch stage of lower Oligocene age. The angular relationship of the Goble volcanic series to the overlying Oligocene sandstone could not be determined as the attitude of the contiguous basalts could not be measured. A marked disconformity is apparent and hence a period of erosion occurred before the deposition of the overlying Oligocene sandstone.

It is not known certainly to what part of the Cowlitz formation the sandstones at fossil localities PF-9 and PF-10 belong. Weaver (1937:90) notes that dark gray to black basalts and tuffs near the mouth of Olequa Creek are interbedded with dark-colored massive sandstones and shale belonging to the lower part of the type Cowlitz section between Winlock and Olequa. In that section, measured by Weaver, about 3000 feet of Cowlitz sediments overlie the youngest of a series of intercalated basalts whose base has not been determined. Weaver (1937:91) suggests that there may be several thousand feet of shales between the base of the measured section and the top of the Metchosin volcanics. Hence he evidently meant to distinguish the basalts in the type Cowlitz section from the older Metchosin volcanics.

The lithology of the type Cowlitz basalt flows and tuffs is similar to that of the Goble and their proximity indicates that they may belong to the same volcanic series. The Goble volcanic flows near Kelso are 15 miles from the basalt in the type Cowlitz section; they are similar to basalts at intermediate points along the Cowlitz River Valley such as near the highway bridge over the Toutle River. Culver (1919) reported that the basalts which predominate in the eastern part of this intermediate area are apparently interbedded with sediments assigned by him to the Eocene. Additional field work probably will show that the Goble flows and tuffs interfinger with the type Cowlitz section farther north. If the basalt at the mouth of Olequa Creek in the Cowlitz section belongs to the Goble volcanic series, then 3000 feet of Cowlitz sediments overlies this member. As no Cowlitz sediments are known to overlie the main mass of Goble rocks (if once present they have been removed by erosion), it seems likely that the sandstones interbedded with the basal members of the Goble volcanic series belong to the lower part of the exposed type Cowlitz section, and that the extrusion of contemporaneous Goble flows and pyroclastics may have forced the Cowlitz sea back to the west.

Weaver (1937:94) states that the type Cowlitz section between Olequa and Winlock represents the southern limb of the North River - Dryad syncline, whose axis lies north of the city of Winlock and trends northwesterly toward Grays Harbor. The section of Goble volcanic rocks and associated Cowlitz sandstone farther south between Kelso and Woodland, Washington, has a southerly regional dip, and thus this section and the type Cowlitz section probably represent the opposing limbs of an anticline. Although a northerly dip was noted at the fossil locality about 2 miles north of Longview, mentioned on page 10, it possibly may be only a local reversal of the general southerly dip of the Goble volcanic rocks and the sandstones of that region.

The Goble volcanic series extends eastward from the northeast corner of the quadrangle to the Lake Merwin area. From there its extension eastward and southward has not been traced. Verhoogen (1937:264) states that the Keechelus andesites are younger than folded basalts which can best be seen 25 miles east of Castle Rock on the road to Spirit Lake near Mt. St. Helens, Washington. These older folded basalts may belong to the Goble volcanic series. Although the petrographic descriptions and assigned ages of the Keechelus andesite and the major part of the Eagle Creek formation which, in the Columbia River Gorge is made up of southward dipping beds of pyroclastics and interbedded lava flows, preclude their correlation with the Goble volcanic series, it is thought that some of the basic lavas exposed along the lower course of the Washougal River may be older and belong to the Goble series. Zeolitic basalt exposed along the Washougal River, 4 miles northeast of the town of Washougal, closely resembles some of the Goble flows. At this locality the basalt dips about 15° to the southeast.

The presence of rocks belonging to the Goble volcanic series south of the St. Helens quadrangle is indicated by well log data. The well of the Richfield Oil Company (Barber no.1) along the crest of the Portland hills 13 miles south of the quadrangle encountered a series of basic flows, breccias, and tuffs at a depth of about 2,100 feet and the series was not bottomed at 7,885 feet at which point the well was abandoned.

The Cooper Mountain well of the Texas Company, 20 miles south of the quadrangle, penetrated in turn approximately 1,000 feet of Columbia River basalt; 1,800 feet of tuffaceous sandstone, shale, and carbonaceous shale; about 1,400 feet of agglomerate, tuff, and amygdaloidal and altered basalt flows; approximately 4,000 feet of sediments; and finally another series of volcanic rocks.

A foraminiferal faunule from a depth of 4,725 feet in the Cooper Mountain well was examined by R. E. Stewart* who stated:

> "This faunule has a very close affinity with Cowlitz material recorded by Beck (1943) and Coaledo material recorded by Detling (1946), as well as Cowlitz and Coaledo material in the collection of the Oregon Department of Geology and Mineral Industries. My present belief is that it is Cowlitz in age, but it is to be borne in mind that much work must yet be done on the foraminifera of western Oregon and Washington before maximum ranges for the various species may be assumed to be definitely established."

The 1,400 feet of volcanic rocks lies a short distance above the beds tentatively correlated with the Cowlitz formation by Stewart and has the same stratigraphic position as the Goble volcanic series.

Zeolitic basalt similar in appearance to some of the Goble flows occurs 13 miles southeast of Cooper Mountain on the east bank of the Willamette River about 1 mile north of New Era and 4 miles south of Oregon City. It is well exposed in cuts along the Southern Pacific Railroad and the Pacific Highway. J. E. Allen of the Oregon Department of Geology and Mineral Industries first suggested to the writers the probable pre-Columbia River basalt age of this rock which also may belong to the Goble volcanic series.

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*Geologist, Oregon Department of Geology and Mineral Industries. Personal communication August 1946.

The Tillamook volcanic series (Warren, Norbisrath, and Grivetti, 1945), comprising the heart of the Coast Range in Tillamook, Washington, and Yamhill counties, occurs to the southwest of the St. Helens quadrangle. They state that the series consists of basaltic lavas and tuffs and that along the Trask River it is from 6,000 to 10,000 feet thick. No petrographic study of the basalts is known to have been made but some are similar in appearance to the Goble basalts. As Warren et al reported that the Tillamook series is unconformably overlain by sediments containing a Cowlitz fauna, it would appear that the Goble volcanic series, whose lower members are interbedded with Cowlitz sediments, is younger. However, the upper Eocene basalt near Glenwood (Warren et al) is probably correlative with the Goble and may possibly be more extensive than mapped.

The relationship of the Goble volcanic series to the Keasey formation of upper Eocene or lower Oligocene age farther west is not known. An exposure of the Keasey formation, about three-fourths of a mile southeast of the town of Timber, contains pumice fragments which probably could not stand up under much reworking and therefore indicate contemporaneous volcanism. In the SW$\frac{1}{4}$ sec. 26, T. 4 N., R. 5 W., Keasey quadrangle, Hans Norbisrath of the U.S. Geological Survey obtained a specimen of greensand from beds assigned by him to the Keasey formation. The only clastic fragments in this specimen were unrounded pieces of basic lava and plagioclase, some of which were as basic as Ab_4An_6 and as much as 1 mm in diameter. The presence of these unrounded fragments in this specimen suggests contribution from the air.

As these pyroclastic fragments in the Keasey are similar in composition to the rocks of the Goble volcanic series, the Keasey may possibly be contemporaneous with part of the Goble, presumably the more pyroclastic upper phase. This idea was first presented by Warren, Norbisrath, and Grivetti (1945), but later Warren and Norbisrath* abandoned it because fossil evidence suggested that at least the upper member of the Keasey formation is equivalent to the Gries Ranch formation of lower Oligocene age. Oligocene sediments containing a fauna tentatively assigned to the Gries Ranch stage unconformably overlap the Goble volcanic series in the St. Helens quadrangle. If this assignment is correct and if the Gries Ranch formation is equivalent to the upper part of the Keasey, then at least that part of the Keasey is not contemporaneous with the Goble volcanic series.

Warren, Norbisrath, Grivetti, and Brown (1945) state that Eocene andesitic tuffs and volcanic breccias with a maximum thickness of possibly 7,000 feet overlie upper Eocene sediments tentatively assigned to the Cowlitz formation, and that Cowlitz fossils occur in tuffaceous sediments interbedded with the upper part of the volcanic series along the highway between Renton and Seattle, Washington. The Eocene volcanic series in that region may be equivalent in age to much of the Goble volcanic series.

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*Personal communication from Warren, July 1946.

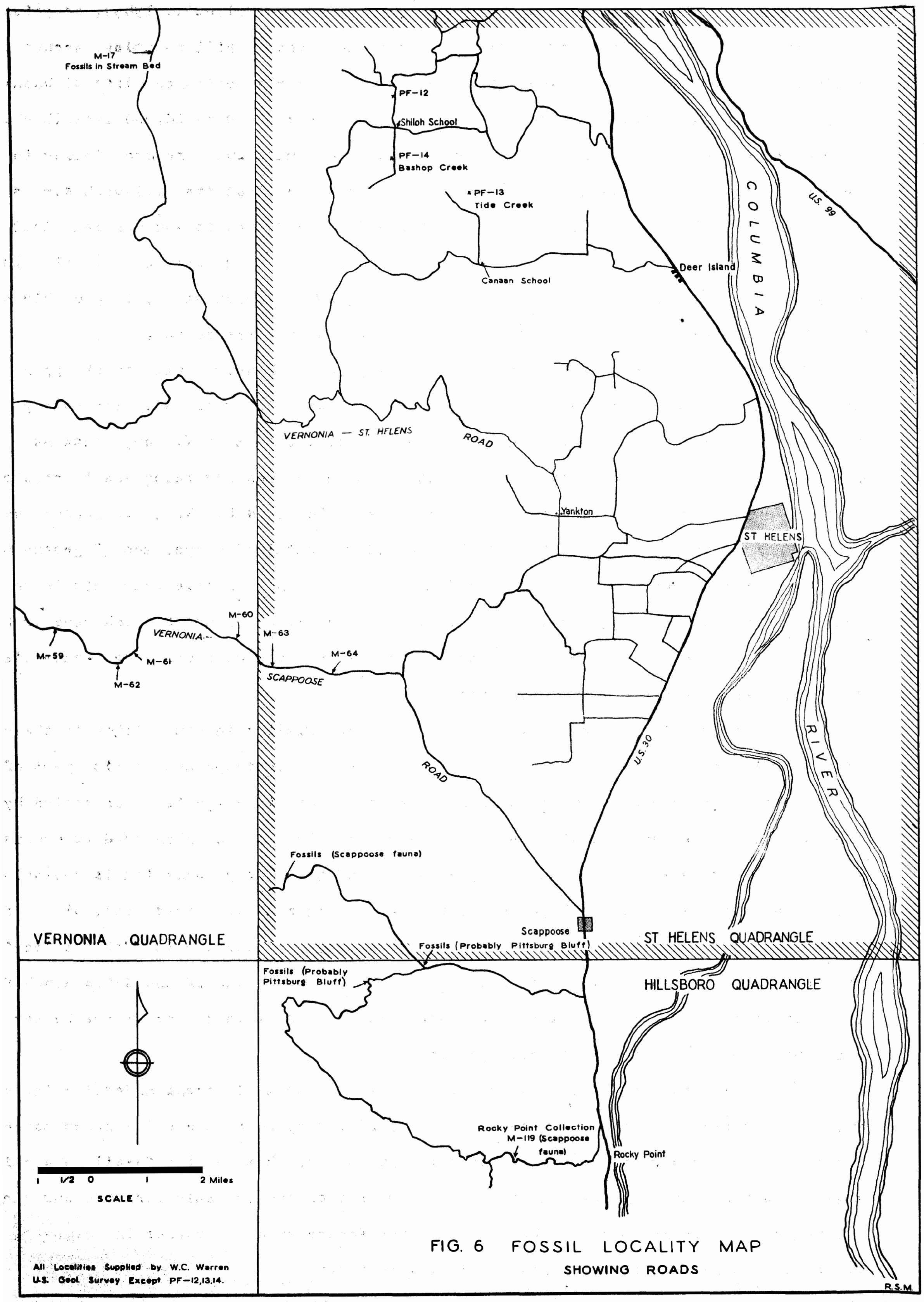

FIG. 6 FOSSIL LOCALITY MAP
SHOWING ROADS

The Goble series probably is equivalent to other volcanic series in Washington and Oregon which occupy similar positions in the stratigraphic column. However, until most of these volcanic units have been dated more accurately and described more fully, no correlation with such formations as the lower part of the Clarno and the Calapooya is warranted.

Oligocene sediments

The oldest marine sediments known to be exposed within the St. Helens quadrangle are Oligocene sandstones whose distribution is shown on the accompanying geologic map (in pocket). The main areas of Oligocene sediments are present along Salt Creek, Cox Creek, and south of Merrill Creek. Good exposures occur along the Scappoose to Vernonia highway and the Clark and Wilson Lumber Company's logging railroad. Beginning at Spitzenberg, these sediments form a continuous outcrop to Pittsburg Bluff, 8 miles to the west. The Oligocene rocks are mostly massive, medium- to fine-grained tuffaceous sandstone with some gritty and conglomeratic components. They are commonly gray in color and weather to buff or yellowish brown. Farther west the sediments are estimated (Warren, Norbisrath, and Grivetti, 1945) to have an aggregate thickness of at least 2,300 feet.

Thin sections of samples taken at different localities and studied by Wilkinson show marked similarity in composition. The sandstone is characterized throughout by an abundance of volcanic glass and by the presence, in varying amounts, of muscovite, biotite, plagioclase, hornblende, orthoclase, and quartz, as well as basic rock fragments. The glass includes magnetite in dustlike particles, in some sections in such quantities that the glass fragments can be picked up by a strong magnet. The mineral grains are angular to subangular in shape whereas the rock particles, with the exception of angular pumice fragments, are usually fairly well rounded. The grains are well interlocked.

Some of the Oligocene sediments are non-marine. Wood and finely divided carbonaceous matter are present throughout the entire section exposed along North Scappoose Creek, as well as at many other localities. Two coal beds, the larger one of which is at least 6 feet thick, are exposed one mile south of Deer Island and 2½ miles west of Scappoose, respectively.

Oligocene marine sediments tentatively assigned to the Gries Ranch stage overlap the Goble volcanic series unconformably along Tide Creek in the Shiloh Basin. Whether this unconformity is angular could not be determined from the available exposures. Tuffaceous grits, sandstone, and minor amounts of conglomerate are the predominating rock types in this lower part of the Oligocene section. The presence of wood fragments and a few leaves, together with the coarse texture of the sediments, suggests that they represent a near-shore facies.

A fauna, PF-12 (see fig. 6, opposite p. 15), collected from a bed of gritty sandstone in the west bank of the road about two-thirds of a mile north of the Shiloh School yielded the following forms:

Myadesma howei Clark
Pachydesma gastonensis Clark
Spisula packardi (Dickerson)

A fauna, PF-13 (see fig. 6, opposite p. 15), collected from the northwest corner of sec. 3, T. 5 N., R. 2 W., on the A. Annicker place north of the Canaan School is listed below. The sediments are tuffaceous and contain lenses of grit with some pumice fragments.

Spisula packardi (Dickerson)
Pitar clarki (Dickerson)
Tellina cf. pittsburgensis Clark
Taras cf. griesensis Effinger
Lucina cf. dalli (Dickerson)
Venericardia sp.
Natica sp.
cf. Molopophorus stephensoni Dickerson

Fossils, PF-14, (see fig. 6, opposite p. 15), were collected from cuts along a farm road on the hillside west of Bashop Creek, a third of a mile south of the confluence of Bashop and Tide creeks. The section exposed is about 100 feet thick and is made up largely of spheroidally weathered tuffaceous sandstone with minor amounts of grit and a few concretionary layers. It is probably not more than 300 feet from the base of the Oligocene section. The following fauna, although fairly abundant, was poorly preserved:

Yoldia cf. merriami Dickerson
Acila shumardi (Conrad)
Pitar clarki (Dickerson)
Spisula sp.
Thracia cf. condoni Dall
Tellina cf. townsendensis Clark
T. cf. pittsburgensis Clark
Taras cf. griesensis Effinger
Venericardia sp.
Solena sp.
Bruclarkia
cf. Molopophorus stephensoni Dickerson
Epitonium cf. condoni Dall
Natica sp.
Dentalium sp.

About half a mile farther south near the George Peterson place and stratigraphically above the fossil locality, the beds become very micaceous.

The above faunas collected from the valley of Tide Creek belong to the basal part of the Oligocene section near the contact with the underlying volcanic series. The faunas are tentatively correlated with those of the Gries Ranch stage, as listed by Effinger (1938) and Durham (1944). The faunas are also similar to a fauna from Conyers Creek in the Clatskanie quadrangle identified by H. E. Vokes, who correlated it with the Gries Ranch stage of the Oligocene (Warren, Norbisrath, and Grivetti, 1945).

The total thickness of these sediments tentatively assigned to the Gries Ranch stage is not known. Probably the greater part of the Oligocene section in the St. Helens quadrangle is made up of beds of Pittsburg Bluff age with some beds of Scappoose age (Warren, Norbisrath, 1946) in the southeastern and northwestern parts of the quadrangle.

Fossils collected by Warren, Norbisrath, and Grivetti (1945) within the St. Helens quadrangle and adjoining areas (see fig. 6, opposite p. 15 for fossil localities) and identified by H. E. Vokes are given in the following list:

Table 1.

Checklist of Fossil Localities in or near the St. Helens Quadrangle

	Pittsburg Bluff					Scappoose*		
	M-59	M-63	M-61	M-62	M-64	M-17	M-60	M-119
Acila shumardi (Dall)	x	-	-	cf.	-	-	-	-
A. muta Clark	-	-	-	-	-	x	-	x
Nuculana cf. N. washingtonensis (Weaver) . . .	-	-	-	x	x	-	-	-
*N. aff. N. ochsneri (Anderson and Martin) . . .	-	-	-	-	-	x	-	x
Yoldia aff. Y. tenuissima Clark	-	-	x	-	-	-	-	-
Y. aff. Y. oregona (Shumard)	-	-	-	-	-	-	-	x
Mytilus cf. M. mathewsonii Gabb	-	-	-	-	-	-	-	x
Crenella porterensis Weaver	-	-	-	-	x	-	-	-
Cochlodesma aff. C. bainbridgensis Clark . . .	-	-	-	-	x	-	-	-
Thracia condoni Dall	x	-	-	-	-	-	-	-
Venericardia cf. V. hannibali Clark	-	-	-	x	x	-	-	-
Lucina cf. L. acutilineata Conrad	-	-	-	-	-	-	-	x
Taras goodspeedi Durham	-	-	x	-	-	-	-	-
T. parilis (Conrad)	-	-	-	-	-	-	-	x
Clinocardium scappoosensis (Clark)	-	-	-	-	-	-	x	-
Macrocallista pittsburgensis	x	-	-	-	x	-	-	-
Pitar cf. P. dalli (Weaver)	-	-	-	-	x	-	-	-
Tellina pittsburgensis Clark	-	-	-	x	-	-	-	-
T. cf. T. kamakawaensis	-	-	x	-	-	-	-	-
T. cf. T. oregonensis Conrad	-	-	-	-	-	-	-	x
Macoma twinensis Clark	-	-	-	-	-	-	-	x
Solen cf. S. clallamensis Clark and Arnold. . .	-	-	-	-	-	-	-	x
S. cf. S. townsendensis Clark	-	-	-	-	x	-	-	-
Solena eugenensis Clark	x	-	-	-	-	-	-	-
Spisula pittsburgensis Clark	x	x	cf.	-	-	-	-	-
S. veneriformis Clark	-	-	x	-	-	-	-	-
S. albaria scappoosensis Clark	-	aff.	-	-	aff.	-	x	x
Panope ramonensis Clark	x	-	-	-	-	x	x	-
P. snohomishensis Clark	-	-	x	-	-	-	-	-
Natica sp.	-	-	-	-	x	-	x	-
Turritella cf. T. wheatlandensis Clark	-	-	-	x	x	-	-	-
Bruclarkia columbiana (Anderson and Martin) . .	-	x	-	-	-	-	-	-
B. acuminata (Anderson and Martin)	-	-	-	-	-	-	x	x
Molopophorus gabbi Dall	-	x	-	-	-	-	-	-
Perse pittsburgensis Durham	-	x	-	-	-	-	-	-
Perse n. sp.	-	-	x	x	x	-	-	?
Spirotropis aff. S. dickersoni (Weaver)	-	-	x	-	x	-	-	-
*Dentalium porterensis Weaver	-	-	-	x	-	-	-	-
*D. conradi	-	-	-	-	-	-	-	x
*Aturia sp.	-	-	-	-	-	-	-	x

* Not shown on checklists with preliminary map.
cf. indicates "compare".

aff. indicates "affinity".
M-119 is the Rocky Point locality.

A much more complete Oligocene section is now recognized in the St. Helens area than was formerly known. Acila shumardi, which was considered the index fossil of the Pittsburg Bluff formation, is now known to occur also in beds of Gries Ranch and Lincoln age. A fauna collected from tuffaceous sandstone along the Rocky Point road just south of the St. Helens quadrangle (M-119, fig. 6, opposite p. 15) according to Vokes and Warren* has its closest affinity with the Sooke formation, but inasmuch as Astoria forms are also present, they think that this fauna may be of intermediate age. Warren and Norbisrath (1946:231) refer these beds to the Scappoose formation of upper Oligocene or lower Miocene age.

No pronounced depositional breaks have been found and there is very little lithological difference within the Oligocene strata in the St. Helens quadrangle. Any break in the St. Helens quadrangle must be implied largely from faunal studies. However, Warren and Norbisrath (1946) state that the Scappoose formation seems to rest disconformably on the Pittsburg Bluff formation and is separated from it by a conglomerate of variable thickness. Channeling and channel fills are common but may not indicate a major break. Some boulders as much as a foot in diameter are present in the channel fillings, and petrographic examination of one of these from a roadcut near Chapman indicates that it is a basalt. Examination of a thin section of another cobble from conglomerate near the base of the Oligocene section in the northwest corner of the quadrangle (P-3442, fig. 5, opposite p. 7), shows that it is similar in composition to the basalts of the Goble series. The sediments containing these cobbles and boulders were evidently derived at least in part from the erosion of a volcanic mass, presumably in part from the Goble series and, during fluctuations of the strandline, were spread over a floodplain or were laid down in shallow seas.

From a regional viewpoint, the older Oligocene sediments dip southwest from the highland of Goble volcanics, and the youngest part of the Oligocene sediments occur in the southwest part of the area. Reliable dips were difficult to obtain, however, and only the most reliable attitudes have been plotted on the geologic map. In some places the beds are nearly flat. The meager structural information indicates gentle folding, and some of the steeper dips are perhaps influenced by faulting. No well-defined pattern of folding and faulting was determined. Tuffaceous sediments in many of the older roadcuts are badly weathered and the clayey material in them facilitates slumping. For this reason many of the apparent dips are questionable.

There is a marked unconformity at the top of the Oligocene section. The overlying Columbia River basalt lies upon a surface of moderate relief amounting to several hundred feet. The surface of unconformity truncates sediments and volcanic rocks ranging in age from Cowlitz (upper Eocene) northwest of Longview, Washington, to those of upper Oligocene or lower Miocene age along the Rocky Point road. In places highlands of rocks older than Columbia River basalt rise above the later lava surfaces.

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*Personal communication from Warren.

Columbia River basalt

The name Columbia River basalt as originally used by Russell (1893:20-22) included basic lavas of several geologic ages in Washington, Oregon, Idaho, and California. The name has since been used by many writers for only the basalt of Miocene age and it is in this restricted sense that the term is employed by the writers.

Columbia River basalt formerly covered much of the quadrangle west of the Columbia River. The present distribution is shown on the accompanying geologic map (in pocket). Good exposures of dark gray to black unaltered basalt may be seen in several quarries along North Scappoose Creek and just north of the town of St. Helens. Fractured and jointed columns, as well as conchoidally fractured "brick-bat" blocks, are common. Associated with these in many places are the usual vesicular phases. Laterization of the Columbia River basalt terrane produced ferruginous bauxite at the surface, and the laterite grades downward into leached basalt that retains only the textural features and the magnetite of the original rock. Hence, fresh rock is encountered mainly along stream valleys where it has been exposed by recent erosion.

The thickness of these lava sheets in the St. Helens quadrangle is about 700 feet. The original thickness may have been somewhat greater. Apparent sources of some of these lavas are dikes which are found on Scappoose, Alder, and Merrill creeks. The Merrill creek dike, standing vertically and striking northeast, has been traced for half a mile. The trend of other dikes was impossible to determine because of the thick soil mantle.

Following are descriptions of the Columbia River basalt by W. D. Wilkinson. The unaltered specimens of these lavas are very fine-grained. On the freshly fractured surface, prismatic feldspars are recognizable and are surrounded by a hyaline matrix which gives a vitreous luster to the surface.

In general, the color is dark gray or black, but samples from some localities are lighter gray. Much of the vesicular lava is gray in color, changing to black in the massive phases. None of the basalt sampled was completely free of alteration which in some places has progressed so far that only relict textures can be found. The usual alteration of iron-bearing minerals has resulted in limonite stain along fractures and joints.

> A number of thin sections of the fresh unaltered basalt were cut from samples taken at widely separated localities. In all sections examined, the most striking feature is the exceptionally high percentage of glass. The amounts as estimated range from 10 to 30 percent. Plagioclase having a compositional range of Ab_5An_5 to Ab_4An_6 is present in amounts as great as 60 percent. The remainder is augite with not more than 3 percent magnetite.
>
> Magnetite was one of the first and also last minerals to crystallize. The first generation consists of well-formed and spearlike skeletal crystals. The second generation consists of well-disseminated dust, which is confined to the interstitial glass. Following the first generation of magnetite, augite crystallized. Although many of the crystals are euhedral, large areas in which the crystals are anhedral are equally common. The prismatic and granular crystals all show fracturing and cleavage traces. Next in order of

crystallization were the plagioclase feldspars which are slender prismatic crystals typical of nearly all fine-grained basaltic rocks. They seldom show more than three or four twinning lamellae. They usually are well-formed along the prism faces and skeletal on the ends. Filling the intervening space is a brown to black glass containing very fine magnetite dust, trichites, and crystallites.

Thin sections of altered material have much the appearance of an altered tuff. Outlines of the plagioclase and augite can be discerned under medium magnification. Glass filled the interstitial space but has been completely altered to clay. The only mineral unaffected is the magnetite which still retains its original form and distribution.

The texture of the basalt is hemicrystalline, frequently linophyric and, with decreased glass and increased crystallinity, it might be called diabasic.

Soil layers several feet thick and limonitic iron beds some of which are more than 10 feet thick occur within the Columbia River basalt series, indicating considerable time intervals between outpourings of the lavas. Such soil layers may be observed in the railroad cuts northwest of the Trenholm road. In addition, stream gravels composed of basaltic material occur enclosed in older basalt and buried beneath younger, relatively unaltered flows east of the Meissner road, about 2 miles west of the Shiloh School in sec. 30, T. 6 N., R. 2 W. A similar conglomerate shown in fig. 3, opposite p. 4, is exposed in the roadcut near the junction of the Meissner and Canaan roads. The conglomerate consists of at least 25 feet of well-rounded basaltic pebbles, cobbles, and boulders together with one large block of sandstone 6 feet in length. Several textural varieties of basalt are present. The conglomerate is capped by a relatively fresh basalt flow but its basal contact is not shown. Possibly this conglomerate is at the base of the Columbia River basalt as it occurs near the contact with the Oligocene sandstone. The presence of the block of sandstone and several textural varieties of basalt less typical of the Columbia River basalt than of the Goble volcanic series suggests that the stream carrying the gravels was still deriving much of its load from older rocks. A basaltic conglomerate is known to occur at the base of the Columbia River basalt at several places in northwestern Oregon (Warren, Norbisrath, 1946:234). One thick section is exposed in the road along the Clatskanie River in the N½ sec. 36, T. 7 N., R. 4 W.

The limonitic iron ores, generally known as the Scappoose iron deposits, are a part of the Columbia River basalt formation. They occur between flows of Columbia River basalt and although some evidence suggests the possibility that more than one limonitic horizon exists, Hotz* states that for any single deposit the ore bed lies between the same two flows and that all the deposits may occupy the same stratigraphic position. The limonite deposits are not to be confused with the laterite which is at the top of the basaltic section as shown in fig. 7 on p. 22. The limonitic ores occur as channel fillings and as sheetlike bog deposits resulting from the deposition of iron derived from the basalts by chemical weathering during a period of volcanic quiescence.

*Hotz, P.E., Iron ore deposits near Scappoose, Columbia County, Oregon: Unpublished report, in files of U.S. Geol. Survey.

Some of the largest deposits of limonite are found at the Oregon Charcoal Iron Company and Colport Development Company, Hill 600, and Bunker Hill localities within the St. Helens quadrangle; and at the Ironcrest and Ladysmith properties both less than 2 miles to the west of the quadrangle. Location of the major deposits is given on the geologic map (in pocket). Erosion has removed part of the overlying basalt so that the deposits are exposed in places. According to Hotz*, some of the limonite deposits are 500 feet above the contact of the basalt with the underlying Oligocene sediments, and in one place the overburden is said to consist of 160 feet of clay and weathered basalt.

The exploration by the federal agencies (U.S. Bur. of Mines War Minerals Report 186, 1944:7) shows that the deposits have the following characteristics:

> "The iron ore occurs in some places as a blanket formation between weathered basalt flows and in others between sandstone and altered basalt.
>
> "There is considerable evidence that much of the ore has been moved by streams and deposited in depressions, thus forming a natural concentrate. Some of it may be a chemical precipitate (bog iron), but there are features, even in the large blanket of the Colport-Charcoal (Oregon Charcoal Iron Co. and Colport Development Co.) deposit, that strongly indicate transportation and deposition. The original source of the ore may have been precipitation in bogs or chemical decomposition and leaching of the basalt followed by transportation by streams and concentration in depressions on the surface."

According to Williams and Parks (1923:14-15) some evidence displayed in the open cuts and tunnels at the Ironcrest property just west of the quadrangle boundary bear on the genesis of the limonite ores.

> "The face of ore shown in the openings ranges from 4 to 18½ feet and will probably average 10 feet. The ore is soft, yellow to brown in color, with irregular bands of the hard variety running through it. At the entrance to one of the tunnels, and in some of the more westerly of the series of open cuts, the bedrock on which the ore rests is a sticky gray clay containing occasional perfectly water-rounded gravel pebbles. The pebbles are large and small, light in color, siliceous, many of them undoubtedly vesicular rhyolite. The clay contains also numerous pieces of silicified wood and masses of opalitic cellular silica which is sometimes banded as if due to the imperfect replacement of a wood structure."

Most of the bodies of limonite are overlain by a bed of white tuffaceous material (Williams and Parks, 1923:12) which in turn is covered by a flow of basalt.

The arithmetical average (dry basis) of the limonite ore from 5 deposits in or just west of the quadrangle is given (U.S. Bur. of Mines War Minerals Report 186, 1944:12) below:

Iron	48.6 %
Sulphur	0.046
Phosphorus	0.73
Manganese	0.58
Silica	5.33
Alumina	4.26
Ignition loss . .	12.45

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*Hotz, op. cit.

The limonite ores were formed during a quiet period between the extrusions of the basalt whereas the ferruginous bauxite, or laterite, was formed later on top of the basalt series as indicated in the accompanying sketch. The thickness of the basalt between these two horizons is known only at the Oregon Charcoal Iron Company and Colport Development Company deposit. Hotz* reports that approximately 75 feet of weathered basalt was encountered in one drill hole between a 4-foot bed of shot ore (ferruginous bauxite) and the limonite horizon. He believes that three flows make up this thickness.

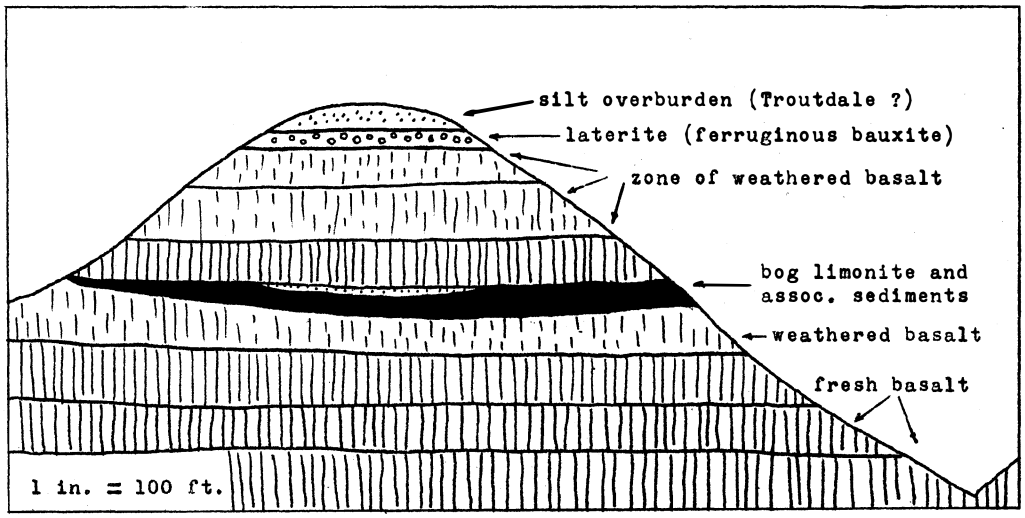

Fig. 7 - Idealized cross-section through Columbia River basalt showing relationship of laterite to limonite.

The ferruginous bauxite deposits at the top of the basaltic section were formed by a long period of laterization which resulted in an extensive cover of laterite on the Miocene basalt terrane. These deposits are more fully discussed by Libbey, Lowry, and Mason (1945). The location of ferruginous bauxite deposits is indicated on the geologic map (in pocket). Although much of the original blanket of laterite has been removed by erosion, the upper part of the lateritic profile is known to consist of nearly 10 feet or more of reddish-brown oölitic or pisolitic ferruginous bauxite with a silica content of about 7 percent. This is underlain by either a nodular or earthy ferruginous bauxite which usually contains a lower iron content. The thickness of this lower horizon is not definitely known but at one locality the silica content of the altered basalt about 5 feet below the contact with the pisolitic horizon is about 15 percent, and it is thought that this material grades downward into less altered basalt. The hard pisolitic ferruginous bauxite in an abandoned railroad cut about half a mile southeast of Yankton is apparently conformably overlain by a soft, light-brown bauxitic clay containing gibbsite, quartz, apatite, muscovite, zircon, tourmaline, as well as other mineral grains. Although the origin of the bauxitic clay is not certainly known, Libbey, Lowry, and Mason (1945)

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*Hotz, op. cit., figure 2.

believe it was formed from a transported silt during the same period of weathering as the underlying ferruginous bauxite. They state that the arithmetical average of the ferruginous bauxite channel-sampled in Columbia County, most of which occurs in the St. Helens quadrangle, is 38.63 percent alumina, 20.70 percent iron, 5.83 percent titania, and 9.36 percent silica.

The laterization took place before the deposition of silty sediments (younger than the bauxitic clay) which disconformably overlie the basalt and ferruginous bauxite. These sediments are tentatively assigned to the upper part of the Troutdale formation of Pliocene age. The relationship of the laterite to the coarser and older phases of the Troutdale is not shown in the St. Helens quadrangle. However, farther east on the Rooster Rock road near Crown Point, ferruginous bauxite, derived from the underlying Columbia River basalt by weathering, is overlain unconformably by tuffaceous Troutdale sandstones and gravels. There a slight angular discordance as well as an erosional break between the Columbia River basalt and Troutdale formation is indicated. As pointed out by Libbey, Lowry, and Mason (1945), the laterization probably took place while the Columbia River basalt terrane was low-lying and before the basalts were folded, because the rate of formation of laterite had to exceed the rate of its removal by erosion, and because the attitude of the laterite apparently conforms to that of the basalts. The presence of Troutdale sands and gravels at sea level on the Washington side of the quadrangle also points to the deposition of these sands and gravels after the laterite had been formed, as the known ferruginous bauxite deposits in this vicinity do not occur much below 300 feet.

The ferruginous bauxite deposits are fairly accurate indicators of the regional structure of the Columbia River basalt as indicated by Libbey, Lowry, and Mason (1945). Williams and Parks (1923) state that the structure of the limonite deposits near Scappoose closely conforms to that of the enclosing basalts and that the Oregon Charcoal Iron Company and Colport Development Company deposit about 2 miles northwest of Scappoose, dips about 3° to the northeast.

Reliable dips in the Columbia River basalt are difficult to obtain because there are few good exposures and because the dips are low, in most places only a few degrees. In the southwest corner of the quadrangle the basaltic surface has in places an altitude greater than 2000 feet whereas near St. Helens the basalt is at sea level. As the basalts poured out over a surface with a moderate relief of about 500 or 600 feet and, as their maximum thickness is about 700 feet, their present topographic distribution is the result of folding with some adjustment due to faulting. Libbey, Lowry, and Mason (1945) suggest that the basalts in the southwest part of the quadrangle appear to form the southwest limb of a southeast-plunging syncline whose axis runs through Yankton and parallels or coincides with Milton Creek. This structure appears to be fairly well established and is shown by structural section B-B' on the accompanying map (in pocket). Faulting of the Columbia River basalt is known to have occurred in several places; however, the extent of faulting is difficult to determine from available exposures. Some faults are suggested in structural section B-B' but no attempt was made to show the location or direction of faults on the geologic map. The southwest side of the probable fault along North Scappoose Creek appears to have moved down in relation to the northeast side. However, the northeast side of another probable fault (not mapped) which appears to trend northwesterly through the road intersection three-fourths of a mile south of Yankton moved down in relation to the southwest side. Hotz* noted that normal faults of small displacement cut the limonite in some exposures.

The Columbia River basalt terrane is characterized by a youthful topography. Many of the divides are quite broad and relatively undissected, and some still retain a partial cover of laterite developed on the original basaltic surface. Also indicative of a youthful stage are the steep gradients of some of the streams which drain areas made up of Columbia River basalt.

The Columbia River basalt in the St. Helens quadrangle is similar petrographically to that found elsewhere in Oregon. It rests unconformably upon strata ranging in age from upper Eocene (Cowlitz) to upper Oligocene or lower Miocene. Weaver (1937:171) states that lavas on the Washington side of the Columbia River contain interbeds of marine sandstone with fossils of the Astoria formation and thus the lavas and intercalated sediments, east, northeast, and southeast of Pittsburg may be regarded as of middle Miocene age. The basalt in the St. Helens quadrangle is a continuation of the Columbia River basalt in the Portland area mapped by Treasher (1942b) where it is overlain disconformably and probably slightly unconformably by the Troutdale formation of Pliocene age.

Troutdale formation

The name Troutdale was introduced by Hodge (1933) for gravels and sands deposited by the ancestral Columbia River which are well displayed near Troutdale, Oregon. The formation was considered by Hodge to be probably of Pleistocene age but later study of the Troutdale flora by Chaney (1944) indicates that it is lower Pliocene. Troutdale sediments can be traced from a locality near Camas, Washington, across the Columbia River from Troutdale, northwesterly into the St. Helens quadrangle.

As much as 600 feet of relatively unconsolidated conglomerate, sandstone, and silt which is tentatively assigned to the upper part of the Troutdale, cover certain parts of the St. Helens quadrangle. One area is north of Woodland, Washington, where it is exposed by recent excavations along U.S. Highway 99. Another patch lies southwest of St. Helens, and a third forms a discontinuous circular belt extending from Deer Island through Shiloh Basin to the Columbia River and then southward to Deer Island. The Troutdale formation is much more widespread than indicated by the mapped area as the mapping of the silty upper phase which covers much of the Columbia River basalt terrane, especially areas underlain by laterite, was not practical everywhere.

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*Hotz, op. cit.

The section of the Troutdale formation exposed in the high cliffs along U.S. Highway 99 north of Woodland, Washington, is represented in the idealized cross-section below, fig. 8. It contains an interbed of massive volcanic breccia about 125 feet thick. The sediments exposed below the breccia are poorly indurated and consist of more than 25 feet of medium-grained sandstone with some gravel and a leaf-bearing sandy shale. They unconformably overlie basalts of the Goble volcanic series.

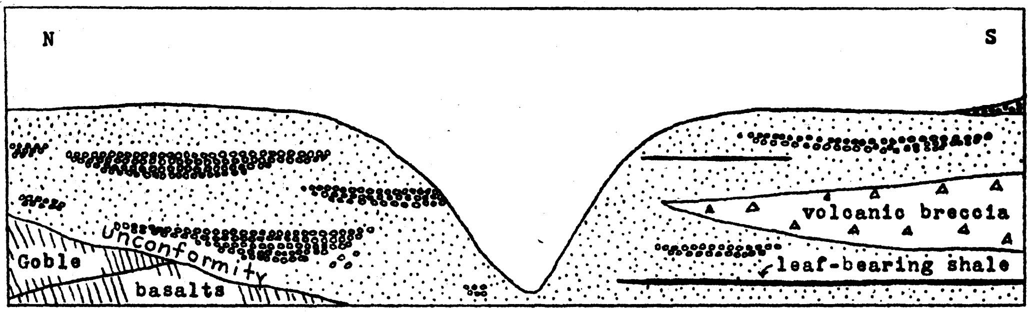

Fig. 8 - Idealized cross-section of the Troutdale formation north of Woodland, Washington, showing interbed of volcanic breccia and unconformable relationship with basalts of the Goble volcanic series.

The beds above the volcanic breccia are similar to those below it; they consist of light-colored medium-grained sand together with beds of intraformational conglomerate and at least one bed of light-colored tuff. Part of the sand is characterized by cross-bedding; local unconformities and cut-and-fill structures are common throughout the section. A steep reverse fault cuts the Troutdale sediments in one of the roadcuts a short distance south of the Goble basalts.

The sandy part of the Woodland section consists of subangular mineral grains and rock fragments with quartz, feldspar, and mica as important constituents. The gravel is made up largely of well-rounded pebbles of basalt and other eruptive rocks but quartzite pebbles characteristic of the type Troutdale are fairly common. The sand and conglomerate extend upward to an elevation greater than 500 feet where the truncated spurs level off, rising gradually away from the river. More than 20 feet of badly weathered conglomerate is exposed in a slide at the break-in-slope just below the top of one of the truncated spurs. The conglomerate here consists mainly of decomposed, well-rounded basaltic pebbles and cobbles in a tuffaceous matrix. Some unweathered quartzite pebbles are present and they are also scattered over the surface up to an elevation of 750 feet. These are presumably residual from the weathering of the Troutdale.

Although the Troutdale formation on the Washington side is composed mainly of conglomerate and sand, on the Oregon side the conglomeratic phase is overlain by a widespread massive silt with associated random pebbles and cobbles. The silt is tentatively considered to be an upper silty phase of the Troutdale formation as there is at present insufficient evidence to justify a distinction.

About 25 feet of somewhat indurated conglomerate is exposed along the Canaan Road one mile west of Deer Island, fig. 4, opposite p. 4. It is composed of well-rounded pebbles and cobbles in a yellowish sandy matrix. As in the Woodland section, basalt and other lava pebbles predominate but many quartzite and a few granitic pebbles are also present. Many of the basalt pebbles are badly weathered and some are completely decomposed; even the granitic pebbles show weathering. The quartzite pebbles are unaffected but some have partial coatings of secondary iron oxide. The conglomerate gives way upward to a massive brown silt which contains random quartzite and basalt pebbles. The basaltic pebbles in the silt are as badly decomposed as those in the underlying conglomerate. Microscopic examination of the silt shows a variety of angular mineral grains ranging in maximum dimension from less than 0.05 mm to more than 0.15 mm. Minerals present include muscovite, biotite, microcline, plagioclase, quartz, augite, hornblende, magnetite, tourmaline, garnet, apatite, and tremolite as well as some other mineral particles. Two genera of diatoms and several sponge spicules were noted. The presence of pebbles, diatoms, and sponge spicules in the silt indicates its waterlaid origin. The silt extends upward to the top of the hill to the west along Canaan Road where it presumably is more than 100 feet thick. Similar massive mottled light-brown silt is exposed in other cuts farther west along Canaan Road to a point a little beyond the Canaan School.

Another section of the Troutdale formation, made up of micaceous sandstone and silty sediments together with two gravelly layers, is exposed in the stream gully less than a quarter of a mile due west of the Canaan School. The gravel includes well-rounded pebbles of quartzite and decomposed basalt. The sediments grade upward into the silt exposed in the roadcut above the gully. Wells as deep as 60 feet on top of the ridge back of the Canaan School were bottomed in silt which contained plant remains and logs. Thus the total thickness of the Troutdale formation near the Canaan School is at least 100 feet.

A section of the Troutdale formation similar to that west of Deer Island is exposed north of Tide Creek in the hill slope along the road to Shiloh Basin, about half a mile west of its junction with the Columbia River Highway. There the conglomerate is slightly weathered near the contact with the overlying massive clayey silt. Microscopic examination of the massive silt shows it to be similar to that west of Deer Island and at other localities.

Similar silt occurs on the Washington side in a roadcut near the northern boundary of the quadrangle at an elevation of about 650 feet. Elsewhere on the Washington side, within the quadrangle, the silt phase is largely missing, probably because of erosion.

A few random, well-rounded quartzite pebbles are scattered in fields underlain by the silt phase. These pebbles have been found in place embedded in silt or fine silty sand in roadcuts and abandoned railroad cuts. Along a branch of the Nicolai Road near the northern boundary of the quadrangle and 1½ miles west of the Columbia River in the SW¼ sec. 14, T. 6 N., R. 2 W., numerous well-rounded quartzite pebbles are scattered through an unconsolidated silty sandstone. Such lack of sorting is not easily explained and the pebbles, which range in size from 1 to 6 inches, are too common to be readily explained by rafting. No glacial striae were noted. The quartzite pebbles scattered over the surface at an elevation of at least 800 feet about $1\frac{1}{2}$ miles northwest of the Shiloh School in sec. 19, T. 6 N., R. 2 W., are believed to be residual from the Troutdale. One rounded and somewhat weathered granitic pebble 6 inches in diameter was found about $1\frac{1}{2}$ miles due north of the above school at an elevation of approximately 700 feet, too high for it to be assigned to the granitic erratics, most of which are unrounded, relatively fresh, and located at elevations below 400 feet. Hotz* noted the presence of quartzite and basalt pebbles at an elevation of about 800 feet near the Spitzenberg ferruginous bauxite deposit. Rounded pebbles have also been found on the Washington side on some of the spurs at elevations above 400 feet.

The topography of the Deer Island-Canaan School area, which is quite characteristic of the Troutdale terrane, is rather flat and rolling with a typical "shot" soil. The "shots" are small concretions made up of silt particles cemented by iron oxide.

Evidence of the probable deformation of the Troutdale formation rests upon a regional perspective, for dips, if present, are either local in significance or too low to determine accurately. The base of the Troutdale formation ranges from 200 to 300 feet above sea level in the Shiloh Basin to sea level near Woodland, and a well log indicates that in the Portland area the base is 1000 feet below sea level. The greater part of this difference of elevation is probably due to gentle deformation during and since Troutdale time, but some of it may be attributed to overlap on the sides of a filling basin. Likewise, elevations of the summits of the silt indicate an eastward slope of 300 feet in 3 miles through Shiloh Basin. However, the Troutdale surface that ranges from 400 to 500 feet along the river to 800 feet in elevation on either flank may be due in part to terracing by the Columbia River during the lowering of base level. North and east of Woodland the Troutdale surfaces above 400 feet have been extensively weathered and seem to correspond to a similarly weathered surface in the vicinity of Mayger described by Treasher (1942a:15). The extensive weathering of the upper Troutdale surfaces suggests a long still-stand of the sea during which time climatic conditions were favorable for the decomposition of basaltic and other gravels. This weathering occurred after the laterization of the Miocene basalts, as Troutdale sandstone farther east rests unconformably upon the laterite.

Troutdale sediments in the St. Helens quadrangle were evidently deposited by the Columbia River in a broad, in part structural, valley between the Clatskanie divide on the west and the highland of Goble volcanic rocks on the east. The sediments may have been deposited over a considerable length of time, particularly if the silt phase tentatively assigned to the upper part of the Troutdale formation should prove to be a younger and distinct unit. The coarse sediments of the lower part of the basin may have been deposited as warping of the Columbia River basalt series began, whereas the upper part of the Troutdale may have been deposited after most of the folding had been accomplished.

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*Hotz, op. cit.

The age of the Troutdale formation has been determined as lower Pliocene by Chaney (1944) on the basis of his study of floras collected on Buck Creek and near Camp Collins, both within the Sandy River drainage. As no marine phase or equivalent of the Troutdale formation is known, it is difficult to determine its relation to known marine formations.

Fossil leaves occur in a gray sandy shale in the lower part of the Troutdale section exposed by recent excavations along the east side of U. S. Highway 99 north of Woodland, Washington. The locality is a little more than 2 miles north of the town and 2 miles north of the junction of U.S. 99 and State Highway 1S. The fossil horizon is 10 to 15 feet above road level and is stratigraphically below the massive interbed of volcanic breccia. The fossils are restricted to a zone 2 or 3 feet thick. Dr. Ethel I. Sanborn of Oregon State College, who studied the leaves, reports*:

> "The most abundant leaves in the collection are two species of Quercus - Q. pseudo-lyrata Lesquereux and Q. winstanleyi Chaney. Other leaves are Platanus paucidentata Dorf, Persea coalingensis (Dorf) Axelrod, and Ulmus californica Lesquereux. There is a very good specimen of a Juglans which resembles J. orientalis MacGinitie and may be this species. Other specimens suggest species of Carya, Carpinus, Fraxinus, and Salix."

The accompanying chart prepared by Dr. Sanborn lists the occurrences of these species and genera in other floras as noted by Chaney (1944: table 33).

Table 2.

Species collected north of Woodland, Washington	Miocene							Transitional				Pliocene					
	Lower		M.	Upper				Mio-Pliocene				Lower				M.	Upper
	Eagle Creek, Oreg.	Molalla, Oreg.	Tehachapi	Mascall, Oreg.	Blue Mts., Oreg.	Trout Cr., Oreg.	Payette, Oreg.-Ida.	Lower Idaho	Remington Hill	Table Mt.	Upper Puente	Ellensburg, Wash.	Dalles, Oreg.	Alvord Cr., Oreg.	Troutdale, Oreg.	Mt. Eden	Sonoma
Quercus winstanleyi Chaney..........	...	...	...	...	...	...	...	...	x	...	...	x	x	...	x	...	...
Q. pseudo-lyrata Lesquereux.........	x	x	...	x	x	...	...	...	x	...	...	x	...	...	...	...	...
Platanus paucidentata Dorf..........	...	...	x	...	...	...	...	...	x	...	x	...	...	...	...	x	x
Persea coalingensis (Dorf) Axelrod..	...	...	x	...	...	...	...	...	...	x	x	...	...	...	...	x	x
Ulmus californica Lesquereux........	...	...	...	...	...	...	x	x	x	x	...	x	x	...	x	...	...
Juglans sp.+	...	...	...	...	...	...	...	...	o	...	o	...	...	...	...	o	...
Carya sp.	...	...	...	o	...	...	o	o	...	o	...	o	...	...	...	...	...
Carpinus sp.	...	...	...	...	...	o	...	...	...	...	...	...	...	o	...	...	...
Fraxinus sp.	...	...	...	...	...	...	...	o	...	...	...	...	...	o	...	o	o
Salix sp.	o	...	...	o	...	...	o	o	o	o	...	o	o	o	•	o	o

+Genera in Woodland flora which could not be identified specifically are represented in the floras where the circles (o) appear.

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*Personal communication.

Pliocene volcanic breccia

As previously noted, a massive indurated volcanic breccia 100 to 125 feet thick is interbedded with the Troutdale sands and gravels in the new highway cuts north of Woodland, Washington, as indicated on the geologic map (in pocket). It consists of angular fragments of dark gray basalt in a tuffaceous matrix. The fragments range in size from a fraction of an inch to about a foot with most of them 6 inches or less in diameter. They do not show any appreciable effects of rounding due to water transportation, and the absence of non-volcanic material also indicates lack of reworking. Source and method of implacement of the breccia are not known. However, similar massive breccias, some of which have been referred to as mud flow breccias, occur interbedded with the Troutdale formation near Estacada and in the Molalla formation* and Fern Ridge tuffs farther south. As these breccias are associated with fluviatile deposits, it is thought that they represent much of the load carried by the streams at a time when a great amount of pyroclastic material was being erupted farther east in the Cascades. Some contain pieces of wood and rounded pebbles and cobbles, but others contain little or none and are strikingly similar to that in the St. Helens quadrangle. Possibly the volcanic breccia interbedded with the Troutdale formation in the St. Helens quadrangle was brought down the Lewis River from the vicinity of Mt. St. Helens. As many of the fragments in the breccia can be broken away from the matrix with the fingers, the induration of the mass is probably due largely to compaction and cementation, not to welding. The glassy portion of the tuffaceous matrix of the volcanic breccia has been altered to clay.

Examination of a thin section of one of the larger fragments shows that it is porphyritic basalt with a groundmass characterized by an intersertal texture. The phenocrysts are plagioclase, hypersthene, augite, magnetite, and altered olivine which together constitute about 35 percent of the rock. The plagioclase phenocrysts, which make up 25 to 30 percent of the section, are basic labradorite, Ab_3An_7, and show both albite and combined Carlsbad-albite twinning. Some of the larger, better formed crystals show rather well-defined zoning and are as much as 3 mm long. They have corroded subhedral to euhedral outlines. The augite and hypersthene phenocrysts each constitute less than 5 percent of the rock and most of the grains are less than 1 mm in length. The outlines of the grains of both minerals are somewhat corroded, with the hypersthene tending to be euhedral and augite subhedral. The hypersthene is slightly pleochroic and may be near enstatite in composition. Magnetite and apatite (?) occur as inclusions in part of the hypersthene. A number of the augite grains show twinning. All three of the above phenocrysts may be grouped either together or separately into clusters so that the texture is both glomeroporphyritic and cumulophyric. The olivine phenocrysts constitute about 2 percent of the section and they are as much as 0.25 mm long. The olivine has been altered to magnetite and serpentine, both antigorite and chrysotile, and the grains have corroded euhedral to anhedral outlines. Although magnetite occurs in the first generation of minerals only as inclusions in some of the phenocrysts, it makes up about 5 percent or even more of the groundmass. The grains are about $0.025\pm$ mm in size and have euhedral to anhedral outlines. The plagioclase in the groundmass is labradorite, Ab_4An_6, in the form of laths about 0.2 mm long. They constitute about 15 percent of the

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*Harper, H.E., Preliminary report on the geology of the Molalla quadrangle, Oregon, Master's thesis, Oregon State College, August 1946.

rock. Subhedral grains of augite about 0.05 mm in size constitute a somewhat smaller percentage which together with the brown and clear glass of the matrix makes up the remaining 45 percent.

The basaltic fragment sectioned is very similar petrographically to a similarly shaped but lighter gray basaltic fragment collected from the Boring agglomerate (Treasher, 1942) on the north side of the Clackamas River about half a mile east of Estacada in sec. 28, T. 3 S., R. 4 E. They probably are of the same age, as the Boring agglomerate is also interbedded with the Troutdale formation. Stratigraphically the volcanic breccia in the St. Helens quadrangle occupies a position analogous to the pyroclastic rocks of the Dalles and the Rhododendron formations which Hodge (1938) states are contemporaneous with part of the Troutdale formation.

As the volcanic breccia is a lenticular interbed in the Troutdale formation, it falls within the same age assignment. The breccia is underlain by at least 25 feet of sandstone which includes the leaf-bearing sandy shale previously described. These sediments may be near the base of the Troutdale section, as the Troutdale a little farther north along the highway lies directly on basalts of the Goble volcanic series.

Terraces

A series of Pleistocene terraces ranging in altitude from near sea level to nearly 250 feet are present along the Columbia River in the St. Helens quadrangle. In the low rolling hills south of St. Helens the terrace deposits are more than 2 miles wide.

The terraces are treated as a unit because they appear to represent a more or less continuous filling to an elevation of approximately 300 feet, followed by recessional stands of river level accompanying sea level changes. Lithologic similarity in color and composition and general lack of weathering and induration indicate that the material in the entire series is essentially the same age. Surficial material on the terraces was no doubt reworked during terrace cutting. At St. Helens the basalt has been beveled to form a prominent rock bench about 100 feet in elevation. The broad terrace between Columbia City and Deer Island is somewhat lower and is underlain by gravel.

Material in the higher terraces is composed predominantly of sand with some gritty lenses. The material in the lower terraces, such as that exposed in the pit at Scappoose at an elevation of about 50 feet, is gravel in a sandy matrix. The size of material in the pit ranges from sand to boulders 1½ feet in diameter but most of the material falls within the pebble-size group. The larger cobbles and boulders tend to be angular, and many of them are Boring-type lava with only slightly rounded corners. Well-rounded pebbles of quartzite, granite, and basalt are also present in the pit which is nearly 50 feet deep. As the Troutdale formation contains large quantities of quartzite pebbles, it is reasonable to believe that some of them found their way into the younger terraces.

These gravels are similar in composition and appearance to the Portland terrace gravels (Treasher, 1942) of Pleistocene age which are sometimes referred to as the Portland delta.

The Portland terrace-gravel deposits show erosional levels corresponding to those in the St. Helens quadrangle and were also formed during pauses in the downcutting by the river.

Sediments of this age are mapped along Merrill and Tide creeks, and are also believed to occur along Milton Creek near Yankton but were not differentiated in this area from beds assigned to the Troutdale.

Glacial erratics

Erratics are common on some of the spurs and flats on the Oregon side of the Columbia River at elevations between 200 and 400 feet. A few have been found below 200 feet but they may have been moved from their original place of deposition. Although rounded quartzite pebbles have been found as high as 1100 feet, only the foreign pebbles associated with the large irregularly shaped granitic erratics are considered in this discussion. It has been assumed that the well-rounded quartzite pebbles are a phase of the Troutdale formation, unless they occur in a "nest" of erratics, are angular, are larger than most of the residual Troutdale pebbles, or have glacial striae.

Nearly all of the erratics are angular or irregular in shape, poorly rounded, and more than 6 inches in diameter. Some are as much as 2½ by 3 feet in size and at least one is known to have been very much larger. They are predominantly of granitic composition, although some gneiss, quartzite, slate, and limy metasediment, as well as a piece of vein quartz with manganese (?) oxide were found. Most of the granitic boulders are a hornblendic variety, but one without hornblende was seen. Nearly all are fresh, showing little weathering.

One particularly large "nest" of erratics is located on top of the spur just west of the Oester place in sec. 26, T. 4 N., R. 2 W., at an elevation of 375 feet, about 3 miles northwest of Scappoose. Many of them are 2 to 3 feet in diameter.

Remains of a very large granitic boulder, which originally may have been 10 feet or more in diameter, occur at an elevation of 325 feet on the north end of a low hill south of Tide Creek and north of Canaan Road about 2 miles west of the town of Deer Island. The boulder had been blasted and part of it removed. Numerous other erratics in this vicinity include both glacially striated slabs of slate and quartzite pebbles. Another cluster of 20 large granitic boulders about a foot or more in diameter, and a few associated rounded quartzite cobbles and boulders were found about 1 mile northeast of the granitic boulder and 2 miles northwest of Deer Island on top of a ridge which is nearly 400 feet above sea level. All the boulders mentioned in the above three occurrences rest upon the silt phase of the Troutdale formation.

These erratics are believed to have been transported in icebergs floating down the Columbia River during the Pleistocene. An extensive study of the erratics problem has been made by Allison (1935).

Recent alluvium

East of U.S. Highway 30 an area of sloughs and swamps separating small islands borders the Columbia River. The surface is only a few feet above normal water level and is composed of silt, sand, and gravel. South of St. Helens a wide strip of this flood plain is good farm land; the same surface has also proved of agricultural value on Deer Island.

Summary of Structural Geology

A definite structural pattern is difficult to obtain from the rock exposures within the St. Helens quadrangle. The Goble volcanic series of upper Eocene age occur in the northeastern part of the quadrangle, and the youngest Oligocene or lower Miocene sediments occur mainly in the southeastern part; both are overlain by the Miocene Columbia River basalt either within or a short distance outside the quadrangle boundaries. The geographic distribution of the pre-Columbia River basalt formations suggests a rather simplified structural pattern which would indicate that they have a regional dip to the southwest, but this is not wholly borne out by the recorded strikes and dips of the strata.

The Goble volcanic flows and pyroclastics dip gently, in most places less than 12°, to the south or southwest except for a reversal along U.S. Highway 99 a short distance north of Woodland, Washington, and another along U.S. Highway 30 about 3½ miles north of the town of Deer Island. The irregular contact of the Goble series with the overlying Oligocene sediments, and the presence in places of conglomerate at or near the base of the Oligocene point to a definite erosional break. However, along Tide Creek at the fossil locality on the A. Annicker place (PF-13, fig. 6, opposite p. 15) the apparently steep contact between the sediments and underlying volcanic rocks may be the result of faulting. Because the contact between the Oligocene sediments and Goble volcanic rocks is poorly exposed and because there is no good evidence which points to an angular unconformity, the only conclusion warranted at this time is that the break is erosional.

There is little or no evidence in the St. Helens quadrangle of a significant erosional break within the series of Oligocene sediments, although Warren and Norbisrath (1946) state that the Scappoose formation seems to rest disconformably on the Pittsburg Bluff formation and is separated from it by a conglomerate of variable thickness. Conglomeratic lenses exposed in railroad cuts about 2 miles west of the Chapman School and a cut-and-fill structure exposed in the highway cut nearby point to minor breaks in deposition near the shore line.

A major unconformity occurs between the Oligocene strata and the overlying Columbia River basalt. The basalt lies on an erosional surface of moderate relief which truncates formations ranging in age from upper Eocene to uppermost Oligocene or possibly lower Miocene. Therefore a period of folding and a great amount of erosion preceded the outpouring of the Miocene basalt. Judging from the few reliable attitudes, structures within the Oligocene sediments consist of gentle folds. Only two dips are as much as 25°; all other dips are less than 17°; and most are less than 11°. Some of the steeper dips may be due to faulting. An insufficient number of reliable attitudes were obtained to indicate a definite structural pattern.

The structure of the Columbia River basalt has been interpreted from the topographic distribution of laterite on the upper surface of the basalt and in a few places from the attitudes of limonite interbeds. Although the basal surface of the basalt is not uniform, additional structural data may be obtained by plotting the elevations of the base of the basalt on a broad scale. The base of the basalt along the western edge, as shown on the accompanying geologic map, lies between 1,000 and 1,400 feet in elevation from which it slopes eastward to sea level. In the northern part of the quadrangle, northwest of the town of St. Helens, the Columbia River basalt has a southerly dip, indicating that a southeast-plunging synclinal axis runs through Yankton. The Columbia River basalt in the southwestern part of the quadrangle lies on the northeastern limb of a broad anticline whose opposite southwestern limb dips beneath the broad Tualatin Valley.

The presence of faults in the Columbia River basalt is suggested by the straightness of some streams such as North Scappoose Creek, by marked differences in the altitudes of adjacent deposits, and by differential altitudes of the base of the basalt. The last may be due largely to pre-basalt relief. The unusually steep dips in the Oligocene sandstone near the supposed North Scappoose Creek fault at Spitzenberg tend to substantiate its presence, and the alignment of Alder Creek suggests a continuation of this fault to the northwest. As conclusive evidence of faulting was not obtained, no faults are shown on the geologic map, and only a few are suggested in cross-section. Most of the evidence suggesting other faults is physiographic. Large-scale slumping of blocks along the rim of the Shiloh Basin and between Columbia City and Deer Island is indicated by the step-like character of the surface of the basalt.

Although the Troutdale formation has been regionally warped, it has not been deformed nearly as much as the Columbia River basalt. One minor reverse fault is shown in the Troutdale section north of Woodland, Washington. The Pleistocene and more recent deposits appear to be undeformed.

Geologic History

The first geologic event known to have taken place in the area of the St. Helens quadrangle was the extrusion in late Eocene (Cowlitz) time of a succession of basaltic lavas and associated pyroclastic rocks herein termed the Goble volcanic series. A short distance to the north the first eruptions gave rise to pyroclastic materials which were incorporated with Cowlitz marine sediments. Some of the earlier flows apparently poured out into the Cowlitz sea, as they are covered by sandstones similar to Cowlitz sandstones lower in the section. The eruptions are believed to have forced the Cowlitz sea back to the west. They continued, possibly into Keasey (late Eocene or early Oligocene) time, until the lavas and fragmental rocks had reached an aggregate thickness of 5000 feet or more.

A period of erosion, probably accelerated by the retreat of the upper Eocene sea, followed the Goble volcanic activity. The sediments deposited later in the Oligocene sea, which covered much of the St. Helens quadrangle area, were mainly tuffaceous sands derived in part from the erosion of the upper Eocene volcanic mass. The Oligocene sea persisted from early Oligocene (Gries Ranch (?) stage) to late Oligocene or early Miocene (Scappoose) time. However, the sea may have retreated temporarily prior to the deposition of the Scappoose sediments. The shoreline of the sea lay in or near the St. Helens area during much of the Oligocene as shown by the lithologic character and depositional structures of some of the sediments and also by the presence in places of fossil leaves and coal beds.

Accompanying or following the retreat of the Oligocene sea the Oligocene sediments and Goble volcanic rocks were folded and eroded to form eventually a low-lying area of rounded hills with rather wide intervening valleys. Some of the stream gravels being derived largely from the erosion of the Goble volcanic rocks in the northeastern part of the area were buried by the first flows of Columbia River basalt in middle Miocene time. Eruptions of these lavas continued until much or all of the Oligocene terrane and part of the Goble volcanic terrane had been buried. In places these lavas, which came up along fissures whose location is now indicated by dikes, accumulated to a thickness of 700 or more feet. However, in a few places in the St. Helens quadrangle small hills of Oligocene sediments may have stood slightly above the lava field. The eruption of these lavas was intermittent and, during at least one major interruption, iron derived from the weathering of the basalt was deposited in the form of limonite in bogs and swamps. Fine tuffaceous sediments were washed in on top of some of the limonite deposits before the lava eruptions were resumed. At least three Miocene basalt flows are believed to have been poured out over some of the limonite deposits.

Following the close of these eruptions, a long period of weathering produced a relatively uniform blanket of laterite on the Columbia River basalt lava-plain while it stood near sea level. Erosion, initiated probably by uplift accompanying gentle folding, actively dissected this blanket of laterite and the underlying rocks prior to their burial by Pliocene Troutdale sands and gravels deposited by the Columbia River. These sands and gravels were deposited in erosional and structural depressions in the St. Helens area while volcanic breccia was being erupted farther east in the Cascades. In later Pliocene time silt tentatively assigned to the upper part of the Troutdale formation was deposited over much of the St. Helens quadrangle, as well as over large adjacent areas, probably as the result of a rise in sea level.

Another period of weathering, which may have begun soon after the deposition of the Troutdale sediments, altered some of the rocks near the surface to clay. Subsequent erosion initiated by regional warping or uplift has actively dissected the rocks in the St. Helens quadrangle. However, during the Pleistocene, downcutting by the Columbia River was interrupted by a rise in sea level, probably eustatic, and sands and gravels were deposited along the Columbia River and tributaries up to an elevation of approximately 300 feet above present sea level in the St. Helens area. As the water receded several terraces were cut in the Pleistocene fill. Also during the Pleistocene ice-rafted erratics were distributed throughout the lower Columbia River and Willamette River valleys up to an elevation of about 400 feet.

Economic Geology

Ferruginous bauxite deposits occur at many places within the St. Helens quadrangle as indicated on the geologic map. Their occurrence and economics have been discussed by Libbey, Lowry, and Mason (1944, 1945) and their stratigraphic occurrence at the top of the Columbia River basalt section is reviewed on pages 22 and 23 of this bulletin. A few of these deposits in the St. Helens quadrangle have been drilled by the U.S. Bureau of Mines and a number of them by Alcoa Mining Company. The deposits drilled by the Bureau of Mines in the Yankton area, along Cater Road between Yankton and Spitzenberg, and on the ridge northeast of Alder Creek were estimated by Bell* to contain 847,000 long tons (dry basis), the greater part of which is inferred. The average composition of the ore as given by Bell is approximately 31 percent alumina (Al_2O_3), 21 percent iron (Fe), 5 percent titania (TiO_2) and 11.5 percent silica (SiO_2). Tonnage estimates of two similar ferruginous bauxite deposits in Washington County drilled by the Oregon Department of Geology and Mineral Industries (Libbey, Lowry, and Mason, 1945) exceed a total of 5 million long tons. Occurrences in Columbia County indicate that reserves are comparable to those in Washington County and are in the order of many millions of tons. An arithmetical average of channel samples taken by the Oregon Department from a few of the deposits is about 38 percent alumina, 21 percent iron, 5 percent titania, and 9 percent silica.

Alcoa reported in the press in January, 1946, that encouraging results were being obtained with the Pedersen process at a pilot plant in East St. Louis, Illinois, where tests are being conducted on ore from both Washington and Columbia counties. In February, 1946, Alcoa announced plans to ship limestone to the Portland area from Alaska. As limestone is required in the Pedersen process, presumably the company plans to use the stone in the treatment of the Oregon ore. As both alumina and pig iron are recovered in the Pedersen process these deposits may prove to be of considerable economic value as a source of both alumina and iron, and possibly titania.

Limonitic iron ores occur at several places throughout the quadrangle as indicated on the geologic map. Their geologic occurrence has been discussed in the description of the Columbia River basalt on pages 20 and 21 which include an arithmetical average analysis of the ores. Some of the limonite deposits in northwestern Oregon have been known to exist since the early 1860's. Ore was mined and pig iron produced from a deposit near Oswego, south of Portland, from 1867 to 1894. Williams and Parks (1923) discussed the occurrence of the limonite ores and their economic value as did Hodge (1938) in his studies of mineral resources of the Pacific Northwest. Utilization of this ore has been considered by Miller (1940) in his investigation of the feasibility of a steel plant in the lower Columbia River

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*Bell, G.L., Preliminary report on laterite deposits and occurrences in the Portland region, Oregon, Strategic Min. Invest., U.S. Geol. Survey, July 1945.

area. The only commercial production of iron from the limonite deposits in northwestern Oregon was that from the Oswego deposit.

These deposits have been trenched, pitted, and drilled by various groups. The U.S. Bureau of Mines drilling project in 1942 (U.S. Bur. Mines War Minerals Rept. 186, 1944) indicated that the Colport Development Co. and Oregon Charcoal Iron Co. limonite deposit contains more than 3 million long tons, and that two other deposits in the quadrangle each contain about 50,000 long tons. The relatively small proved tonnage and the high phosphorus content of the Columbia County ores have hindered their development as iron ore. The limonite has been used at times for paint pigment and, during 1945, 20 carloads of ore from the Ironcrest property, just west of the quadrangle, were shipped to California for this use.

Two deposits of coal occur in the Oligocene sediments and are shown on the geologic map. They are reported to have been mined at various times for domestic purposes. The deposit located 2 miles west of Scappoose in the N½ sec. 10, T. 3 N., R. 2 W., has been prospected by 2 tunnels, one of which follows the coal up a grade of 4° for more than 100 feet*. The coal bed, which strikes northwest and dips about 10° to the northeast, averages about 3 feet in thickness. The coal is said to be lignitic in rank.

Coal in a prospect 4 miles north of the town of St. Helens in sec. 18, T. 5 N., R. 1 W., has been exposed by a drift. The coal is reported (Yancey and Geer, 1940:17) to strike north and to dip as much as 5° to the west. Total thickness of the bed is undetermined but 6 feet was exposed where sampled at a point 50 feet west of the portal. Analysis of the coal as given by Yancey and Geer is:

	As received	Moisture free	Moisture and ash free
Ash	16.0 %	22.7 %	
B.t.u.	6690	9470	12259
Moisture	29.4		

Both the Goble and Columbia River basalts of this area, where unaltered, make satisfactory road metal and some of the quarries are indicated on the geologic map. These rocks are rather flinty and brittle owing to the high percentage of glass. River gravel from the broad terrace in the vicinity of Scappoose is being utilized for construction purposes. There is an abundant supply of this relatively unweathered material.

Deep weathering has produced some clay from the Columbia River basalt and Troutdale gravels. The thick deposits of silt tentatively assigned to the upper part of the Troutdale formation have also been weathered, and are similar to those utilized for making brick and tile in the Portland area.

Very fine, somewhat stratified white volcanic ash, which may prove to be of some economic value as a fine abrasive or filler, occurs on the Gus Nelson place on the north side of the

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*Allen, J. E., Scappoose Creek coal prospect, Oregon Dept. Geology and Min. Ind. unpublished report, March 1940.

Dark Creek road in the SW$\frac{1}{4}$ sec. 19, T. 5 N., R. 1 W., 2$\frac{1}{2}$ miles west of Columbia City. Petrographic examination shows that it is a silicic ash with a minor amount of mica. About three-fourths of the ash is minus 200-mesh. The deposit has been prospected by an open cut which exposes as much as 17 feet of uniformly white ash; at the top of the deposit the ash is stained a buff color. Areal extent of the deposit is not known but similar ash was encountered in a well at the Talbot place, less than half a mile to the north. The stratigraphic position of this deposit has not been definitely determined. It occurs beneath Columbia River basalt and stratigraphically above the Oligocene sediments. There may be some basalt beneath the ash horizon at this locality, and possibly this ash may be of the same age as that reported to be associated with the limonite deposits (Williams and Parks, 1923).

During 1944 and 1945 geologists of several major oil companies studied oil and gas possibilities of the area. In 1945 a dry test was drilled to a depth of 5660 feet at a location southeast of Clatskanie just northwest of the quadrangle. Another dry test, located south of the quadrangle in sec. 23, T. 1 N., R. 1 W., Multnomah County, was abandoned June 7, 1946, after reaching a depth of 7885 feet. A third dry test on Cooper Mountain, about 20 miles south of the quadrangle, reached a depth of 9263 feet.

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Oregon mineral localities map (22 X 34 inches) 1946	0.10
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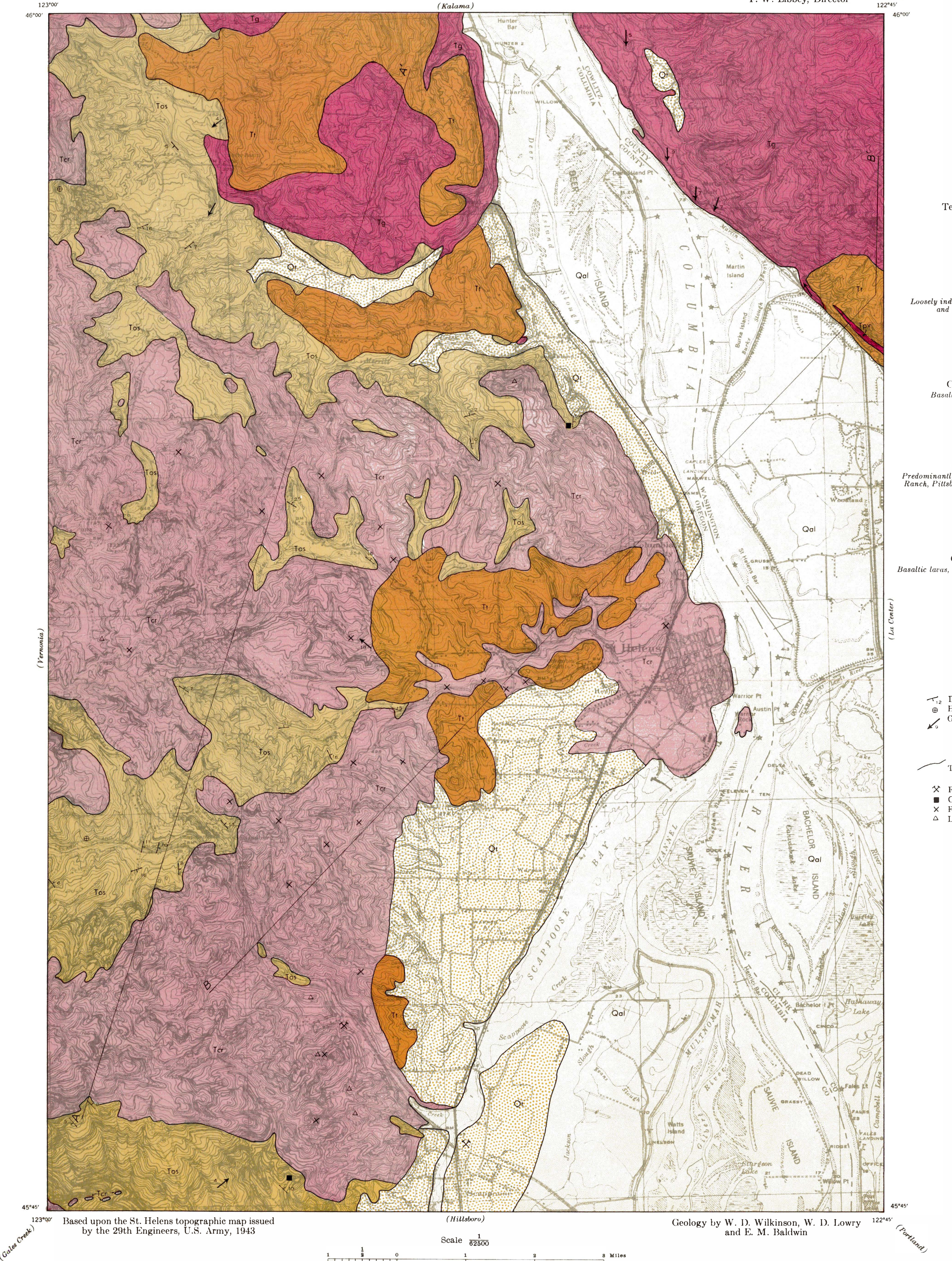
Geologic Map of the ST. HELENS QUADRANGLE Oregon-Washington

Issued by
State of Oregon
Department of Geology and Mineral Industries
Portland, Oregon
F. W. Libbey, Director



EXPLANATION

Qal — Alluvium — RECENT

UNCONFORMITY

Qt — Terrace sands and gravels (*Portland delta stage*) — PLEISTOCENE

UNCONFORMITY

Tt, Tpv — Troutdale formation — *Loosely indurated sandstone, conglomerate, silt and interbedded volcanic breccia.* — PLIOCENE

UNCONFORMITY

Tcr — Columbia River basalt — *Basaltic lavas and associated dikes.* — MIOCENE

UNCONFORMITY

Tos — Oligocene sediments — *Predominantly marine tuffaceous sandstone of Gries Ranch, Pittsburg Bluff, and possibly Blakeley age.* — OLIGOCENE

UNCONFORMITY

Tg — Goble volcanic series — *Basaltic lavas, pyroclastics, and associated sediments.* — UPPER (?) EOCENE

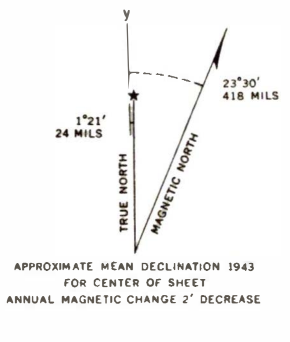
Attitude of bedded rocks

- Dip and strike
- Horizontal
- General trend of dip

Formational contacts

All contacts are approximate, especially the Troutdale contacts.

- Rock quarry
- Coal prospects
- Ferruginous bauxite deposits
- Limonite deposits



Based upon the St. Helens topographic map issued by the 29th Engineers, U.S. Army, 1943

Geology by W. D. Wilkinson, W. D. Lowry and E. M. Baldwin

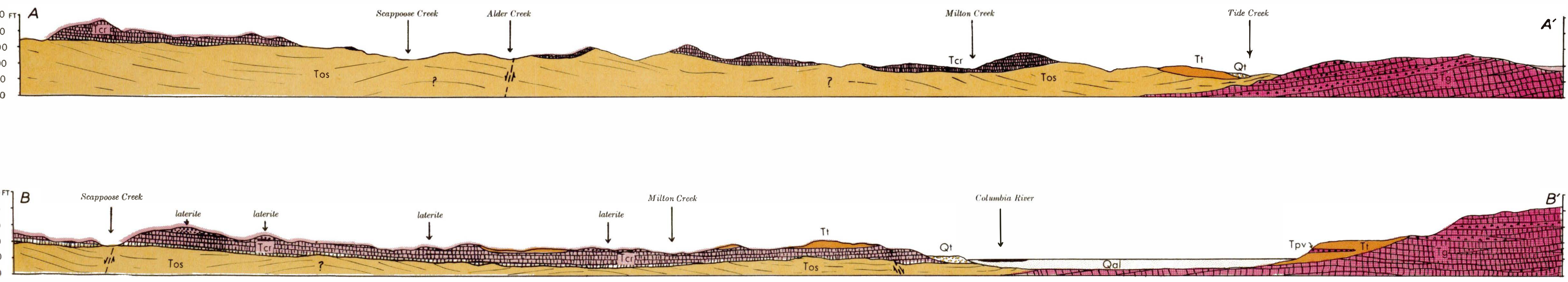
Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 Miles

Contour interval 25 feet

Datum is mean sea level (1929 Adj.)

1945



Generalized Structural Sections