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Geology of the Salem Hills and the North Santiam River Basin, Oregon

By

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ERRATA:
Page 5, 2nd paragraph, 9th line, change "see p.12" to "see p.9".
Page 32, 2nd paragraph, 2nd line, eliminate "(fig.6)".
Page 38, 4th paragraph, 8th line, change "fig.6B" to "fig.8-II".

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FOREWORD.

Owing to the nature of the Act which created it, this Department functions in Oregon as a State Geological Survey, a Bureau of Mines, and a Department of Mineral Industries, all combined. In view of this rather broad scope of activities the departmental publications are divided among several categories, including geology, mining, metallurgy, state-wide mineral inventories, industry analyses, etc.

This bulletin is confined strictly to a geologic subject and embodies an academic discussion of the structure, age relations, glaciation, physiography and general geology of the area covered - the Salem Hills and the North Santiam River Basin. Although a reasonable amount of areal geologic work has been done in the Cascade area from Eugene north to the Columbia River, the results of most of such work have not been made accessible to the public. The work done by Dr. Thayer and published herewith is an addition to the geology of this country and fits in with Eugene Callahan's Cascade work. We believe that the author, Dr. Thayer, now one of the geologists of the U. S. Geological Survey, has made a worth-while contribution to Oregon's geological literature, especially by his outlining the relations between the older "Western Cascades" and the younger "High Cascades" volcanic series. The bulletin should be of interest and value to geologists and students making investigations anywhere along the Cascade belt of the Pacific Northwest.

Earl K. Nixon
Director

Portland, Oregon,
December 1939.

INTRODUCTION

The Cascade Range in Oregon forms the central part of a range of volcanic peaks that extends from the vicinity of Lassen Peak, at the northern end of the Sierra Nevada in California, to Mt. Baker, a few miles south of the Canadian line. In Oregon the base upon which the volcanic rocks lie for the most part is concealed, but in Washington and California near the ends of the Cascade Mountains proper, the lavas lie on the eroded surfaces of much older rocks. It is reasonable to expect that exposures of the older or "basement" rocks will be found in the Oregon Cascades as geologic mapping progresses.

Major structural features such as anticlines and synclines commonly are difficult to determine in volcanic rocks, especially when heavily covered with forest litter because irregularities in individual flows may be, and often are, very great. It is not surprising, therefore, in the heavily timbered Cascade Range that the pioneer geologists believed the Range was a simple pile of lavas, on which the volcanoes like Mt. Jefferson were built. I. C. Russell, in 1897 1/, appears to have been the first to suspect that the Cascades were formed of two or more series of volcanic rocks, some of which were folded, and some of which were not folded. The accuracy of Russell's observations has been fully borne out by later geologists 2/, and in 1933 Callaghan 3/ suggested the terms Western Cascade and High Cascade for the older and younger volcanic series, respectively. These names have been accepted for the Oregon Cascades to differentiate the folded Miocene and older Tertiary volcanic rocks from the unfolded younger (Pliocene to Recent?) volcanic rocks, and will be used in this sense in this paper. The terms originate in the fact that in Oregon between the North Santiam River west of Mt. Jefferson and the Rogue River southwest of Crater Lake, the Cascade Range is made up of two distinct north-south ranges. In general, the Western Cascade Range is characterized by mature topography, with narrow valleys and sharp ridges which bear little obvious relation to bedrock structures. In the High Cascade Range the topography is controlled almost everywhere by the structure of the lavas.

The Western Cascade Range is about 50 miles wide east of Salem; if the Salem Hills which are structurally part of the range be included, the width is 65 miles. The average elevation of the Range is between 4500 and 5000 feet, and the relief between 3000 and 4000 feet. The Salem Hills and the foothill slopes west of Stayton are nearly all under 1000 feet in elevation.

The structure of the Western Cascade Range is relatively simple. The Oligocene-Miocene volcanics are mainly andesitic flows and tuffs which have been folded

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1/ Russell, I. C., Volcanoes of North America: p.233-239, 1897, MacMillan Company, N. Y.

2/ For complete bibliography see: Treasher, R. C., and Hodge, E. T., Bibliography of the geology and mineral resources of Oregon: Oregon State Planning Board, Portland, 1936.

3/ Callaghan, Eugene, Some features of the volcanic sequence in the Cascade Range in Oregon: Am. Geophysical Union, Tr., p.243, 1933.

into gentle synclines and anticlines trending northeastward. These folds, in order from west to east are: the Willamette syncline, the Mehama anticline, the Sardine syncline and the Breitenbush anticline. (fig.2). Dips in the lavas average 3 to 5 degrees, except in the Breitenbush anticline, in which the western limb dips 50 degrees, and the eastern limb 12 degrees. The western border of the range is marked by dip slopes of 2 to 3 degrees extending nearly down to the floor of the Willamette valley. The eastern border of the Western Cascade Range is buried under High Cascade lavas.

In the latitude of Mt. Jefferson the High Cascade Range is about 25 miles wide, and the crest line is about 10 miles east of the western base. This post-Miocene range is built largely of basaltic and andesitic lavas 4/ that seemingly are unfolded. Most of the lavas dip away from plugs that are exposed near the crest of the range. Glaciated dip slopes, deeply trenched by glaciated valleys, characterize the High Cascade Range for several miles south of Mt. Jefferson, whereas north of that peak the Range widens and assumes the aspect of a glaciated plateau. South of the bend in the North Santiam river, northeast of Mt. Bruno, hereafter referred to as the Elbow, the western limit of the High Cascade Range proper is the valley of the North Santiam River; north of the Santiam Elbow no sharp physiographic or topographic boundary is evident.

4/ For detailed petrographic discussion of the Western Cascade rocks see: Callaghan, op. cit., and Buddington, A. F., and Callaghan, Eugene, Dioritic intrusive rocks and contact metamorphism in the Cascade Range in Oregon: Am. Jour. Science, 5th ser., vol. 31, p.421-429, 1936; and Metalliferous mineral deposits of the Cascade Range in Oregon, U. S. Geol. Survey, Bull. 893 (1938).
For descriptions of High Cascade rocks see: Thayer, T. P., Petrology of later Tertiary and Quaternary rocks of the north-central Cascade Mountains in Oregon, with notes on similar rocks in western Nevada: Geol. Soc. America, Bull., vol. 48, p. 1611-1652, 1937; and Williams, Howel, Mt. Thielsen, a dissected Cascade volcano: Univ. Cal., Pub. Dept. Geol. Sciences, vol. 23, p. 195-214, 1933.

Table 1. Comparison of Western Cascade and High Cascade Ranges in the North Santiam River region.

Western Cascade Range	High Cascade Range
Form	
Width 50 miles; if Salem Hills included, 65 miles. Average elevation 4,500 to 5,000 ft., except in western part which slopes toward Willamette Valley; average maximum relief 3,500 to 4,000 ft. Maturely eroded, with narrow ridges and valleys which show little relation to structure, although in western part dip slopes predominate. Small glacial cirques above 3,500 feet elevation.	Width about 25 miles. Maximum average elevation 5,000 to 7,000 ft., with isolated higher peaks. Average relief 2,500 - 3,500 ft., maximum 8,000 ft. Crestline forms divide of Cascade Range as a whole. Triangular in cross-section south of Mt. Jefferson, with crest about 10 miles from western base; north of Mt. Jefferson is northward-sloping plateau surmounted by volcanic cones. Glaciated dip slopes, "U" valleys, and eroded volcanoes dominate topography.
Formations	
Eastern part: Eocene? rhyolites under Oligocene-Miocene Breitenbush tuffs grade up into Miocene Sardine lava series: Mainly andesitic to rhyolitic tuffs and lavas. Western part: Oligocene marine Illahe formation equivalent to continental Mehama volcanics. Miocene Stayton lavas unconformable on Oligocene beds, and conformable under Fern Ridge tuffs. Sardine lavas intruded by Upper Miocene? diorite porphyry. Pleistocene glacio-fluviatile deposits in main valleys.	Pliocene-Pleistocene volcanics, divisible into 3 probable age groups by erosional unconformities: Outerson volcanics (oldest); Minto and Battle Ax lavas; Olallie lavas and Santiam basalts. Lavas very fresh, range from olivine basalts to dacites; olivine-bearing andesitic basalts dominant. Glacial and glacio-fluviatile deposits widespread.
Structure	
Rocks folded in open anticlines and synclines trending east of north. In order from west to east: Willamette syncline, Mehama anticline, Sardine syncline, and Breitenbush anticline. Dips in Miocene rocks average 3° to 5°, range up to 50°; dips in older beds average 10° to 15°, in places beds are vertical. Faulting in region east of Detroit. Diorite intruded into Sardine syncline.	Volcanics not visibly deformed; initial dips from 1° to 28°. Outerson volcanics mostly dip eastward. South of Mt. Jefferson Minto lavas dip east and west from crestline; north of Mt. Jefferson vents scattered and structure more obscure. Dips in Olallie lavas steeper than in Minto, and cones much smaller. Santiam basalts form valley flows. Battle Ax volcano built up on Western Cascade Range north of Detroit.

Western Cascade Range	High Cascade Range
Underlying Formations	
Not exposed in North Santiam River region. Elsewhere the Western Cascade volcanics rest on Eucene or pre-Tertiary marine formations, or on old crystalline rocks.	High Cascade lavas rest on the Western Cascade volcanics with large angular and erosional unconformity.
Age	
Rocks folded, intruded by diorite, and uplifted, probably near end of Miocene epoch. Attained essentially present elevation in Middle Pliocene (?) time.	Chain of volcanoes built up during later Pliocene and Pleistocene time. Youngest lava flows post-glacial, and probably only a few hundred years old.

The field work for this report was done mainly during the summers of 1932 and 1933. In that part of the area west of Mehama the formation contacts were traced in detail. In the area east of Detroit, except in the places which appeared to be critical, tracing of the contacts by walking along them was impossible because of limited time and the nature of the terrain. In the middle portion between Mill City and Detroit, except for mapping of the diorite porphyry, only sufficient field work was done to yield data on the structure and physiography. The background of regional geology was gained largely during the summer of 1931 when the author assisted Dr. Eugene Callaghan of the United States Geological Survey in a reconnaissance of the Oregon Cascades as a whole, with emphasis on the mining districts of the Western Cascades. The writer began his field work in the Oregon Cascades in the summer of 1928 with Dr. E. T. Hodge in the Mt. Hood region, and since then has made many short trips into the northern portion of the range.

The author wishes to express his appreciation to Dr. Ian Campbell and Dr. J. P. Buwalda of the California Institute of Technology for their criticisms and suggestions, and to Dr. Eugene Callaghan of the United States Geological Survey for his many helpful discussions and critical reading of the manuscript. Mr. Ray C. Treasher and Mr. S. G. Lasky of the Geological Survey suggested many improvements in the manuscript, and their contributions are acknowledged with pleasure.

FORMATIONS

The bedrock formations of the Western Cascades probably range in age from Upper or Middle Miocene to Middle or Lower Oligocene, and possibly to Eocene. The surficial Quaternary glacial and river deposits are important only in interpreting the later history of the Range. Detailed stratigraphic work is handicapped by the uniformity of the several formations, by local structures in the volcanic rocks, and by the scarcity of fossil remains. Marine fossils are apparently limited to the Oligocene beds along the western margin of the Range, although a 6-inch waterworn sandstone boulder containing (Oligocene?) marine fossils is reported to have been found in low river terrace gravels along the North Santiam River about 6 miles east of Detroit. Fragmentary leaf imprints and petrified wood have been found in place east of Stayton.

EOCENE ROCKS.

Rhyolites, probable of Clarno age, are exposed in the axis of the Breitenbush anticline. They crop out along the North Santiam River for a distance of about 5½ miles west of the Elbow, and similar flows are exposed near Fox Creek in the Breitenbush River. The rhyolites are massive, and are interbedded with green pumiceous tuffs. In both localities the rocks are cut by numerous faults. Since these rhyolites underlie approximately 7500 feet of andesitic tuffs of the Oligocene-Miocene Breitenbush formation, it seems reasonable to correlate them tentatively with the Clarno formation. The evidence against similar correlation of the rhyolites in Minto Mountain and Sentinel Hills is discussed below. (See p.12).

OLIGOCENE AND MIOCENE ROCKS.

The differentiation of Oligocene and Miocene formations in the Oregon Cascade Range as a whole is as yet unsatisfactory. Along the western edge of the Range rocks belonging to the two epochs are separated by a distinct unconformity which along the North Santiam River has been traced eastward to the crest of the Mehama anticline. East of the Mehama anticline no good evidence of a stratigraphic break was found in the Western Cascade succession, and the formations are separated solely on the basis of lithology. The relations of the Oligocene-Miocene formations are diagrammatically shown in the following table.

Table 2. Correlation in the Western Cascade Range.

	Western	Central	Eastern
	Fern Ridge tuffs		
Miocene	Stayton lavas	Sardine Series	lavas
- - - - - - - - - -	Unconformity - - - - - - - -	- - No visible unconformity	
Oligocene	Illahe-Mehama	Breitenbush formation	
		Unconformity?	
- - - - - - - - - -	- - - - - - - - - - - - - -	- - - - - Rhyolite	
Eocene			

Illahe Formation

The type locality of the Illahe formation is Illahe Hill, which crosses the range line east of sec.1, T.8 S., R.4 W., about one-half mile east of the Willamette River. As geological mapping of the Willamette Valley progresses it may be advisable to drop the name Illahe as a synonym for either the Eugene or Pittsburg Bluff formations, but for the present the name is useful and will be used in this paper.

The Illahe formation is composed of rather well bedded, tuffaceous marine sandstones ranging from pebble conglomerates to massive white ash and fine silts; fine-grained silty sandstones are most common. In the western and southern edges of the Salem Hills a few thin limey beds and concretionary masses were found. These beds weather less readily than the others and yield the best preserved fossils, although the fossils are harder to break out. Northeast of Turner, in the southern part of T.8 S., R.2 W., the formation consists mainly of well bedded unfossiliferous pebble conglomerates. Shales interbedded with coarse conglomerates and agglomerates in Thomas Creek east of Schimonek bridge, about 2 miles northeast of Scio, strongly resemble Illahe beds. Although fossils were not found in Thomas Creek the beds are believed to be the same age as the Illahe, and possibly were deposited along the shore of the Oligocene sea by a stream from the east.

The Illahe formation weathers readily to gray or light brown sandy soil which contrasts with the red clays formed from the overlying Stayton lavas, and it is possible to map the upper limit of the Illahe beds fairly closely by noting carefully the change from red clay soil to light colored sandy soil. Along the western side of the Salem Hills erosion and deep weathering of the Illahe sediments have caused many landslides, and large landslide blocks of the Stayton lavas have reached the river in places. Coarser and more massive beds like those in the northeast corner of T.9 S., R.3 W., form steep slopes free from landslides. The thickest continuous section of Illahe sediments seen is exposed in a ditch down the abandoned county road southwest of Bunker Hill, in the NW$\frac{1}{4}$ sec.5, T.9 S., R.3 W. The beds dip 10 to 13 degrees northward into the hill. The thicknesses given in Table 3 are estimated.

Table 3. Illahe beds exposed below Stayton basalts in abandoned road in NW$\frac{1}{4}$ sec.5, T.9 S., R.3 W., and SW$\frac{1}{4}$ sec.32, T.8 S., R.3 W.

	Feet
Stayton basalts (Middle Miocene)	400±
Unconformity	
Illahe formation:	
Massive, obscurely-bedded, coarse sandstone	120±
Calcareous, medium-grained sandstone, containing large numbers of Pitaria Clarki Dickerson	3
Fine-grained silty sandstone	50
Hard water-laid tuff containing half-inch angular fragments	12
Fine-grained silty sandstone	90
Coarse water-laid tuff similar to 12-foot bed	3
Fine-grained silty sandstone	10

Coarse water-laid tuff	2
Fine-grained soft sandstone	25
Well cemented water-laid tuff containing quarter-inch pebbles	2
Silty sandstone	45
Dark-gray calcareous siltstone, very hard (base of exposure)	1
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Marine fossils are numerous in parts of the Illahe formation. They are most abundant south of Illahe Hill in road cuts near Finzer and in the sandstone bluff in the E½ sec.12, just to the south. Pelecypods are common in gray to white sandstones in road cuts 1¼ miles west of Macleay, at about 400 feet elevation in the NE¼ sec.3, T.8 S., R.2 W. The fauna includes Macrocallista pittsburgensis (Dall), Molopophorus gabbi Dall, Nucula (Acila) shumardi Dall, and Tellina eugenia Dall.

Mehama Volcanics

The Mehama volcanics are terrestrial tuffs, lavas, and breccias which for the most part were water-laid. They are best exposed near the crest of the Mehama anticline, north and east of the town of Mehama, where there are about 600 feet of fine-grained white and green tuffs containing fossil wood. The hill about a mile southeast of Mehama is composed entirely of very coarse flow breccia and agglomerate which dip 40 to 45 degrees northward; a flow fragment 50 by 25 by 10 feet indicates that the source of the material can not have been far away. The thickness of the formation is not known because the base is not exposed.

Though it was not possible to trace the Mehama volcanics continuously into beds known to be Illahe, the tuffaceous nature of the Illahe and the increase in proportion of beds of volcanic pebbles toward the east indicate that the Mehama beds are very likely the terrestrial equivalent of the Illahe formation. The ancient shoreline must have crossed the western edge of the Stayton basin and swung northeastward near Turner. The Mehama volcanics are evidently comparable in age to the Warrendale or Eagle Creek formation in the Columbia River gorge section.

Stayton Lavas

The Stayton lavas overlie the Illahe formation in the Salem Hills and have been traced eastward continuously to the crest of the Mehama anticline. In the vicinity of Stayton they form dip slopes which dominate the topography where the younger formations have been stripped off. The lavas attain a maximum thickness of about 400 feet in the Salem Hills and apparently increase in thickness toward the northeast; east and southeast of Stayton they average less than 200 feet thick. The lavas are mainly medium-gray to dark-gray basalts in some of which olivine is visible; andesite flows occur south and east of Stayton.

The Stayton lavas lie unconformably on the Illahe and Mehama formations. Dips in the lavas average 3 degrees, whereas dips in the Illahe and Mehama formations average 10 or 12 degrees. The irregularity of the basal contact of the lavas indicates that they were poured out on a rolling landscape that had a relief of 600 feet or more. The magnitude of the unconformity underlying the

Stayton flows and their increase in thickness toward the northeast suggest that they may be marginal flows of the Columbia River basalts, which they resemble in many ways. The Stayton lavas are therefore tentatively correlated with the Columbia River basalts, which are commonly regarded as Middle Miocene in age.

Fern Ridge Tuffs

Fern Ridge, about 5 miles northeast of Stayton, is the type locality of the Fern Ridge Tuffs. The formations consist of conglomerates, tuffs, and breccias which attain a maximum thickness of about 1500 feet northeast of Mehama. The lower beds are mainly tuffs, sandstones and fine pebble beds, and the upper portion of the formation comprises coarse andesitic conglomerates which contain boulders as much as 18 inches in diameter in a tuffaceous matrix. Toward the northwest the beds have been thinned by erosion and occur in the Stayton quadrangle only as thin patches or low rounded hills.

The Fern Ridge tuffs lie conformably on the Stayton lavas and are probably part of the same general volcanic sequence. The abundance of water-laid and crystal tuffs, like those exposed in road cuts in the SE$\frac{1}{4}$ sec.20, T.9 S., R.1 E., indicate explosive activity during deposition. No evidence was found to suggest that the tuffs are Upper Pliocene or Pleistocene, as indicated by Hodge.5/. If the Fern Ridge were Pleistocene, there should be a large erosional and structural unconformity at its base, yet there is little, if any, evidence that the basalts were appreciably eroded before deposition of the tuffs. Moreover, the boulders seen in the Fern Ridge formation are all Western Cascade types, and the apparent absence among them of epidotized andesites and vein quartz indicates that deposition of the formation preceded mineralization of the Sardine lavas and intrusion of the Halls diorite porphyry. As will be shown later, the Western Cascade Range was folded, elevated, and eroded to maturity before eruption of the first High Cascade lavas, probably in late Pliocene time. Therefore, deposition of the Fern Ridge formation in Pleistocene time as a continuous mantle apparently conformable on the Stayton lavas seems improbable.

Sardine Series

The type locality of the Sardine series is Sardine Mountain, in which 4000 feet of lavas, tuffs, and breccias are exposed. The entire thickness of about 6000 feet is revealed in the east limb of the Sardine syncline. The series is very resistant to erosion and forms the highest part of the Western Cascade Range. Stream valleys in the belt of Sardine lavas are notably narrower than to the east or west.

The lavas are chiefly andesites, although they range from rhyolite to basalt, and greatly predominate over the tuff and breccia. As the ratio of lavas to tuffs decreases the Sardine series grades downward into the Breitenbush tuffs. This gradation is well shown in both the Breitenbush and North Santiam river valleys east of Detroit. The relation of the Sardine series to the for-

5/ Hodge, E. T., The Cascade Plateau Province: Geol. Soc. of the Oregon Country, Geological News Letter, vol.4, no.2, p.17, 1938.

mations exposed farther west is not well known. The Mehama volcanics, Stayton lavas, and Fern Ridge tuffs are readily traceable as distinct formations to the crest of the Mehama anticline. East of the Anticlinal crest lava flows are interfingered in both the Fern Ridge and Mehama formations; so that these formations could not be separated from the Stayton lavas in the time available for field work. All were therefore grouped in the Sardine series. This arrangement is not entirely satisfactory because the unconformity between the Mehama volcanics and Stayton lavas is disregarded. Whether the Mehama volcanics grade eastward into a lava series or dip under one was not determined with certainty. The entire Sardine series may be Miocene, or the lower part may be Oligocene; it is not intended that any Eocene formations be included.

Breitenbush Tuffs

The name Breitenbush tuffs has been proposed for about 7500 feet of water-worked, land-laid tuffs, breccias, and conglomerates, interlayered with a few lava flows. The type section is exposed in the Breitenbush River between French and Fox Creeks, which are 1 and 5½ miles, respectively, east of Detroit. Sandy or conglomeratic beds are common in the upper part, and massive green pumiceous breccias showing little or no bedding are more common in the lower part. Along the eastern edge of the Western Cascade Range the Breitenbush beds are chiefly massive pebbly sandstones interbedded with andesitic flows and containing lenses of well bedded, almost white ash that probably was deposited in quiet water. Well preserved leaf impressions were found at two places in these ashy lake (?) deposits. Impressions of Quercus (oak), Cercidiphyllum, and Abies (fir) were found in Skunk Creek, about 2 miles south of Breitenbush Hot Springs. The best remains were found in a small landslide on the west bank of the creek opposite exposures of High Cascade dark olivine basalt. Another promising locality was found on the northeast slope of Mt. Bruno, near the south line of Township 10 S., between 4000 and 5000 feet elevation. The exposure is visible as a white scar resembling a landslide cirque from the North Santiam Highway in the vicinity of Woodpecker ridge. One Abies bract was found at this locality, but the nature of the beds is such that further search might be well rewarded. The leaves were identified by Chaney as Upper Miocene. 6/.

The presence of Upper Miocene leaves shows that beds which were mapped as part of the Breitenbush formation on the basis of lithology may be stratigraphically equivalent to part of the Sardine series. It is probable that the rhyolite in Minto Mountain and the Sentinel Hills is similar in age to rhyolites that occur in the Sardine series in the vicinity of Quartzville, south of the area mapped. The rhyolite in Minto Mountain dips southeastward essentially parallel to the Breitenbush flows and tuffs along the North Santiam River, and appears to overlie andesitic flows and tuffs which are exposed between Grizzly and Pamelia creeks. Moreover, the southward slope of the base of the High Cascade lavas in Mt. Bruno and Minto Mountain suggests that the rhyolite formed the point of a Western Cascade spur which was buried by the Pliocene (?) flows. The Sentinel Hills rhyolite is structurally in line with the Minto Mountain rhyolite, and both masses are apparently remnants of a series of rhyolite flows in the Sardine series.

6/ Chaney, Ralph, Personal communication, May 1935.

Although the upper beds are Miocene in part, most of the Breitenbush tuffs are probably Oligocene, and some may be as old as Eocene. If, as mentioned above, the base of the Sardine series is equivalent to the Mehama volcanics, the entire type section of the Breitenbush series is Oligocene or Eocene, but if the Sardine lavas are all Middle Miocene, the upper age limit of the tuffs is correspondingly higher. The relation between the lower rhyolites and the Breitenbush tuffs proper is not known as the contact is obscured by faulting and vegetation; the rhyolites may be of either John Day or Clarno age. The apparent absence of the Miocene-Oligocene unconformity east of the Sardine syncline may be accounted for by a disconformity or by volcanism so nearly continuous during the period of post-Oligocene folding that a major unconformity is concealed in a great number of minor discordances.

Halls Diorite Porphyry.

Diorite porphyry is exposed in a roughly rectangular area of about a square mile in the North Santiam River gorge; the southeastern contact is approximately a thousand feet east of Halls siding. Dioritic dikes are common as much as a mile west of the northwestern edge of the main plug. Just west of Mayflower creek two vertical dikes, 25 and 125 feet thick, respectively, strike N. 50° W. along a narrow altered zone. The fact that no dikes were seen east of the main intrusion suggests that the main mass at depth lies west of the exposed portion. The rock of the main mass varies from a fine-grained, purple-gray porphyry at the contact to a medium-grained almost white porphyry containing hornblende and plagioclase phenocrysts.

The intrusion of the diorite disturbed the lavas very little, if at all. The northern contact appears to be almost flat and the flows above the contact in Sardine Mountain are horizontal and apparently undisturbed. Mineralized and brecciated zones are common within the diorite near contacts and in inclusions of the andesite country rock. The lack of disturbance in the surrounding lavas and the contact breccias suggest that the diorite was intruded quietly rather than forcibly. As the diorite was intruded into the Sardine lavas, it may be late Middle Miocene or Upper Miocene, and similar in age to the Snoqualmie granodiorite in the Washington Cascades. 7/.

A small exposure of intrusive andesite porphyry probably related to the Halls diorite was noted just south of the divide on the old trail from Detroit to Elk Lake. The pre-Battle Ax rocks northeast of Humbug Creek have been mineralized and several mining prospects in the vicinity of Elk and Dunlap lakes have been worked intermittently, apparently with little success. The Dunlap mine, on which the most work was done, is a half-mile southeast of Dunlap Lake at 4100 feet elevation on the trail up the ridge northeast of Gold Butte. Material on the mine dump indicates that the tunnel, now caved, was driven in altered tuff along a vein zone of cryptocrystalline quartz containing pyrite, and possibly other sulfides.

7/ Smith, G. O., and Willis, B., Contributions to the geology of Washington: U. S. Geol. Survey, Prof. Paper 19, p. 22, 1903.

PLIOCENE - PLEISTOCENE ROCKS.

The Pliocene-Pleistocene High Cascade lava sequence is separated from the pre-Pliocene Western Cascade succession by a marked structural unconformity that is traceable the entire length of the Oregon Cascades. This break in the record represents the time interval between the cessation of Western Cascade volcanism, probably near the end of Miocene time, and the beginning of the High Cascade eruptions probably during Pliocene time. During this interval the Western Cascade lavas were folded; the Halls diorite was intruded and the associated metalliferous deposits were formed; and the mountain range was deeply eroded.

The High Cascade volcanics consist of at least four structurally distinct series of flows and breccias that are separated by pronounced erosional unconformities. They are, in chronological order: the Outerson volcanics; the Minto lavas; and two probably nearly equivalent formations, the Olallie lavas and the Santiam basalts. The Battle Ax lavas are probably similar in age to the Minto lavas. The High Cascade lavas as a whole are petrographically homogeneous, a fact which makes field mapping very uncertain in places. Light-gray olivine basalts and breccias predominate, and true ash beds are comparatively rare. In the upper part of the Outerson volcanics, and in the Olallie lavas, andesites are most numerous and the rocks show most variety. In a single group of flows the thickness may range between 5 feet and 300 feet.

Outerson Volcanics

The Outerson volcanics are the oldest formation of the High Cascade series in this part of the Oregon Cascades. The lavas and pyroclastics were erupted on the eastern border of the Western Cascades from vents in the vicinity of Outerson Mountain, Triangulation Peak, Mt. Bruno, and from other vents which have not been found. Reddish agglomerates are very abundant, and the type section east of Outerson Mountain is composed of agglomerates, flow breccias and tuffs, with relatively few thin lava flows. The maximum thickness of the Outerson formation is probably about 3000 feet.

Minto Lavas.

The Minto lavas are named from the exposures at the east end of Minto Mountain. They are associated with the plugs from which they were erupted. This formation forms the main bulk of the High Cascades, and is probably 4000 to 5000 feet thick along the crest of the range. These rocks are mainly gray olivine basalts and agglomerates, though the upper part of the formation is markedly andesitic. The basalts grade into comparatively coarse-grained granular rocks which form the plugs. Three Minto plugs were found; two of them, 500 to 1000 feet across, form prominent pinnacles in the west wall of Hunts Cove and Hunts Creek valley, and one nearly a half mile across forms Park Butte, north of Mt. Jefferson.

Battle Ax Lavas.

The Battle Ax lavas were erupted from a volcano in the vicinity of Battle Ax Mountain, about 7 miles north of Detroit. They have been deeply eroded, and their present thickness is about 1000 feet; however, they were once much thicker as they occur through a vertical range of 3000 feet in a rather limited area. They are very similar to the Minto lavas and probably are of about the same age.

Olallie Lavas

The Olallie lavas are the basaltic and andesitic flows and breccias which form the young pre-Wisconsin peaks of the High Cascades. The lavas of Mt. Hood, Mt. Jefferson, and Crater Lake probably belong in this formation. The formation is named after Olallie Butte, a beautiful 2000 foot cone which has suffered only moderate glacial erosion. These lavas are extremely variable in thickness; in Mt. Jefferson they may be 5000 feet thick, yet a few miles away they are absent.

Santiam Basalts

The Santiam basalts consist of about 1600 feet of thin, light-gray olivine basalt flows, which occupy the old valley of the North Santiam River. Pigeon Prairies occupy part of their almost flat, slightly eroded upper surface. The basalts are thickest near the Santiam Elbow and thin southward and westward. That they formerly extended nearly to Detroit is indicated by large angular blocks of red and gray basalt which form a narrow bench at 2200 feet elevation and are common up to 2350 feet on the Hoover Ridge trail about 2 miles east of Detroit. They also are exposed nearly continuously southward to Minto Creek and probably form the bench at 2900 feet elevation south of Independence Prairie Ranger Station.

The Santiam basalts and Olallie lavas are probably of approximate age. Both formations occupy deep valleys cut in the Minto lavas, and both are pre-Wisconsin. Wisconsin glacial moraines lie on the floor of the valley cut through the basalts north of Mt. Bruno and suggest that the flows are not younger than Middle Pleistocene.

Present knowledge of the age of the High Cascade lavas is very meager. The lavas are probably Pliocene and Pleistocene, but it is a moot question whether the Outerson volcanics, for instance, are Lower Middle, or Upper Pliocene, or even uppermost Miocene. The evidence for considering them later than Middle Pliocene will be brought out later in the detailed discussion of the physiographic history of the region. No post-glacial flows were found in the area mapped, although they are common in other parts of the High Cascades, and occur southeast of Mt.Jefferson.

The later volcanic history of the Mt. Hood region must have been similar to that of the North Santiam region, and the various eruptive units seem to be represented in both areas. The fragmental nature of the Outerson volcanics suggests that they are equivalent to the Rhododendron-Dalles-Troutdale sequence described by Hodge 8/, although the upper part of the Dalles formation may be equivalent to the lower Minto. The Cascan formation is probably the correlative of the Minto lavas, as the two series are lithologically similar and the degree of dissection is comparable. In fact, these two formations appear to be parts of an irregular lava sheet that extends through both regions.

Glacial deposits of possibly three different ages occur in the North Santiam River valley and river terraces are notably developed west of Niagara.

8/ Hodge, E. T., Geology of the Lower Columbia River, Geol. Soc. Am., Bull., vol. 49, p. 841, 1938.

GEOLOGIC STRUCTURE

INTRODUCTION.

Division of the central portion of the Oregon Cascades into the Western Cascade and High Cascade Ranges has been outlined. The structure of the range as a whole can be described most effectively by considering the two units separately as far as is practicable.

It is important that initial structures of volcanic rocks be distinguished from structures caused by deformation. In marine deposits like the Illahe formation, which were laid down on a nearly flat ocean floor, very low dips may be ascribed to folding. Volcanic rocks, however, are usually deposited on irregular landscapes, and may be laid down on steep slopes. Moreover, volcanic deposits form cones or parts of cones, whose slopes may vary from place to place. For example, dips of 13 degrees in the Illahe formation are obviously caused by folding, yet dips between 8 and 28 degrees in High Cascade lavas are just as plainly initial. When the volcanics are folded, and deformational dips are superimposed on the initial dips, the structure seen in the field is a combination of the two, and other evidence must be adduced to determine, if possible, how much of the dip is original and how much due to folding.

Great lava flows like the Columbia River basalts evidently flow long distances on very gentle slopes, and their structure may be treated essentially as that of flat bedded deposits. Tuffs deposited over large areas of low relief may be treated in a similar manner. The prevailing low dips of the Western Cascade lavas, and the reversal of the dips on opposite limbs of gentle folds suggest that the lavas are the flat-lying type erupted from fissures, especially as there is very little evidence that they were poured out along the crests of the folds. It is the author's opinion that, except very locally, initial dips are relatively unimportant in determining the present attitude of the Western Cascade rocks, but that they are the controlling structures of the High Cascades.

WESTERN CASCADE RANGE.

The Western Cascade Range consists of a thick mass of volcanic rocks of various types. Compression has produced a series of gentle folds trending northeast to north, the easternmost being the sharpest. All appear to plunge northward at low angles.

Willamette Syncline

The Willamette Syncline (fig.2) is a broad open fold that plunges somewhat east of north at a very low angle, and is revealed by the dips in the Stayton lavas. The Salem Hills are essentially a slightly warped lava-capped mass whose eastward dip is best shown west of Marion (section B-B'). The Salem, Eola, and Amity Hills are all part of a single eastward dipping homoclinal block which is transected by the Willamette River west of Salem. Erosion of the soft Illahe beds exposed below the western edge of the Stayton lavas has given the hills their asymmetrical, cuesta-like form. Along the foothills of the Cascades proper, north of Thomas Creek, the lavas slope gently northwestward toward the Willamette Valley. (fig.4). The lavas are covered by alluvium in the vicinity of Stayton but northeast of Turner they have been cut through in many places and the underlying Illahe sediments are exposed in a low escarpment. The lavas west of Marion in the south end of the Salem Hills are undoubtedly continuous with those south of Shelburn, $3\frac{1}{2}$ miles to the southeast. North of Turner the lavas can be matched almost flow for flow across Mill Creek Gap, and it is certain that they are parts of a single lava formation, which has been folded along a northeast-southwest line. Minor warping of this major structure probably accounts for flattening of the lavas in an east-west belt in the latitude of Turner. Cross warping probably also formed the depression in the lavas west of Stayton, for which the name Stayton Basin is suggested. There is no evidence of the fault along this portion of the Willamette Valley margin suggested by Washburne, 9/, and the Western Cascade folds extend unbroken across the Willamette River.

The unconformity between the Stayton lavas and the Illahe formation has been indicated as large. Dips in the Illahe beds average about 10 degrees to the northeast, but local variations in direction and angle of dip are great. The basal contact of the Stayton lavas near Milepost 62 on the Pacific Highway dips 45 degrees, whereas the contact between the two lowermost lava flows dips only 15 degrees northeast. The Mehama-Stayton unconformity is equally large, and the Oligocene beds northeast of Scio dip 10 to 12 degrees eastward, though the overlying lavas dip northwestward into the Willamette syncline. (Section C-C', plate 1.)

Mehama Anticline

The Mehama Anticline trends about N.45° E. Its axis passes through McCully Peak (see fig.5), lies a mile or two east of Mehama, and apparently continues northeastward across the Clackamas River at the junction with the Oak Grove Fork, where the Bull Creek and Eagle Creek formations are exposed under the Columbia River basalts. 10/. The base of the Stayton lavas in the crest of the anticline is 1000 to 1200 feet higher than in the Willamette syncline. Dips in the Mehama volcanics average 7 to 10 degrees, and the volcanics are highly folded about a mile east of Mehama. In the bed of the Little North Santiam River the tuffs stand on edge and are cut by numerous dikes. The 45 degree dip of the agglomerates in the hill just to the east in sec.17, T.9 S., R.2 E., is probably due to the same disturbance, which seems to be very local.

East of Mill City structural evidence can be obtained only along the banks of the North Santiam River by tracing single flows for some distance. This procedure at best gives little better than apparent dips. In the gorge between Niagara and Halls, where exposures are best, the structure has been obscured by contact metamorphism. Flows at Mill City dip 3 to 5 degrees eastward, and the fragmentary evidence in the gorge indicates a low dip upstream. The horizontal lavas in the south end of Sardine Mountain above the diorite contact are evidently in the axis of the Sardine syncline. The diorite and the Battle Ax volcanic plug were intruded into the lower part of the syncline.

9/ Washburne, Chester, Reconnaissance of the geology and oil prospects of northwestern Oregon: U. S. Geol. Survey, Bull.590, p.8, 14, 1914.

10/ Barnes, F. F., and Butler, J. W. Jr., The structure and stratigraphy of the Columbia River gorge and Cascade Mountains in the vicinity of Mt. Hood: Unpublished master's thesis, University of Oregon, 1930.

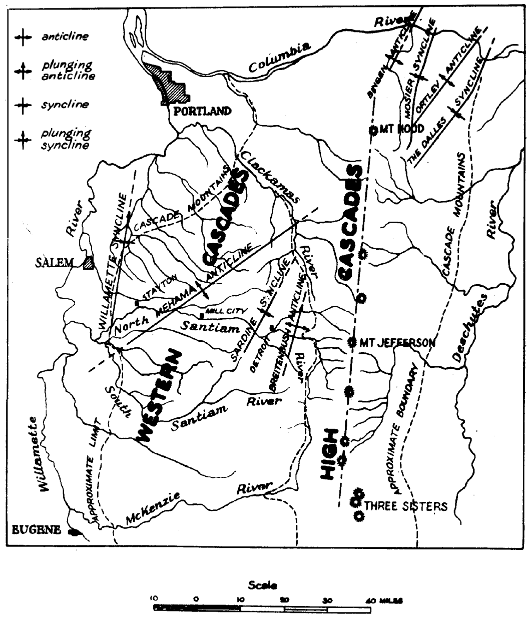

Figure 2. Northern portion of the Cascade Range in Oregon, showing the geographic relation between the Western Cascades and the High Cascades and the major folds in the Miocene lavas of the Western Cascades. Folds in the Columbia River basalts northeast of Mt. Hood after Hodge.

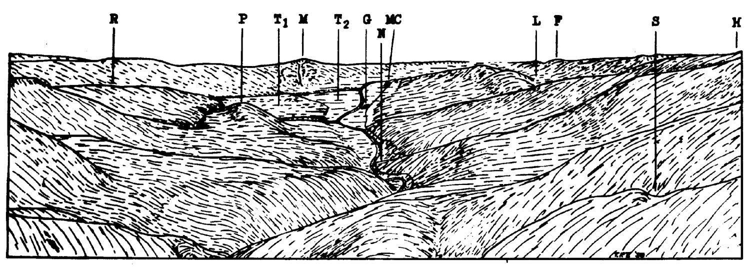

Figure 3. View west from Sardine Mountain down the North Santiam River valley, showing remnants of ancient broad valley stage. H, Mt.Horeb; S, Sardine Creek valley; F, Fern Ridge; L, Little North Santiam River valley; MC, Mill City; N, Niagara; G, Gates; T_2, Gates terrace; M, McCully Peak; T_1, 1025 foot terrace; P, Potato Hill; R, valley of Rock Creek. Sketched from a photograph.

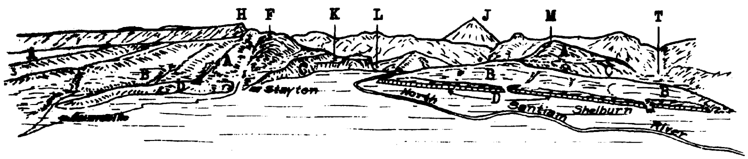

Figure 4. View east across the Stayton Basin from the base of the Salem Hills, showing the south end of the belt of dip slopes in the Western Cascades. A, Fern Ridge tuffs; B, dip slopes on Stayton lavas; C, Mehama volcanics; D, Leffler terraces; F, Fern Ridge; J, Mt.Jefferson; K, high level valley of Little North Santiam River; L, Little North Santiam River; M, McCully Peak; T, Thomas Creek valley.

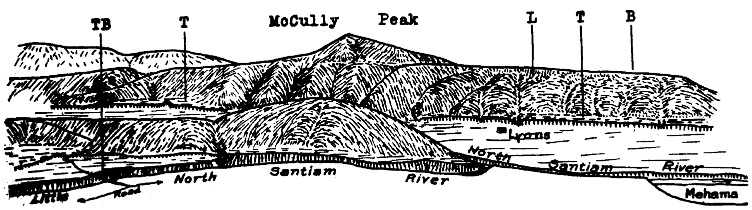

Figure 5. View south from point northeast of Mehama, to show change in dip of structurally-controlled surfaces at crest of Mehama anticline. McCully Peak is composed of Fern Ridge tuffs. B, dip slope on Stayton basalt; L, landslide in Mehama volcanics at base of Stayton lavas; T, Lyons Terraces; TB, Taylors bridge. Moraine Flat is to the left just out of the field of view, and over the ridge in the foreground.

Basaltic and andesitic dikes are common in the east limb of the Mehama anticline, and several basaltic dikes are exposed along the Little North Santiam River east of the center line of R.2 E. Although exposed only for short distances along the river, they probably are much longer. Some of these dikes are 50 feet thick, and may have been feeders for the Sardine flows with which they are petrographically identical. The many small dikes between Gates and Mayflower Creek trend north or northwest.

Sardine Syncline.

Northwest of Detroit the east limb of the Sardine syncline is best shown in the ridge. From the trail up Byars Peak the flows can be followed visibly from a horizontal attitude in Dome Rock to 50-degree westward dips in the eastern end of the ridge. North of French Creek the western limit of steep dips lies between Byars Peak and Marten Buttes, and probably a short distance west of Battle Ax Mountain. South of Detroit exposures are too poor to reveal dips. The flows in Detroit Hill seem to dip steeply, and horizontal tuffs crop out in Blowout Creek below Blowout Lake. The north slopes of Blowout Cliff mountain are heavily timbered and exposures are rare, but the valley pattern of the eastern half of the mountain strongly suggests inclined strata. The strike of the strata and the trend of the belt of steep dips indicate that, locally at least, the eastern limb of the Sardine syncline trends north at a sharp angle to the Mehama anticlinal axis. The flows were folded with the underlying Breitenbush tuffs, and evidence of the unconformity mentioned by Hodge 11/ was not found by the writer.

Breitenbush Anticline.

The Breitenbush anticline seems to be an irregular fold. Along the Breitenbush River the westerly dips decrease somewhat irregularly from 53 degrees at French Creek to 20 degrees at Humbug Creek. In the vicinity of Fox Creek the older rhyolites are brecciated and jumbled in a zone about a quarter-mile wide, and andesite dikes striking N.10° W. to N.30° W. are numerous. East of this zone, which apparently marks the crest of the anticline, dips are 12 to 15 degrees southeastward. In the vicinity of Gold Butte extensive exposures of tuffs dipping 10 to 15 degrees northward indicate that the anticline plunges northward. Additional evidence of northward plunge is the southward increase in width of the rhyolite zone, from a quarter of a mile in the Breitenbush River to $5\frac{1}{2}$ miles in the North Santiam River, although some of this increase may be due to faulting. Little is known of the geology between the North and South Santiam Rivers in the region east of Quartzville, but the occurrence of rhyolites in an anticline in the South Santiam River east of Cascadia, as pointed out by Hodge 12/, suggests that the Breitenbush anticline is a long fold which plunges north of the North Santiam River.

11/ Hodge, E. T., Framework of the Cascade Mountains in Oregon: Pan.Amer.Geol., vol.49, no.5, p.346, 1928.

12/ Hodge, op. cit.

The eastern edge of the Breitenbush anticline is buried under the High Cascade volcanics and very little is known about it. All contacts between High-Cascade lavas and Western Cascade rocks which have been examined in detail are unquestionably overlap contacts. Except for the rhyolite in the Sentinel Hills and Minto Mountain the eastern limit of outcrops on the east limb of the anticline is an almost north-south line about two miles east of Breitenbush Hot Springs and following the east side of the North Santiam River valley south of the Elbow. The seeming linear nature of the boundary and the scarcity of exposures of Western Cascade rocks in the western slopes of the High Cascades suggest a north-south fault along which the area to the east was dropped or the mountains to the west were elevated. However, the structural alignment of the rhyolites with the eastern limb of the Breitenbush anticline casts doubt on the presence of a fault. Moreover, the southward slope of the High Cascade contacts in Mt.Bruno and Minto Mountain indicate that the two mountains were originally part of the same Western Cascade ridge. The Sentinel Hill rhyolite must have stood as an isolated hill east of the main Western Cascade front. No positive evidence of faulting along the eastern margin of the Western Cascades was found, but possibly future work may reveal such a fault.

HIGH CASCADE RANGE.

The division of the High Cascade lava series into four or five major formations, chiefly on structural evidence, has been outlined above.

Outerson Volcanics

The earliest of the High Cascade volcanics, the Outerson volcanics, were erupted from vents near the eastern edge of the Western Cascade Range. The dips of these deposits as a whole are eastward at angles between 2 and 25 degrees. The initial dips vary with the steepness of the Western Cascade slopes. The greatest local center of Outerson eruptions was east of Outerson mountain in the vicinity of Spire Rock and Boca Cave, where there is a typical vent complex of intrusive plugs, dikes, giant breccias, and very steep and irregular dips in the lavas. Dips of 30 degrees in agglomerates in the western spur of Mt.Bruno indicate a smaller volcano. The source of the thick flows which dip eastward in Coffin and Bachelor Mountains is not known.

The configuration of the base of the Outerson lavas suggests that the flows were poured out on a comparatively uniform eastward-facing erosion scarp of the Western Cascades and may have overflowed westward onto a surface of slight or moderate relief. North of Breitenbush Hot Springs, where the Miocene rocks are mainly lavas, the lower Outerson contact descends eastward nearly a half mile in a horizontal distance of one mile. There is no evidence that the slope flattens toward the foot of the ridge, and it goes under the Breitenbush River at about 2,500 feet in altitude. The contact slopes eastward about 600 feet per mile in the vicinity of Outerson Mountain, where water-laid volcanic sediments constitute most of the Miocene rocks. The basal contact is concealed in the north side of the North Santiam River valley, but in the southern valley slope it dips eastward about 1,000 feet in a mile. In the vicinity of Coffin Mountain these volcanics appear to lie on a remarkably even surface at an altitude of 4,000 feet; however, more detailed work might show that the smoothness is more apparent than real. It is probable that Outerson lavas form the higher peaks southwest of Coffin Mountain, and that more positive data regarding the pre-Outerson form of the

Western Cascade Range may be obtained in that area. The fresh gray basalt on Galena Mountain, in the southern part of the Quartzville district 13/, may be a correlative of the Outerson flows.

Deep erosion of the Outerson volcanics before extrusion of the Minto lavas is shown by relations in the vicinity of Woodpecker Hill. The Outerson flows in Woodpecker Hill dip southeast and were erupted from the Spire Rock-Boca Cave vents. The Minto lavas southeast of Chest Creek dip 5 degrees west, nearly at right angles to trends of the Outerson breccias, and probably poured into a deep valley cut into the southeast slopes of the Outerson volcano. In most places relations between the Outerson and Minto lavas are obscure.

Minto Lavas.

From Park Butte southward the Minto lavas dip east and west away from the plugs along the crest of the High Cascades. They extend well to the east some distance into eastern Oregon, but about 5 miles west of the crest they abut against the Outerson flows. North of an east-west line through Park Butte the lavas dip radially away from Park Butte. These dips are reflected in the radial drainage shown by the headwaters of Whitewater River, Shitike Creek, the North and South Forks of the Breitenbush River, and Whitewater Creek. The Park Butte 14/ plug is nearly a half-mile in diameter, and marks the approximate center of ancient Mt. Minto. Mt. Minto was a volcano whose lower slopes extended northwestward at least 11 miles, and whose lavas now cap Mansfield Mountain. Its flows probably extended an equal distance eastward and northward. Dips in the lavas range from 1 to 8 degrees, and average 3 or 4 degrees, so the slopes of the ancient peak were comparatively gentle. Many small cones undoubtedly were built up on the slopes of Mt. Minto, and north of it they were probably the chief sources of the Minto lavas.

Battle Ax Lavas.

The Battle Ax lavas erupted from a Minto-type micro-gabbro plug in Battle Ax Mountain, about 7 miles north of Detroit, and now form prominent cliffs for about 4 miles along the north wall of the Breitenbush River valley. The seemingly horizontal flows exposed in the cliffs are in marked contrast to the steeply dipping Breitenbush tuffs in the south wall of the gorge. One flow of hypersthene-cristobalite andesite, which in places is 300 to 350 feet thick, caps the ridges south and east of Byars Peak, and form the summit of Gold Butte. This is the greatest single flow that was recognized in this part of the Cascades; it originally probably covered an area of 15 square miles and contained about a cubic mile of lava.

The Battle Ax volcano was erected on a maturely eroded portion of the Western Cascade Range and locally buried the old topography. Flows dip as much as 20 degrees near the vent and flatten in a short distance. The base of the lavas north of the Breitenbush River slopes southward about 1,500 feet per mile down to

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13/ Callaghan, Eugene, and Buddington, A. F., Metalliferous mineral deposits of the Cascade Range in Oregon: U.S.Geol.Survey Bull.893, p.100, 1938.

14/ Classification of these rocks as norites is incorrect, because of the large amount of augite present; see Thayer, op.cit., p.1629.

about 2,300 feet in altitude, and the flows evidently filled an ancient valley. In the lower end of the ridge east of Canyon Creek the basal contact is notably steeper, as if a narrow steep-walled valley at least 150 feet deep had been incised into the bottom of the broad valley. The radial drainage southeast of Battle Ax Mountain must have originated on the southeast slopes of the old cone, and has been superimposed on the older rocks. No Battle Ax lavas were found in place south of the Breitenbush River or west of French Creek. The Battle Ax volcano evidently was the southernmost peak of a chain of volcanoes that extended northeastward toward Mt. Hood, and appears to be equivalent in age to the Minto lavas.

Olallie Lavas.

The Minto lavas were deeply eroded, and the granular Minto micro-gabbro plugs were exposed before the eruption of the Olallie lavas. This unconformity can be seen at the northwestern corner of Jefferson Park, where the South Fork of the Breitenbush River falls over a 200 foot basaltic flow. This flow dips approximately 30 degrees north, at right angles to the underlying Minto lavas which dip 3 to 5 degrees westward. Olallie Butte and Mt. Jefferson, which were built up on the ruins of the Minto volcanoes have much steeper slopes than the older cones. The basalts dipping 28 degrees on the west slopes of Mt.Jefferson contrast strikingly with the almost flat lying Minto flows in the east end of Woodpecker Ridge. North of Olallie Butte cones of Olallie age, like Sisi Butte and the Pinhead Buttes, are numerous. The Olallie and Minto lavas could not be distinguished as map units between Pyramid Butte and Olallie Butte in the time available, because of lithologic similarity and complexities of structure, resulting from numerous scattered vents. Olallie lavas probably are absent between Pyramid Butte, which may be an Olallie plug, and Jefferson Park.

Santiam Basalts

The Santiam Basalts are a series of practically flat-lying flows which partially fill an ancient valley of the North Santiam River cut into the Minto lavas and older rocks.

The surface of the Santiam basalts attains a maximum altitude of about 3,700 feet north of the Santiam elbow, and slopes westward and southward from that point. This suggests that the lavas issued in the vicinity of the Elbow and flowed upstream as well as downstream. The base of the basalts lies near the 2,000 foot contour for about 3 miles between Boulder Creek and the Elbow, along the North Santiam River; the slight westward slope suggests that this contact closely follows the floor of the old valley. The north contact in the narrow ridge south of Boulder Creek follows the ridge crest for a third of a mile, and although basalt cliffs 100 feet or more in height form the south face of the ridge, no basalt croppings were found on the north slope. Farther east along the same ridge the basalts appear to overlap the Breitenbush tuffs on a comparatively gentle slope.

The maximum present width of the basalt mass is about 2½ miles, west of Pigeon Prairies, and erosion along the southern edge has probably reduced the original width by a mile. (See Section G-G'). The old valley must have been almost a gorge at the westernmost point where probable Santiam Basalts were found, about 1 mile east of Detroit. The Santiam Basalts become narrower south of the Elbow, and extend down to the main valley floor just north of Minto Creek. For most of the distance south of the Elbow, the basalt contact is 200 to 400 feet above the east bank of the North Santiam River.

REGIONAL STRUCTURAL RELATIONS.

In a previous paper 15/ the Mehama anticline was tentatively considered the North Santiam equivalent of the broad fold which brings up the Eagle Creek formation in the Columbia River gorge between Crown Point and Shellrock Mountain. This interpretation is probably wrong. The Mehama anticline actually trends N.45° E., and its projection would cross the Columbia River in the vicinity of The Dalles. (fig.2) The trend of the fold is clearly shown by the dip slopes on the Miocene formations in the west limb, and the position of the Oligocene beds brought up along the axis of the fold. This anticline can be traced from the vicinity of Lebanon northward to the junction of the Oak Grove Fork and the Clackamas River, a distance of about 40 miles.

In this paper, also, the Breitenbush anticline was depicted as parallelling the Mehama anticline. However, careful examination of the dips and strikes of the Breitenbush tuffs shows that the Breitenbush fold probably trends 10-15° east of north, and the dips in the vicinity of Humbug Creek indicate a northward plunge between 10 and 15 degrees. The persistence of the Mehama anticline suggests that it is the master fold of the region; the Breitenbush fold may join it in the vicinity of Mt. Hood, may die out northward, or may bend and parallel the Mehama anticline. Faulting apparently analogous to that in the crest of the Breitenbush anticline has been described by Hodge 16/ in the Columbia River gorge between Lindsay Creek and Hood River.

In Figure 4 of the same paper, Hodge shows the folds northeast of Mt. Hood trend northeast more or less parallel to the Mehama anticline. In Figure 7 Hodge indicates that the folds swing westward in the area covered by High Cascade lavas, and shows the Mutton Mountain anticline crossing the Western Cascade Range in an east-west direction in the latitude of Salem or Molalla. The continuity of the dip slopes on the west limb of the Mehama anticline south of the Clackamas River seems to be good evidence that no east-west fold in the lavas emerges from the Western Cascade Range in the place indicated by Hodge. It also seems reasonable to correlate the complicated structures south and west of The Dalles with the Mehama and Breitenbush anticlines, especially since the Breitenbush anticline is faulted, and the faulting in both places is clearly pre-High Cascade. The southward dipping basalts in the western portion of the Columbia River gorge, which were indicated by the writer as continuous with the Mehama anticline, apparently form part of another fold.* The Breitenbush anticline is tentatively correlated southward with the steeply dipping structures in the vicinity of Cascadia.

15/ Thayer, T.P., Structure of the North Santiam River section of the Cascade Mountains in Oregon: Jour. Geol., vol.44, p.712-716, 1936.

16/ Hodge, E.T., Geology of the Lower Columbia River: Geol.Soc.Am., Bull., vol.49, no.6, 1938.

* Insert: It is noteworthy, also, that the dioritic intrusive masses in Wind and Shellrock Mountains, which are similar in composition to, and probably contemporaneous with the Halls intrusive, are situated at the western edge of the belt of steep folds, as is the Halls diorite.

The northeast-southwest folds of the Western Cascade Range apparently lie across the projected axes of the major structures of eastern Oregon, namely: the Tygh Ridge, Mutton Mountain, and Ochoco Mountain anticlines. The area in which the two systems meet is concealed under the High Cascade Range. The folding in both regions was probably simultaneous, since the Pliocene rocks of eastern Oregon, like the High Cascade lavas, are undisturbed.

The faults in the Columbia River gorge described by Hodge, and those in the Breitenbush anticline show that faulting has occurred in the High Cascade zone. Gilbert has described Basin Range normal faulting in the Klamath Lake region 17/, and the scarp south of Crater Lake is commonly regarded as a fault scarp. In view of these considerations, it seems likely that the High Cascade Range follows an ancient zone of weakness between the divergent structural systems of western and eastern Oregon. The apparent persistence of the Western Cascade Range structure under the High Cascade Range in the vicinity of Mt.Hood may be interpreted as evidence that this zone dies northward.

The general distribution of the High Cascade vents apparently shows response to this structural control. The larger post-Minto peaks and the Minto plugs are restricted to a narrow zone along the crest of the High Cascade Range which south of Olallie Butte is almost a line. North of Olallie Butte the eruptive centers are scattered over the High Cascade plateau. This plateau is superimposed on the Western Cascades in the vicinity of Mt. Hood by the intersection of the High Cascade and Western Cascade structural axes. The alignment of High Cascade cones and plugs is most pronounced where the structural zone is better developed, namely, toward the south. In the north, where the deep seated adjustment is distributed over a wider area, the High Cascade vents are scattered haphazardly.

GLACIAL GEOLOGY.

GENERAL STATEMENT

Three stages of glaciation appear to be represented by deposits in the North Santiam River valley. These stages have been named after places at or near which the deposits are found, namely: the Mill City, the Detroit, and the Tunnel Creek. They are tentatively correlated with the Sherwin, Tahoe, and Tioga stages, respectively, which have been recognized on the eastern slopes of the Sierra Nevada 18/. These correlations are inferred from comparative erosion of the moraines and forms due to glaciation, and on the premise that Alpine glacial stages in all parts of the Pacific Coast ranges were essentially contemporaneous. The Tunnel Creek moraines are probably similar in age to the Late Wisconsin deposits of the Great Lakes region. All the glaciers were of the Alpine type, and the larger ones headed in snowfields of the High Cascade Range, whence they moved westward down the valleys in the Western Cascade Range. The Mill City glacier traversed two-thirds the width of the Western Cascade Range, whereas the

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17/ Gilbert, G.K., Studies of Basin Range structure: U.S.Geol.Survey, Prof. Paper 153, p.76-85, 1928.

18/ Blackwelder, Eliot, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geol.Soc.America, Bull., vol.42, pp.865-922, 1931.

Wisconsin ice barely entered the eastern side.

MILL CITY GLACIATION.

Distribution and character of deposits.

Deposits left by the Mill City glacier are exposed about $7\frac{1}{2}$ miles along the North Santiam River from Gates to a point almost 3 miles west of Mill City. The best exposures of till are in the river banks at Mill City where the old mill of the Hammond Lumber Company was built on glacial till. Till, 25 to 30 feet thick, extends to an unknown, but probably shallow depth below river level (fig.6). North of Mill City morainic (?) deposits reddened by weathering occur at an elevation of about 1000 feet. A nearly continuous section is exposed through nearly 200 feet vertically in the sides of an old log skidway north of the road in the $S\frac{1}{2}$ sec.23, T.9 S., R.2 E. The top of this section is marked by a sloping bench 300 to 500 feet wide at an elevation of 900 feet. Gray till lying on green pebbly tuff is exposed in the north bank of the river a short distance east of this section. The tuff surface is polished, slopes 10 degrees upstream, and bears striae trending northwest. The exposures in the river are at the 725 foot level, so the till is 175 to 200 feet thick.

The Mill City till is very fresh in all exposures along the river, although it is more or less weathered elsewhere. The fresh till is medium-gray, very compact, and similar to the moraines of continental glaciers in fineness of matrix and polishing of boulders. It contains fresh erratics of all sizes up to 6 feet in diameter, and of practically all types of rocks found in the North Santiam drainage. Its compactness and its habit of forming vertical banks along the river cause the till to be easily mistaken for the volcanic agglomerates on which it rests. In shallow road cuts the matrix is brown, and all but the largest boulders are decayed. The freshness of the river bank exposures is probably due to the fact that the river was entrenched very recently; and before entrenchment the till lay below river level, where movement of groundwater was exceedingly slow.

Contorted varved silts occur in the till under the railroad bridge at Mill City, and about one-third mile west of the bridge the till in the north bank of the river grades westward into steeply bedded outwash gravels. West of Gates varved silts are found for nearly a half-mile along the north bank of the river, and are well exposed at the spring in the picnic grounds west of the High School. Their average exposed thickness is about 20 feet, but the beds are gently folded and extend below river level, so their total thickness is probably considerably greater. These silts end downstream against bedrock, and upstream they wedge out on top of outwash gravels and till; they are overlain by 10 to 20 feet of bouldery river deposits.

The silts near Gates were deposited in a morainally dammed lake, and are the easternmost drift definitely attributable to the Mill City glacier. However, the saddle south of the 2200 foot diorite knob between Cumley and Kinney creeks, west of Halls Siding in sec.18, T.9 S., R.5 E., has features that may be Mill City in age. The saddle is occupied by a 5-acre marsh and is characterized by smooth topography in contrast with the rugged slopes at either end. Deep sandy soil, large boulders of High Cascade basalt, and the undrained marsh all point to glacial action. Since the saddle is now 900 feet above the river, and the

Mill City ice was probably rather deep in the narrow gorge, the deposits may reasonably be considered part of the Mill City glacial drift.

Morainic topography.

Definite morainic topography attributed to the Mill City glacier was found only on Moraine Flat, about 200 feet above the river on the north bank, approximately halfway between Mill City and Mehama. The bench is a half-mile across at its widest part and the dominant feature is a rounded lobate ridge which forms the top of the river bluff and slopes gently to the west. The north side of the ridge slopes smoothly down 25 to 30 feet to a triangular alluviated flat, which narrows northwestward between the lobed end of the ridge and an irregular rolling terrace along the base of the mountain to the northeast. Two shallow depressions, about 200 feet across, lie just northwest of the triangular flat, which itself was once a depression and even now is poorly drained. The rolling terrace extends northward nearly a mile from the triangular flat to the saddle crossed by the road, and ends abruptly about 150 feet above the terraces of the Little North Santiam River.

The topography of Moraine Flat is best explained as a series of lateral moraines built by the Mill City glacier. The eroded terrace along the base of the mountain formerly must have extended in a smooth gentle slope to the Little North Santiam River, and may have been a bypass for glacial melt-water. The triangular flat was an inter-moraine depression which was later drained by headward erosion of the small creek to the west. No strictly morainic deposits were found on the south side of the valley, and those on Moraine Flat are probably less than 100 feet thick. Terraces along the south side of the valley at elevations corresponding to that of Moraine Flat were probably formed at the same time.

The possibility that the Mill City deposits might be landslides is remote, and the evidence against the landslide hypothesis is overwhelming. Landslides may produce deposits which closely resemble glacial till, but the materials must be derived from nearby sources. The presence of High Cascade lavas which are not known to occur west of Detroit, and of diorite and epidotized andesite from the gorge nearly 20 miles to the east cannot be explained reasonably by landslide. The association of varved silts and outwash gravels with the deposits is characteristically glacial. Furthermore, the striae on tuff bedrock at the base of the deposits are parallel to the main valley rather than across it, as would be the case with landslide grooves. It does not seem out of order, while discussing such deposits, to remark that in the Pacific Northwest many pseudo-glacial striae have been made by logging cables!

Western Limit

Although the western limit of the Mill City glacier may never be known, the apparent absence of till west of Moraine Flat suggests that the ice did not go much farther down the valley, and probably not beyond Mehama. The outwash gravels near Mill City show that the till there was a recessional deposit. Contortion of the varved silts may have been caused by oscillations of the ice front, during which the glacier overrode recessional moraines, or it may be due to simple slumping.

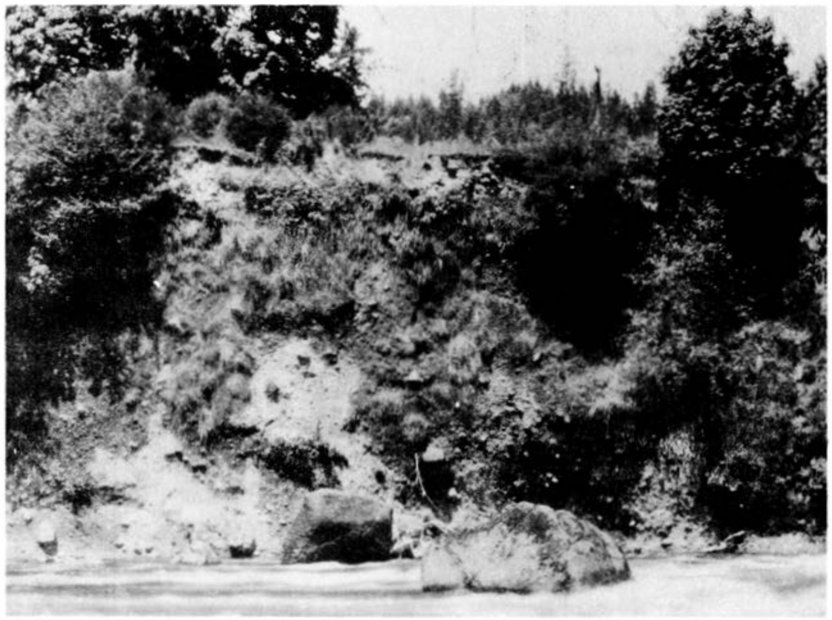

Figure 6. Glacial till in the north bank of the North Santiam River about a quarter mile west of Mill City. Height of exposure is about 30 feet. Note large proportion of fine material, and rounded corners on large erratics in the river.

Figure 7. Varved lake silts exposed in North Santiam River about one mile below the Detroit Ranger Station. The wide bands which appear homogeneous are composed of paper-thin laminae of very fine silt.

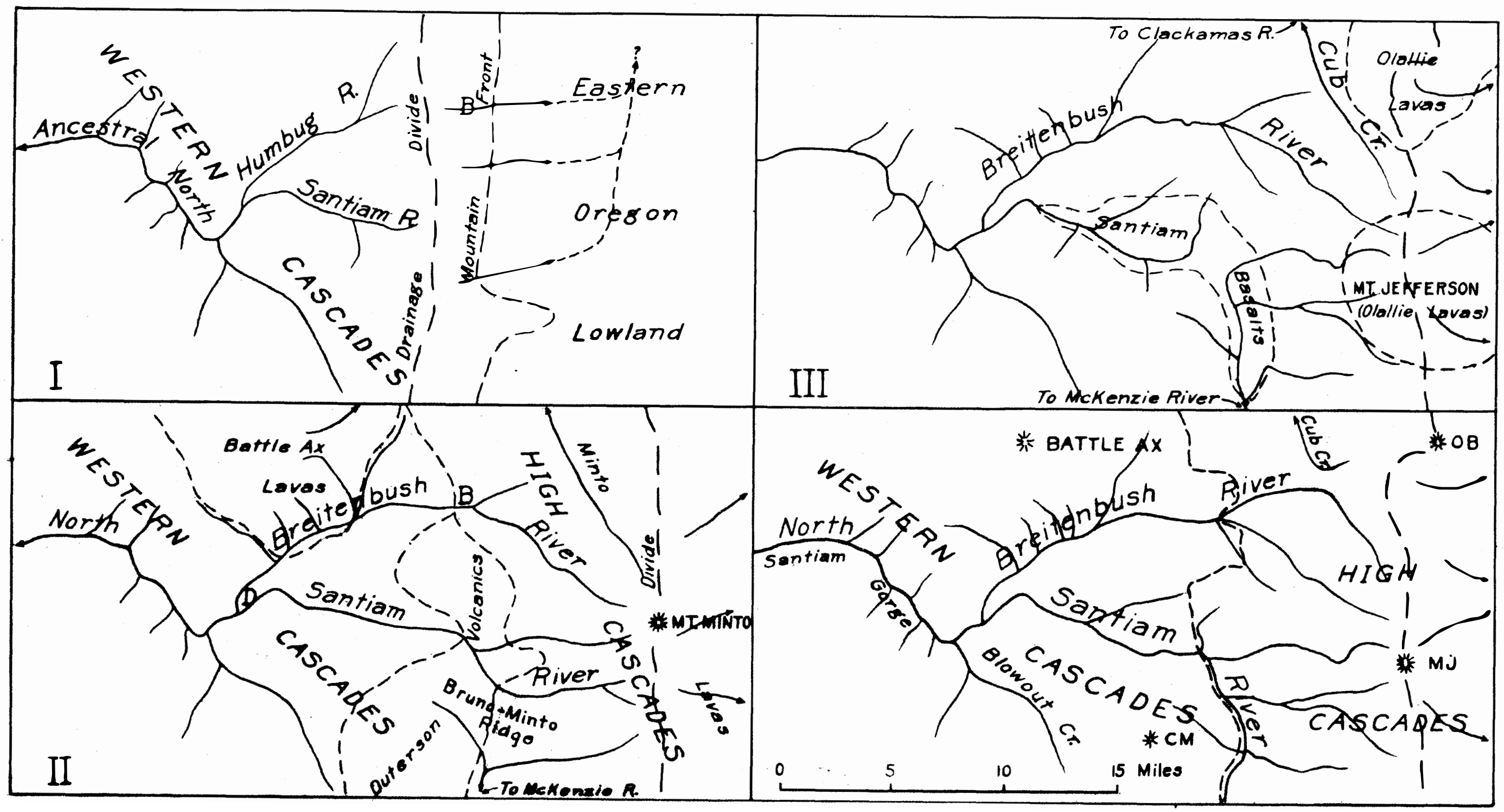

Figure 8. Probable steps in the integration of the North Santiam River System. I, Pre-High Cascade drainage; II, Post-Minto drainage; III, Early post-Santiam basalt stream pattern; IV, North Santiam River System today; B, Breitenbush Hot Springs; D, Detroit; OB, Olallie Butte; MJ, Mt.Jefferson; CM, Coffin Mountain.

Age

The age of the Mill City moraines is best indicated by their relations to the present floors of both the North Santiam and Little North Santiam River valleys. The presence of till in the North Santiam River bed below Mill City suggests that the "hung up" position of the moraines on Moraine Flat is due more to lateral planation than to down-cutting of the two streams. The absence of known Mill City drift east of Gates, and the lack of a glacial profile in the gorge east of Niagara suggest that the river gradient in Mill City time was somewhat steeper than at present. However, the glacial valley must have been very narrow, so that a comparatively small amount of river erosion would have destroyed the glacial profile. Although destruction of the glacial profile in the gorge may have been rapid, levelling of the massive lava flows east of Gates and planation of the wide valley floor must have required much time. Therefore correlation of the Mill City glacial stage with the Sherwin stage in the Sierra Nevada seems justified.

DETROIT GLACIATION

Distribution and character of deposits.

Very few deposits left by the Detroit glacier were found. Till crops out in the North Santiam River just above the bridge on the Quartzville trail; and in a road cut a half-mile southwest of Berry. A large mass of gray till in river gravels is exposed where the highway crosses the Breitenbush River southwest of Detroit. All the exposures are small and the till is similar to the Mill City till. Varved lake silts are well exposed in railroad cuts and the northwest bank of the river for about a mile downstream from the Detroit ranger station. The varves, or bands, are very fine and some are paper-thin. As in the silts at Gates, well developed larger bands about 6 inches apart are superimposed on the finer ones (fig.7). The silts in most places are disturbed, and have been greatly contorted, faulted, and even brecciated. The brecciation suggests disturbance by overriding ice when the silts were frozen. Upstream from the ranger station the silts grade into outwash and river gravels. The till near the Quartzville trail bridge is probably a remnant of the dam behind which the lake was formed. It is possible that the fine varves were related to daily variations in rate and character of deposition and the larger bands to seasonal changes; if so, deposition of the silts required about a century, since the beds are at least 40 feet thick stratigraphically.

The limited exposures of the Detroit drift render determination of its extent uncertain. The till below Berry is 150 feet above the river, and the valley at Halls has the aspect of an aggraded and modified glacial trough. Moreover, an 8-foot boulder of fresh pyroxene andesite bearing remarkable glacial striae is associated with subangular water-worn river deposits approximately 100 feet above the river at a point about 1/2 mile east of Mayflower Creek. A boulder of this size would probably lose its striae before travelling far, even in a powerful stream, so that this one was probably carried no great distance from the glacier. Moraines in narrow valleys are destroyed nearly as fast as built and their absence in the gorge is not significant. The north bank of the gorge, from Sardine Creek east, in places is plastered to a height of about 150 feet with poorly sorted silts and angular debris, which appears to be a mixture of valley train and talus. Some of this material resembles glacial till, but no well faceted boulders or definitely glaciated bedrock surfaces were found. The Detroit glacier may have extended as far west as Mayflower Creek, approximately 7 miles west of Detroit.

Age of the Detroit Glaciation.

The glacial drift in the vicinity of Detroit may have been left by the Mill City glacier, although this seems unlikely to the writer. The till downstream from Detroit goes below river level, yet there is no glacial profile in the gorge to the west. If the Detroit till is Mill City in age one of three things must have happened: (1) the glacier gouged out a shallow basin east of the present gorge and failed to alter appreciably the form of the gorge; (2) the region has been warped upward between Halls and Gates since the glacier traversed the gorge; (3) the glacier gouged a basin and eroded the gorge to a glacial profile which has since been destroyed. The first hypothesis seems improbable, since the Mill City glacier extended 15 miles beyond the narrowest part of the gorge and probably had much eroding power in the gorge. There is little support for the second hypothesis, although there is evidence of warping on a very broad regional scale in northwestern Oregon 19/. The third hypothesis is entirely reasonable and may be the actual case.

The glacial drift in the gorge east of Sardine Creek seems too poorly sorted and too angular to have been derived from the Wisconsin moraines some 15 miles eastward and probably is not Wisconsin in age. It seems equally improbable that unconsolidated silts of Mill City age could have remained in the bottom of the gorge during the period required for planation of the valley below Mill City. Therefore the Detroit till is believed to be the product of an intermediate glacial stage. Detailed comparison of the varved silts at Gates and Detroit to see whether they record similar seasonal changes, and might be contemporaneous, has not been attempted.

LATE WISCONSIN (TUNNEL CREEK) GLACIATION

Distribution and character of deposits

Most of the late Wisconsin moraines are well preserved. The terminal moraine of the late Wisconsin glacier in the North Santiam River valley is 10.8 miles east of Detroit, and about a mile west of Tunnel Creek at an elevation of 2000 feet. Except for a gap cut by the river near the northern end the moraine extends across the valley. It is about a quarter-mile wide and 100 feet high, and has good knob-and-kettle topography. The till is largely made of angular blocks which bear few facets or striae. The corresponding moraine in the Breitenbush River valley has been almost obliterated by river terraces and landslides. A small cropping of till was found in a road cut at 2200 feet elevation below Cleator Bend, a mile or more west of Breitenbush Hot Springs.

Late Wisconsin recessional moraines occur in many places, a few of which are worthy of mention: the main North Santiam River valley at 2250 feet elevation opposite Woodpecker Ridge, and north of Independence Prairie at 2500 feet;

19/ Hodge, E. T., Geology of the lower Columbia River: Geol. Soc. America, Bull., vol.49, p.913, 1938.

along the Pamelia Creek trail at 2400 feet, and probably at 3000 feet just below Heidike Creek (a branch of Milk Creek). A well formed hooked lateral moraine was seen at 4400 feet elevation on Milk Creek below the Skyline trail. The only recessional moraine noted in the Breitenbush drainage is at 2900 feet elevation in the valley of the South Fork.

Glaciation of the High Cascade Range

The High Cascade Range shows the effect of severe glaciation. The higher ridges sloping westward from the summit plainly show the effects of glaciation, yet have a comparatively heavy soil cover; Minto Mountain and Woodpecker Ridge are examples. The higher flats such as Grizzly Flats and Bingham Basin likewise fail to show the severity of recent ice action commensurate with their topography. From these facts it is inferred that the highest parts of the range were eroded by the Mill City and Detroit glaciers and were unaffected or only slightly modified by the late Wisconsin glaciers. If the valleys were well filled with ice during the Tunnel Creek stage the glacier should have gone farther beyond Tunnel Creek, so it is probable they were formed by the end of the Detroit stage and were merely freshened by the late Wisconsin glaciers.

The High Cascade upland in the vicinity of Olallie Butte was covered by an ice sheet between 500 and 1000 feet thick, which covered the smaller peaks and after melting left a landscape similar to parts of the Lake Superior region. The lower slopes of Olallie Butte were markedly steepened by this ice sheet. Fully half of the forty-five lakes visible from the summit of Olallie Butte are in rock basins. Bedrock striae indicate that the ice moved northward past Olallie Butte and fanned out toward the edges of the plateau. The breadth and altitude, between 5,000 and 6,000 feet, of the upland doubtless account for the thickness of the ice.

Jefferson Park

Jefferson Park is a remarkable example of a flat glaciated mountain divide and merits special mention. The Park averages 5,800 feet in altitude, is one and a half miles long from east to west, and is over 1,000 acres in area. Park Butte rises 1,000 feet above it to the north, and Mt. Jefferson towers 5,000 feet above the Park on the south. The main portion of the Park is so flat that the actual divide is revealed only by the streams. The east end slopes gently toward a cirque at the head of Whitewater River valley. The west end drops by a series of low steps to 5,500 feet, where it is hung up by receding cliffs on lava flows. The Park was apparently formed by large glaciers which flowed down the north slopes of Mt. Jefferson, impinged on the Park Butte ridge, and split into two east-west glaciers. Striae on the bedrock support this hypothesis. The notch that originally guided the glaciers was probably formed between the initial north slope of Mt. Jefferson and the eroded Minto volcanics in Park Butte ridge. This ridge probably was never buried by the Mt. Jefferson flows. The inception of Jefferson Park, therefore, in all likelihood was directly related to the unconformity between the Olallie and Minto lavas. Russell Lake, incidentally, is not a glacial lake, but is dammed by detritus from the valley east of Park Butte. In much the same way Pamelia Lake is hemmed in by debris from the western slopes of Mt. Jefferson.

Western Cascade Range Cirques

Glaciation in the Western Cascade Range is slight compared to that in the High Cascades. Fresh cirques of late Wisconsin age are common in the higher parts of the Western Cascade Range but there is little evidence of the Detroit or Mill City glacial stages outside of the main through valleys. The glacial cirques should not be confused with landslide cirques, which are also numerous in the Western Cascade Range. For instance, Tumble Lake, southeast of Sardine Mountain, lies in a glacial cirque, whereas the small lake northeast of Sardine Mountain was probably formed by a landslide. The lower limit of late Wisconsin ice in the Western Cascade Range was approximately 3,500 feet.

The valley of Elk Creek, southeast of Battle Ax Mountain was occupied by a Wisconsin glacier at least 4 miles long, which spilled over into the Humbug Creek drainage in two places. The ice extended down to about 3,600 feet in altitude through the western gap, south of Elk Lake, and down to 3,200 feet through the gap in which Dunlap Lake is perched. Glacial overflow of this type probably initiated major drainage changes in other parts of the Cascades. Two well preserved moraines were noted in Elk Lake valley; one forms the dam for the lake, and the other is a quarter-mile to the east below a meadow which represents a filled lake. The freshness of the moraines and small size of the delta in Elk Lake shows that the valley was glaciated during the last, or late Wisconsin stage.

PHYSIOGRAPHY

GENERAL RELATIONS

The physiographic dissimilarity between the Western Cascade and the High Cascade Ranges is no less pronounced than the structural discordance, especially from Outerson Mountain southward. The Western Cascade Range from Thomas Creek north may be divided into three longitudinal belts, namely: a western belt of dip slopes; a rugged central belt formed by the massive Sardine lava flows; and an eastern belt of comparatively open valleys formed with Breitenbush tuffs. These belts in general conform to the regional structures and trend northeast. The main streams flow westward across the range, and various features related to the stream history are common to all three belts. The High Cascades differ from the Western Cascades in that structurally controlled surfaces and glacial forms are dominant. The physiographic interrelations of the two ranges are complex, and erection of the High Cascades greatly affected the streams in the Western Cascades. Drainage changes have also occurred within the High Cascades.

WESTERN CASCADE RANGE

The three main physiographic divisions mentioned above are illustrated in the Mill City quadrangle. The belt of dip slopes is in the northwest corner of the quadrangle; the lava belt extends diagonally from the southwest corner toward Battle Ax Mountain, where it is buried by the High Cascade lavas; and the tuff belt occupies the southeastern corner of the area.

Western Belt of Dip Slopes

The belt of dip slopes extends northwestward to the Willamette Valley from the crest of the Mehama anticline, and extends northeastward beyond the Clackamas River. Below the 1,000 foot contour the dip slopes are formed on the Stayton lavas, which underlie a thin soil cover or small patches of Fern Ridge tuffs. Between altitudes of 1,000 and 2,000 feet sloping benches formed on the more resistent beds of the Fern Ridge tuffs are dominant (fig.4) and dip slopes on the tuffs attain an altitude of approximately 4,000 feet 8 to 10 miles north of Mill City, in the vicinity of House and Lookout Mountains. The Salem Hills are characterized by analogous surfaces developed on the eastward dipping Stayton lavas.

The degree of dissection of the structural surfaces varies greatly. The structurally flatter parts of the Salem Hills exhibit a rolling landscape which shows indistinct relation to structure, whereas cuesta topography is clearly developed where the lavas are tilted in the southern part of the hills. (Section B-B'). The structural surfaces are shown best north of the North Santiam River valley. The western face of the Salem Hills is an escarpment formed by erosion of the weak Illahe beds which underlie the resistent Stayton lavas.

Northeast of Stayton the stream valleys are practically parallel to the direction of dip of the beds, and are cut into and locally through, the Fern Ridge tuffs. The Stayton lavas have been cut through only near the Willamette Valley margin. The valleys are deepened in the lavas mainly by headward recession of waterfalls over individual flows. In this area there are many beautiful falls, of which Silver Falls is the highest and best known.

The Mehama volcanics are exposed under the Stayton lavas where the valleys of the North Santiam River and Thomas Creek cross the Mehama anticline. (Section D-D'). The tuffs are readily eroded and the capping Stayton lavas destroyed by landslides, with the result that both valleys widen rapidly eastward toward the crest of the fold. Where they enter the Sardine lava series the valleys become narrow again; they are widest just west of the anticlinal axis.

The change in character of the eastern boundary of the Willamette Valley at Thomas Creek likewise is related to the position of the Stayton lavas in the Mehama anticline. The Willamette River cuts across the anticline in a manner analogous to the North Santiam River, even though the two streams flow at right angles. North of Thomas Creek the Stayton lavas lie at low altitudes in the flank of the fold. Here they are secure from indirect attack by sapping, and removal must be by the slow processes of weathering and surface run-off. South of Thomas Creek the lavas are high enough above the Willamette Valley floor so that landslides develop, and destruction of the lavas is rapid. As a consequence, the eastern edge of the Willamette Valley south of Thomas Creek is an irregular steep erosion scarp, which has receded 3 to 5 miles east of the foot of the dip slopes farther north. The lava caps on hills like Franklin Butte, which lies south of the area mapped, are remnants of the Stayton lavas, and reveal the southward extension of the Mehama anticline.

The Stayton Basin

The Stayton Basin is a rudely triangular topographic and structural basin which has been breached by stream valleys at all three apices. The North Santiam River enters through the eastern apex and leaves by the southwestern; it also at times undoubtedly flowed through Mill Creek Gap at the northwestern corner. The floor of the basin is occupied by a gravelly alluvial fan built by the North Santiam River as it swung from one outlet to the other; this fan is so flat that the divide between Mill Creek and the river is less than 25 feet high.

The depth of gravel fill in the basin is not known although terraces along the northeast and southeast sides of the basin show ample evidence that it was formerly filled about 100 feet above the present floor. The terraces are best preserved southwest of Kingston, and the name "Leffler terraces", after the Southern Pacific station of that name, is suggested for them. Around Sublimity they have been eroded to such an extent that their original form has been obscured. The deposits have been removed from the foot of the Stayton lava dip slopes mainly by lateral planation of the North Santiam River and smaller streams.

The terrace deposits vary in coarseness from clays to cobble beds that contain well rounded boulders up to 15 inches in diameter. In road cuts north of Aumsville and Sublimity the gravels are deeply weathered, and all pebbles except vein quartz and rhyolite are decomposed to clay "ghosts". In the road cut 0.8 mile north of Sublimity the silts and pebbles have been so thoroughly weathered to a depth of about 15 feet that they could be used as second-grade fire clay 20/. In the uppermost 2 or 3 feet practically all traces of the original pebbles and bedding have been obliterated. Although the gravels overlie the Fern Ridge formation in places, the two formations are readily distinguished, since the Fern Ridge contains ash beds, and dips with the underlying Stayton lavas. The gravels appear to have been laid down by the North Santiam River during a period of extensive aggradation in the Willamette Valley as a whole, and are probably early or middle Pleistocene in age. The Leffler terraces may be equivalent in age to the 100 foot terraces south and east of Lyons, which very likely are composed of valley train material from the Mill City glacier.

Central Lava Belt

The central lava belt is underlain mainly by the Sardine lavas, and the topography is largely controlled by this formation. The western limit of the belt follows the crest of the Mehama anticline, and corresponds to the east edge of the belt of dip slopes. The eastern boundary follows the upturned base of the Sardine lavas. (Section F-F', between Mt. Horeb and Marten Buttes). The belt is 12 to 15 miles across, and has the highest relief of this portion of the Western Cascade Range. The relief ranges between 3,000 and 3,500 feet in distances of 1 to 2 miles; the maximum relief is nearly 4,000 feet. The higher ridges average between 4,000 and 4,500 feet in altitude, and the principal peaks are between 4,500 and 5,100 feet. The ridges are sharp crested and the valleys are narrow and steep-walled. Landslides are comparatively rare, and a few small glacial cirques occur at altitudes above 3,500 feet,on the northeast slopes of the highest peaks.

The North Santiam River is the only stream that crosses this belt in a distance of more than 40 miles. The Clackamas River tributaries to the north were superimposed across this zone from the High Cascade Battle Ax lavas. The South Santiam River flows far to the southwest and crosses the belt where it is lower. Water falling in the head of Kinney Creek runs northward 4 miles before it starts across the lava belt, whereas water falling on the south side of the same divide, in the South Santiam River drainage travels nearly 30 miles southwest before it crosses the lava belt.

20/ Wilson, Hewitt, and Treasher, R. C., Preliminary report of some of the refractory clays of western Oregon: Oregon State Department of Geology and Mineral Industries, Bull.6, p.61, 1938.

Eastern Tuff Belt

The belt of tuffs forms the eastern portion of the Western Cascade Range within the Mill City quadrangle. The area underlain by the tuffs is a rude triangle between the northeast-trending central lava belt and the north trending High Cascade Range. In the northeast corner of the Mill City quadrangle the tuffs appear to be buried completely by the High Cascade lavas; at the southern edge of the area the tuff belt is 10 to 12 miles wide.

The differences in form between the central lava belt and the belt of tuffs are those that would normally be found in adjoining areas which have had similar physiographic histories, but in which the rocks differ greatly in resistance to erosion. The ridges in the tuff belt are similar in altitude to those in the lava belt, but the valleys are wider. The relief is between 2,500 and 3,000 feet, or about 1000 feet less than in the Sardine lavas, since the general level of the streams, which head in the tuffs, is higher. The manner in which the main valleys widen out at the eastern edge of the lavas is well shown southeast of Quartzville, along the southern edge of the Mill City sheet, where the stream history apparently has not been complicated by valley flows of High Cascade lavas. Landslides are numerous. Hogback topography is developed on the steeply dipping beds in the ridge east of Detroit, but elsewhere there is little apparent relation between topography and structure.

High Cascade lavas dominate the topography where they overlie the tuffs. The High Cascade lavas for the most part are massive or platy, and commonly form cliffs 200 to 300 feet high. The flat-lying massive Outerson flows in the vicinity of Coffin Mountain stand 1,000 to 1,500 feet above the tuff ridges to the west, and form a conspicuous group of high peaks along the eastern margin of the Western Cascade Range. Thin flows give rise to very sharp crested ridges that are triangular in cross-section; Battle Ax Mountain and the ridge southwest of Elk Lake are good examples.

Uniformity of Ridge Crests

The skyline in the central lava and eastern tuff belts appears remarkably smooth when viewed from some high point, as for instance, the summit of Olallie Butte. The most prominent high points are Battle Ax Mountain and the peak of the Coffin Mountain group, all of which are composed of High Cascade lavas. From Olallie Butte, the valleys of the North Santiam River system are seen as deep trenches cut into the Western Cascade upland.

Although they are spread over an area of several hundred square miles the high peaks in the central lava belt, all on Sardine lavas, are between 4,500 and 5,100 feet in altitude. These high points are 500 to 700 feet above the main divides. In the tuff belt the uniformity is not so apparent, because the peaks are widely scattered. The Mill City topographic map likewise reveals uniformity of ridge crests and high points.

Some of the peaks which conform to the Western Cascade Range are formed by High Cascade lavas. Those ridges in the vicinity of Battle Ax Mountain that are capped by Battle Ax lavas are good examples. From topography alone, one would have little reason to suspect the existence of the ancient Battle Ax volcano deep within the Western Cascade Range. Battle Ax Mountain itself is the only point which stands above the 5,100 foot skyline level, and it is 5,547 feet in altitude. The ridges capped by Battle Ax lavas are between 4,500 and 5,200 feet in altitude, and when seen from a distance of 5 or 10 miles blend into the general skyline. How many other Western Cascade ridges may be capped by lavas of High Cascade age is a question that can be answered only by extensive field mapping.

HIGH CASCADE RANGE.

In the High Cascade Range the topography is controlled directly, and in most places, obviously, by the structure of the lavas. Initial surfaces are preserved on the Recent lava flows, and stripped surfaces on the older lavas dominate the range.

South of Park Butte the High Cascade Range is essentially a pile of lavas, triangular in east-west cross-section, and deeply trenched by broad "V" shaped glaciated valleys. The slopes are uniform eastward and westward from the divide, which averages approximately 6,000 feet in altitude and is about 7 miles east of the western base of the range. The dissection of the volcanics has not progressed past a youthful stage, and the ridges are generally flat topped. The broader spurs like Minto Mountain slope 2 to 3 degrees westward and are characterized by glaciated high flats. Mt. Jefferson rises nearly a mile above the High Cascade Range divide, and has been severely eroded by glaciers, remnants of which are still active. The steep slopes of Mt. Jefferson present a striking contrast to the flat spurs formed on the Minto lavas.

North of Park Butte the High Cascade Range crest widens and assumes the aspect of a plateau. This plateau slopes from 6,500 feet in altitude near Park Butte to approximately 3,500 feet at Clackamas Meadows, 27 miles to the north. In the vicinity of Olallie Butte the relief of the plateau, excepting Olallie Butte, is about 500 feet, with a few hills as much as 1000 feet high. Intense glaciation is apparent everywhere, and lakes dot the landscape. But for the valleys of Cub Creek and the North Fork of the Breitenbush River, this part of the High Cascade upland would be a north to northwest sloping surface nearly 10 miles wide occupying the area between Breitenbush Hot Springs and Olallie Butte. The maximum relief in this area of nearly 50 square miles, which averages more than 5,000 feet in altitude, would be approximately 1,000 feet.

Olallie Butte is a young cone built up on the plateau before the last glacial stage, whereas many of the smaller peaks like Pyramid Butte are plugs from which the effusive covering has been stripped.

RELATIONS OF WESTERN AND HIGH CASCADE RANGES.

In places the physiographic boundary between the Western and the High Cascade Ranges is pronounced, and in other places no boundary is visible. Moreover, the physiographic boundary does not coincide everywhere with the geologic boundary.

South of the Santiam Elbow the valley of the North Santiam River follows the broad Santiam-McKenzie trough, between the western slopes of the High Cascades and the eastern face of the Western Cascades. The Santiam-McKenzie structural trough probably terminated northward at a high ridge between Mt. Bruno and Minto Mountain (the Bruno-Minto ridge), for the present surface of the Minto lavas is 1,600 feet higher in Minto Mountain than at the McKenzie-North Santiam drainage divide, and this difference seems to be a reflection of the dip in the lavas. The river valley is a north-south glaciated trough entrenched in the bottom of the larger structure along the line of intersections of the surfaces on the Minto and Outerson volcanics to the east and west, respectively. For a distance of about 15 miles, before it turns eastward toward the High Cascade divide, the North Santiam River bears the same relation to the western slopes of the High Cascades that a gutter does to a roof. The broad physiographic and structural trough continues southward beyond the North Santiam drainage and is followed by the McKenzie River nearly 20 miles. The divide between the two streams is very broad and low. If the Santiam-McKenzie trough is accepted as the logical High Cascade-Western Cascade boundary, the Outerson volcanics in the vicinity of Coffin Mountain, like the Battle Ax lavas, physiographically are part of the Western Cascade Range even though they are High Cascade flows.

North of the Breitenbush River no distinct physiographic boundary was found between the Western Cascades and High Cascades. The Breitenbush River valley cuts directly across the geologic contact ranges, and the divide to the north continues practically unbroken from one part of the range to the other. In the area to the north the dissected western edge of the High Cascade plateau has the same general altitude as the Western Cascade summit level, and the ridges merge. The valley of the Collowash River, a tributary of the Clackamas River, probably follows the geologic boundary northward from the divide north of the Breitenbush River. The High Cascade boundary between the North Santiam and Breitenbush Rivers follows the western edge of the Outerson volcanics in the vicinity of Outerson Mountain and is crossed by the Santiam basalts.

VALLEY OF THE NORTH SANTIAM RIVER.

The North Santiam River system heads on the western slopes of the High Cascades and flows westward across the Western Cascades. Since the river crosses several structural and physiographic belts, its valley varies greatly in different parts. Furthermore, the region has undergone a long physiographic history, and the stream has been greatly affected by regional uplift and volcanism.

The North Santiam River emerges from the Western Cascade Range much as a railroad leaves a cut in a gentle hillside; the valley is analogous to the railroad-grade, and the Stayton lava dip slopes may be compared to the hillside. The gravels in the Stayton basin are analogous to the railroad fill. West of Gates the valley is flat-floored and steep-walled, as if lateral planation had been active recently. The valley bottom averages a mile to a mile and a half in width between Stayton and Gates, and narrows where it crosses the lavas near Stayton. The floor is veneered with gravel and there are several terraces from 5 to 25 feet high. The river has cut through the gravel veneer, and beginning at a point a mile west of Mehama has cut a narrow trench that gradually increases in depth eastward to the mouth of the gorge east of Niagara. At Mehama the river bed is 20 to 25 feet below the main valley level, and at Gates it is incised about 50 feet. South of Gates there is also a terrace approximately 125 feet above the river; the 50 foot terrace is cut across tilted lava flows east of Gates.

The most conspicuous terrace remnants extend discontinuously along the south side of the valley for a distance of nearly 7 miles opposite Mehama. This terrace, called the Lyons terrace, is 80 to 100 feet high and $\frac{1}{4}$ to $\frac{1}{2}$ mile wide south of Lyons. Farther east the Lyons terrace is preserved as a narrow rock cut bench covered by a thin layer of gravel. Deep soil has been developed on, and the slopes above are graded to, the Lyons terrace, indicating that it is a good deal older than the lower terrace.

High Broad Valley Stage

Remnants of a high valley stage are well preserved along the North Santiam River west of Sardine Mountain (fig.6). They are not particularly noticeable from the lower part of the valley, but they are conspicuous when seen from Sardine Mountain or the prominent spur at 2,000 feet elevation north of Minto station (fig.3). The spurs on both sides of the valley are concave upward above 2,000 feet in the vicinity of Niagara. Below that level they slope steeply to the river, which flows in the bottom of a sharp "V" valley. The higher valley rises eastward and is not certainly identifiable in the gorge east of Sardine Creek, although it may be represented by the prominent spurs south of the river between Cumley and Box Canyon creeks, and between 2,000 and 2,500 feet in altitude. The saddle at 1,700 feet southeast of the Potato Hill, southeast of Gates, is only a little above the broad valley level which drops to about 1,500 feet in the ridge north of Mill City. A corresponding broad valley stage is shown above 1,500 feet elevation in the valley of the Little North Santiam River west of Elkhorn.

Projection of the high valley profile westward as a normal concave river profile suggests that the perched flat northwest of Mehama is closely related to the high valley stage. This flat is about a mile wide and 2 miles long, and lies at an altitude of 900 to 1,000 feet, or 300 to 400 feet above the North Santiam River. It is partially dissected by several small westward flowing streams, but still has the form of a flat floored valley that was made by the lateral planation of a graded stream of considerable size. Although the flat was cut in resistent Stayton lavas, it is nearly as wide as the present floor of the North Santiam River. It is almost in line with the Little North Santiam River valley, and formerly may have been part of that valley.

If the perched flat west of Mehama was part of the old broad valley system, the ancient stream fell about 900 feet between Sardine Creek and Mehama, or approximately 45 feet per mile. The present river has a total fall of 550 feet, or about 28 feet per mile between the same points. The higher gradient and the rounder profile of the ancient valley would mean that it was formed by a smaller stream than the North Santiam River, and that side tributaries had a more important part in shaping the valley than they do now.

The Santiam Gorge

Between Niagara and Halls the North Santiam River flows through a narrow, rock walled gorge. For much of this distance the stream runs in a slot in bedrock and seems to be cutting down rapidly. The gorge apparently is caused by the extreme erosional resistance of the metamorphosed volcanics and the Halls diorite. East of Halls the valley broadens out into the Detroit Basin.

The Detroit Basin

The basin at Detroit presents an interesting physiographic problem. The North Santiam and Breitenbush rivers enter the basin from the southeast and northeast, respectively, in narrow valleys without perceptible change in grade. The Breitenbush River follows, in general, a straight course through the basin, whereas the North Santiam makes a right angle turn as it enters. In contrast to the narrow valleys upstream, the basin is more than a mile wide at the northeastern end and narrows southwestward toward the gorge. Detroit Hill is an elongate bedrock ridge 700 feet high and 2,100 feet in altitude that occupies the center of the basin. The North Santiam River flows southeast of Detroit Hill through a glaciated trough about one-third mile wide and cut 200 to 300 feet below a broad bedrock bench which was probably left from an earlier erosion cycle. The summit of Detroit Hill slopes southeastward and evidently was once part of the same erosion surface as the bench, which extends along the base of Blowout Cliff. The Breitenbush River flows northwest of Detroit Hill, and there is little if any evidence of the old valley stage along that side of the basin. The gap northeast of Detroit Hill and between the two rivers is filled with river gravels down to stream level. On the northwest slopes of the basin there are terrace remnants at altitudes of 1650 and 2,800 feet, or 350 and 1,500 feet, respectively, above the river. Boulders of High Cascade lavas are found on both terraces, which slope southward 2 or 3 degrees. Tumble Creek was diverted a quarter-mile southward behind the lower one; the upper terrace crosses Tumble Creek valley but does not extend up it.

The origin of the basin is obscure. The basin lies east of the metamorphosed zone in the gorge, and has been eroded mainly out of the Sardine lavas. It is much wider than either of the tributary valleys immediately to the east, although these are cut in the Breitenbush tuffs. Although glacial scour may have been largely responsible for its formation, the basin is probably the product of several factors, none of which is apparent individually.

One possible explanation for the origin of the Detroit Basin is as follows: Detroit Hill may have been part of a long and relatively low divide between the North Santiam and Breitenbush rivers, which presumably joined about where they do now. The Mill City glacier undoubtedly overrode Detroit Hill, which is a roche moutonnee, and the 2,800 terrace on the northwest side of the basin may mark the upper ice limit. The powerful North Santiam branch of the Mill City glacier was forced to turn abruptly southwestward, and the pressure was apparently sufficient to cause the main glacier to override the divide and impinge on the west wall of the Breitenbush River valley. A smaller ice stream probably flowed down the east side of the old divide. The later and weaker Detroit glacier may have been deflected east of Detroit Hill by Mill City deposits left in the gap to the northeast, or by a glacier from the Breitenbush River valley.

North Santiam River East of Detroit

The North Santiam River valley is constricted at its entrance into the Detroit Basin, apparently by lava flows at the base of the Sardine lavas. From this point nearly to the Elbow, the valley is in the Breitenbush tuffs and is comparatively open. From Boulder Creek east the Santiam basalts form steep cliffs surmounted by benches along the north side of the valley. The flat on upper basalt surface attains a maximum width of nearly 2 miles in the vicinity of Pigeon Prairies, and narrows rapidly to east and west. West of the Elbow the valley bottom is narrow and the flood plain is restricted, whereas south of the Elbow the floor has been flooded with glacio-fluviatile debris and terraces up to $\frac{1}{2}$ mile wide have been formed. This change in the character of the valley floor occurs in the vicinity of the Tunnel Creek moraine and seems to be due to the late Wisconsin glacier.

Valley of the Breitenbush River

The Breitenbush River flows on bedrock in a very narrow valley most of the way between the Detroit Basin and Breitenbush Hot Springs. The lower 4 miles of the valley is a gorge 1,000 to 1,500 feet deep. The south wall of this part is marked by inclined ribs on tilted resistent beds and lavas in the Breitenbush tuffs, and the north wall is characterized by high cliffs of the Battle Ax lavas. The valley widens at the junction with Humbug Creek, and from there to the Hot Springs lies in a shallow gorge cut entirely in the Breitenbush formation and underlying rhyolites. East of Humbug Creek there is obscure evidence of a broad valley stage at about 2,500 feet altitude, 600 to 700 feet above the river. This shallower part of the Breitenbush River gorge opens eastward into the Breitenbush Basin.

The Breitenbush Basin is an intermontane valley whose aggraded floor is 2 miles long and a mile wide. The basin straddles the geologic boundary between the Western Cascade and High Cascade Ranges, at the junction of the two main branches of the Breitenbush River, namely: the North and South Forks. The valleys of both forks have been severely glaciated, and the floor of the North Fork valley is continuous with the floor of the basin; a short gorge marks the mouth of the South Fork.

The Breitenbush Basin has been excavated mainly in the Breitenbush formation, and the western edge of the High Cascade Range has been eroded to a lesser extent. The High Cascade lavas, of Outerson and Minto ages, form steep ridges in which cliffs 50 to 100 feet in height are common. The tuffs, in contrast, are so easily weathered that exposures are rare except in stream banks. Landslides are common and landsliding is still in progress in an area of about 5 square miles southwest of Breitenbush Hot Springs, where blocks of Outerson lavas have slid over 2 miles from Timber Butte to the river. Landslides have undoubtedly been an important factor in the formation of the basin, and account for the location of the basin in the tuffs.

The North Fork has beheaded Cub Creek, a tributary of the Clackamas River. The Cub Creek valley has a flat floor a mile in width where it ends abruptly nearly 800 feet above the North Fork. At the head of Cub Creek the North Fork turns an angle of 60 degrees, and flows southeastward along the extension of Cub Creek. A broad bench on the northeast side of the North Fork valley forms a continuous link between the Cub Creek valley level and the upland surface in the vicinity of Breitenbush Lake. The North Fork is now cutting a gorge nearly 1,000 feet deep into the upland.

GEOLOGIC AND PHYSIOGRAPHIC HISTORY

OLIGOCENE AND MIOCENE EPOCHS.

Although the geologic history of the Oregon Cascade Range is complicated in detail, because of intermittent volcanism, diastrophism, and glaciation, it is comparatively simple in general outline.

Little is known of the Cascade region in Eocene time, and the geologic record as deciphered in the North Santiam River region begins with explosive volcanic eruptions in the Oligocene, when the Breitenbush tuffs were deposited. Some of the ash from the Breitenbush eruptions was probably carried by wind into eastern

Oregon and deposited with the John Day formation, while streams carried much debris westward to the ocean, where it was laid down as the Illahe formation. The waste piled along the aggraded western margin of the chain of volcanoes is now recognized as the Mehama volcanics. Toward the end of Oligocene time the region was gently folded along northeast-southwest axes, and the Willamette Valley region was elevated above sea level. After an erosion interval the Stayton lavas were erupted in Miocene time along the western margin of the range; within the range volcanism obscured the record and no break is apparent between the Breitenbush tuffs and the Sardine lavas. The Miocene volcanic activity was less violent than the earlier phases, and the Stayton and Sardine lavas were extruded, probably from fissures, at the same time the region to the east was flooded by the Columbia River lavas. The Sardine lavas accumulated to a depth of at least 6,000 feet before eruptions ceased. The Sardine lavas thinned rapidly eastward and westward, and their erosional products, intermingled with tuffs from explosive eruptions, were deposited to the west in the Fern Ridge formation. Toward the end of Miocene time the volcanic activity died down, and the region was again folded. The thick massive lavas bent only slightly, but the weaker tuffs were buckled into the Breitenbush anticline. Intrusion of diorite porphyry probably closely followed the folding, and then the range was subjected to a long erosion period which probably was marked by a series of uplifts. By the time the first High Cascade lavas were erupted the Western Cascade Range had attained essentially its present elevation and was maturely eroded. This erosion surface must have been continuous with the Coriba Surface, which has been described in the Columbia River region by Hodge 21/.

PLIOCENE AND PLEISTOCENE EPOCHS.

Although the form of the Cascade Mountains in Miocene and earlier times is relatively unknown, the record of the rocks reveals many events since the Western Cascades became a distinct mountain range, probably near the end of the Miocene.

The "Cascade Peneplain"

Since uniformity of ridge crests is widely accepted as one of the criteria for recognition of elevated ancient erosion surfaces, early investigators in the Cascade Mountains were led to believe that except for the high peaks, the entire range, including the part in Oregon, had been peneplained in late Tertiary time. Willis and G.O.Smith described ancient erosion surfaces in the Northern Cascades in Washington 22/, and it was thought by some that these surfaces were represented in the Oregon Cascades 23/. W. D. Smith suggested that the slopes northeast of Stayton may represent part of a warped peneplain.24/.

It seems clear that the High Cascade Range has never been worn down to a surface of low relief, yet the postulated peneplain on the Western Cascade Range must have extended across the High Cascade Battle Ax lavas. The evenness of the ridges

21/ Hodge, E. T., op.cit., p.853-860.

22/ Smith, G. O., and Willis, B., Contributions to the geology of Washington: U.S. Geological Survey, Prof. Paper 19, 1903.

23/ Fenneman, N. F., Physiography of the western United States: McGraw-Hill Book Co., New York, p.430-441, 1931.

24/ Smith, W. D., Physical and economic geography of Oregon; the Willamette Valley: Commonwealth Review, Univ. of Oregon, vol.7, no.4, p.158, 1925.

in the Western Cascades therefore appears to have originated from action of a uniformly well developed stream pattern on a comparatively homogeneous mass, rather than from dissection of an ancient erosion surface. The basis for this inference is the fact that Battle Ax volcano was reduced almost to the general summit level while the entire region evidently stood at essentially its present elevation. It has already been shown that the Battle Ax lavas were erupted on a Western Cascade surface whose relief probably exceeded 3,000 feet, thus proving that the range stood high in pre-Battle Ax time. No evidence has yet been found suggesting that this entire region was depressed approximately 3,500 feet and re-elevated during High Cascade time. If the Western Cascade skyline represents a widespread ancient erosion surface which extended across High Cascade lavas, movements of the magnitude indicated must have occurred in post-Battle Ax time. Moreover, these movements must have been separated by a very long period of erosion.

Broad Valley Stages of the North Santiam River

The degradation of the North Santiam River to its present level was a long process which probably was interrupted by many periods of stationary level or of aggradation. One period of extensive lateral planation at a grade between 400 and 500 feet above the present river level is shown by the perched flat northwest of Mehama. The flat appears to be a remnant of the old valley of the Little North Santiam River, and was probably formed when that stream meandered on a broad flood plain. While the Little North Santiam was forming its flood plain the North Santiam was meandering on a similar, but probably somewhat wider and lower flood plain, since it was a larger stream. At a point somewhere in the vicinity of Mehama one of the streams in its meandering cut through the divide and the two streams were joined. Technically speaking, the Little North Santiam River was intercised, and was shortened 4 or 5 miles. The intercision may have occurred in the early Pleistocene and long antedated the Mill City glacier. The width of the perched valley segment, especially since the excavation was almost entirely in Stayton basalt, indicates a long halt in downward cutting. The intercision took place in the Mehama volcanics where lateral planation must have been much faster. The altitude of the old valley suggests that the region was elevated about 500 feet in early Pleistocene (or Late Pliocene?) time.

The high broad valley stage west of Sardine Mountain, the perched flat northwest of Mehama, and the pre-Battle Ax valley of the Breitenbush River may have been formed simultaneously as 3 segments of one valley. The apparent close relation between the western and middle segments has been indicated. If the broad valley segment west of Sardine Mountain were projected headward 10 miles on its apparent gradient of 45 feet per mile, the valley bottom would be at least 200 feet above the base of the Battle Ax lavas. Actually the river profile must have steepened headward, and moreover, the base of the lavas may have been lower. Therefore, if these two segments are equivalent, the old valley was warped during uplift or was rejuvenated in pre-Battle Ax time. The narrow inner valley under the Battle Ax flows, east of Canyon Creek, indicates that the valley was rejuvenated, and it may have been warped as well. This interpretation implies that the inner gorge east of Niagara and the modern gorge in the Breitenbush River valley east of Detroit were cut nearly simultaneously. When the size of the streams and the hardness of the rocks is considered this hypothesis does not seem unreasonable.

The low broad valley stage shown along the southeast side of the Detroit Basin may be equivalent to the pre-Santiam basalt valley. The pre-Santiam basalt valley is cut partly in Minto lavas, therefore is probably younger than the pre-Battle Ax valley. The gradient between the base of the Santiam basalts at Boulder Creek and the surface in the Detroit Basin is almost the same as that of the North Santiam River. This low broad valley stage has not been recognized elsewhere along the North Santiam River, and may have been formed above a temporary base level in the gorge west of Halls.

Changes in Drainage Caused by High Cascade Eruptions

The eruption of the High Cascade volcanics not only buried the old topography in the region now occupied by the High Cascade Range, causing complete reorganization of the local stream pattern, but also must have greatly affected many streams in the Western Cascade Range.

In late pre-High Cascade time the Western Cascade Range appears to have been a maturely eroded mountain mass with a relief similar to that of the present range. The ancient range was bounded on the east by an irregular front with outliers which stood above the lower landscape of eastern Oregon. In places, as in the vicinity of Breitenbush Hot Springs, the eastern boundary seems to have been comparatively straight and scarp-like. The drainage divide was many miles east of the center of the range, and the streams on the eastern slope were short. These eastward-flowing creeks were probably tributary to rivers which flowed north or south to antecedent valleys across the range. The ancestral Columbia River described by Hodge 25/ was apparently one of the antecedent master streams of the region. However, when the mountains were lower the rainfall in the region to the east was probably heavier, and many rivers may have maintained courses across the Western Cascade uplift.

The building of the High Cascade Range not only buried the eastern margin of the Western Cascade Range, but it also shifted the regional drainage divide several miles east of the Western Cascades (fig.8-I and 8-II). All antecedent valleys across the Western Cascades were blocked, and the new streams that rose on the western slopes of the High Cascades found courses across the Western Cascades.

Headward Lengthening of the Breitenbush River.

The history of the Breitenbush River has in all likelihood been duplicated by many other streams in the Cascades, and on that account merits detailed discussion. The pre-Battle Ax Breitenbush River, which for convenience will be called the Humbug River, headed east of Battle Ax Mountain, possibly near the head of East Humbug Creek. The dips in the Outerson lavas on both sides of the Breitenbush Basin indicate that they were poured out on a continuous eastward-sloping surface, and that the basin was formed later. It seems likely, therefore, that the pre-Outerson divide lay 2 or 3 miles west of the site of Breitenbush Hot Springs.

The Outerson lavas probably affected Humbug River very little, because they were poured out on the eastern slope of the range, but the Minto and Battle Ax eruptions caused profound changes. The Battle Ax lavas filled the lower part of the valley, and established a radial stream pattern in the vicinity of Battle Ax Mountain. Although these lavas must have flowed down the valley into the portion now occupied by the Detroit Basin, none have been found in place in the basin. The flows from Mt. Minto, whose crater was near Park Butte, rose nearly to the level of the Western Cascade divide, if they did not flow through low gaps in it. One of

25/ Hodge, E.T., Geology of the Lower Columbia River: Geol.Soc.America, Bull., vol.49, p.848-860, 1938.

the consequent streams on the northwest slope of Mt. Minto, the modern South Fork of the Breitenbush, spilled over the low divide, either on Minto lava or by ponding, into the Humbug River. The Humbug River was thereby lengthened a dozen miles, increased greatly in flow, and the ancestral Breitenbush River was born. The Cub Creek piracy increased the size of the river still more. The modern Breitenbush River probably is twice as large as the ancient Humbug River, since the Western and High Cascade portions of the Breitenbush watershed are approximately 40 and 50 square miles in area, respectively.

The North Santiam River was similarly increased in length and volume. The watershed of the North Santiam River system was enlarged by 300 to 400 square miles, in a region of heavy rainfall, as a result of the Minto eruptions. The principal changes effected in the lower portions of the valley by the increased flow must have been oversteepening of the valley walls and aggradation of the valley floor with coarse debris.

The North Santiam valley west of Minto Station may reflect the difference in character of the ancient and modern streams. The remnants of the high valley stage give the impression of a rounded valley which probably had a narrow flood plain, especially in the portion just west of the present gorge. The later valley is marked by steep walls which form a sharp angle with the valley floor. The ancient valley was apparently formed by a smaller stream system in which work of the minor side tributaries was very important, whereas the modern one was cut mainly by lateral planation of a vigorous through-flowing stream whose side branches were pressed to maintain grade. Most of the planation, however, is later than the Mill City glaciation, and was in all likelihood done mainly by glacial melt-water.

Five streams in a distance of 180 miles cross the Western Cascades and head on the western slopes of the High Cascades. They are: the Clackamas, the North Santiam, the McKenzie, the Middle Fork of the Willamette, the North Umpqua, and the Rogue rivers. All of them now are in a sense compound streams similar to the North Santiam, which is in part superimposed, and whose consequent portions may be of greatly different ages. The trunks of some of the other streams may be antecedent instead of consequent. The building up of the High Cascades shifted the drainage divide eastward (fig. 6B), so all of the five streams which did not cross the Western Cascades originally were lengthened; those that did cross may have been shortened.

The watersheds of the streams that were extended onto the High Cascade Range were greatly enlarged in regions of heavy precipitation, and the flow of the affected streams must have been materially increased. The later history of all these valleys has been so complicated by glaciation, and the drainage changes occurred so long ago that the pre-High Cascade valley profiles have been destroyed or obscured.

The increase in flow of the North Santiam River during Minto time must be considered in determining the age of the ancient high valley stage. The ancient mature valley must have been eroded by a much weaker stream than the present one, and the time required for erosion must have been proportionately longer. In other words, the post-Battle Ax gorge of the Breitenbush River must have been cut in a small fraction of the time needed by the Humbug River to erode the pre-Battle Ax valley, and the pre-Battle Ax erosion period must have been far longer than all of post-Battle-Ax (and Minto?) time.

Changes in Drainage within the High Cascades

The drainage history of the High Cascades, like that of most volcanic regions, is complex. Valleys cut in the Outerson volcanics and Western Cascade rocks were filled by Minto lavas, and the valleys in the Minto lavas were filled or partially filled in turn by Santiam or Olallie lavas. Only the more obvious disturbances of the stream pattern can be discussed here.

In Minto and early post-Minto time the McKenzie River probably headed on the south slope of the Bruno-Minto structural ridge, 15 miles north of its present head at Fish Lake. The North Santiam River then probably headed on the north slopes of the same ridge. It would appear that the North Santiam later cut through the ridge by a combination of superimposition and headward erosion, and beheaded the McKenzie. The McKenzie River must have had a very low gradient because of its length, and the North Santiam River a rather steep one, so that headward erosion by the latter was rapid. However, glaciation must have also played a great part in the beheading of the McKenzie.

The McKenzie and North Santiam river valleys were the only large outlets to the west for glaciers from the western slopes of the High Cascades between Mt. Jefferson and the Three Sisters. Therefore the north-south Santiam-McKenzie trough must have been filled with ice during the Detroit, Mill City and any earlier glacial stages. Low gaps west of the trough, like the one between the Three Pyramids and Fisher Point in the southeast corner of the Mill City quadrangle, probably only partially relieved the ice pressure, so that two main glaciers were formed, one moving north and the other south, from an indeterminate point near the present Fish Lake divide. Once the Bruno-Minto ridge was breached by the northward-moving glacier, it was rapidly cut through. The North Santiam River was established in its present course and at nearly its present grade before the Santiam basalts were poured out.

Eruption of the Santiam basalts must have ponded the North Santiam River south of the Elbow, and may have shifted the divide northward to the Elbow. The altitude of the top of the Santiam basalts is practically the same as that of the present McKenzie divide north of Fish Lake, which is an area covered by Recent lava flows. If the present divide has been appreciably raised by Recent flows, it is probably safe to assume that the Santiam basalts reversed the flow of the North Santiam River south of the Elbow; if Minto lavas form the divide the reversal may not have taken place. If the river was completely dammed by the Santiam lavas, glaciers reestablished the northward course of the stream, in pre-Wisconsin time. The North Santiam River south of Minto Mountain has probably been reversed at least once, and may have been reversed three times.

Glaciers probably also contributed to the piracy of Cub Creek. The High Cascades have doubtless been subjected to intermittent glaciation ever since they were built in Minto time. Therefore it is reasonable to suppose that glacial overflow like that shown south of Elk Lake actually accomplished the diversion, after headward stream erosion and glaciation together had reduced the inter-stream ridge (fig.8-III and 8-IV). The amount of down-cutting since capture suggests that Cub Creek was beheaded in pre-Wisconsin time, possibly during the Detroit glaciation.

The Pleistocene history of the lower portion of the North Santiam River was marked by periods of aggradation and down-cutting probably related to glacial and

and interglacial stages. The Willamette River, as base level for the North Santiam, exerted a great influence on the latter, and the histories of these two streams, along with that of all the other large tributaries of the Willamette, will have to be worked out together.

The Mill City glacier is the earliest one of which any evidence has been found locally. Its terminus lay not far east of Mehama, and the valley from there westward was undoubtedly choked with valley train debris. Since the retreat of the Mill City glacier, the river has cut down more than 100 feet and planed off a valley floor exceeding a mile in width. The Lyons and Leffler terraces may tentatively be regarded as remnants of the Mill City valley train, although they may be much older. The bottom of the Santiam gorge has been cut down far enough to destroy any glacial profile left by the Mill City ice. The latest trenching from Mehama eastward to the gorge may have been caused by slight regional tilting, or by a decrease in the river gradient resulting from altered volume and decreased load.

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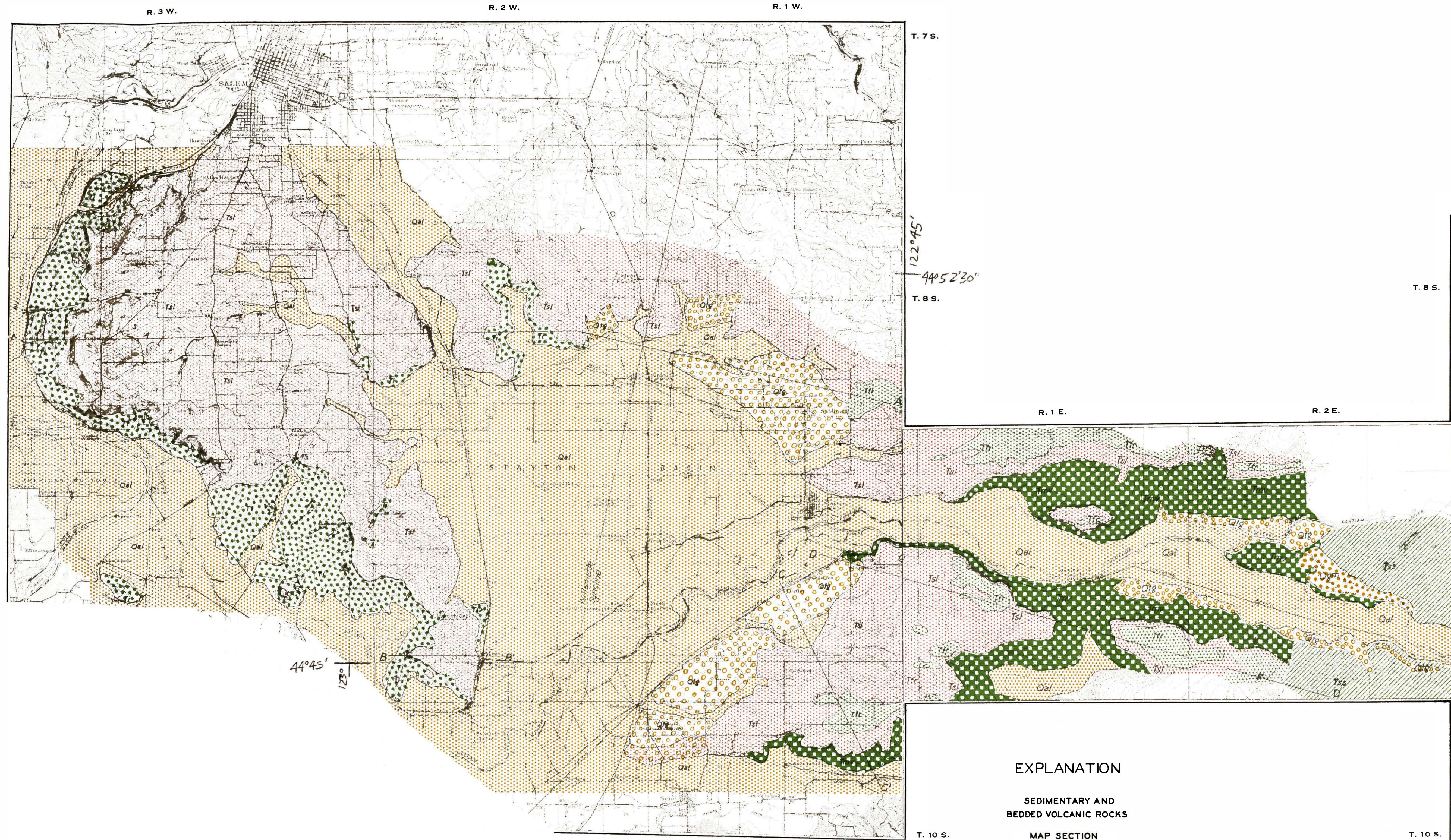
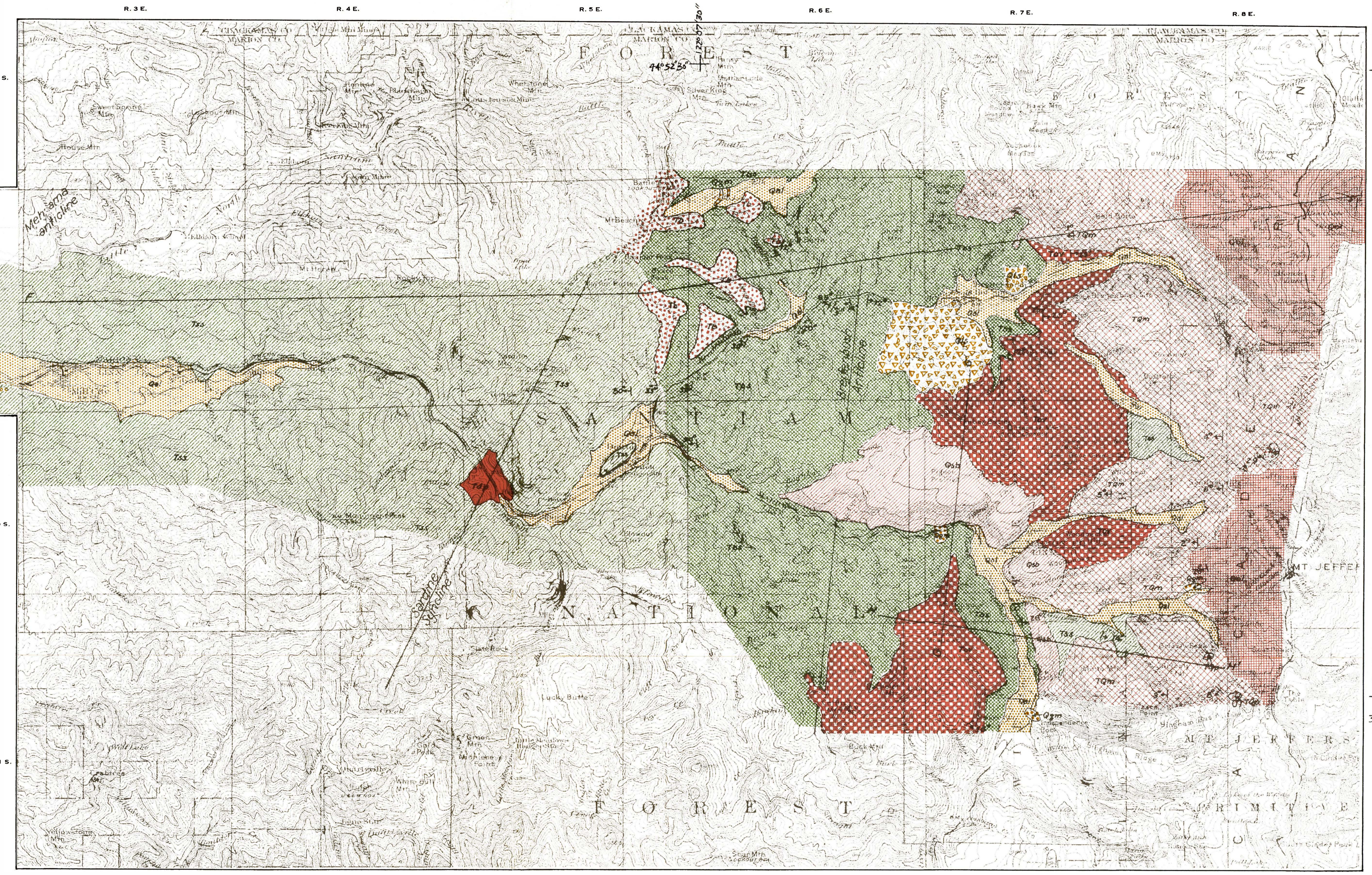
19	Dredging of Farmland in Oregon: F. W. Libbey	0.40

Miscellaneous Publications

	Price
Short Papers; No. 1, Preliminary Report upon Oregon Saline Lakes: O. F. Stafford	$0.10
The Ore.-Bin: staff, issued monthly, as a medium for news items about the Department, mines and minerals	Free
Geologic Map of the Medford Quadrangle	0.25
List of Mines in Oregon	0.25

Oregon Bureau of Mines and Geology

	Price
Ore Deposits of Northeastern Oregon: A. M. Swartley, 1914	$0.50
Report on Oil & Gas Possibilities of Eastern Oregon: John P. Buwalda, 1921	0.25
The Limonite Iron Ores of Columbia County, Oregon: Ira A. Williams, 1923	0.10
Economic Geological Resources of Oregon, 1912	0.25
Road Materials in the Willamette Valley, 1912	0.05

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
329 S.W. OAK STREET
PORTLAND, OREGON

GEOLOGIC MAP of SALEM HILLS and the NORTH SANTIAM RIVER BASIN, OREGON

TO ACCOMPANY BULLETIN No. 15

BY

T. P. THAYER

APPROXIMATE MEAN DECLINATION, 1926

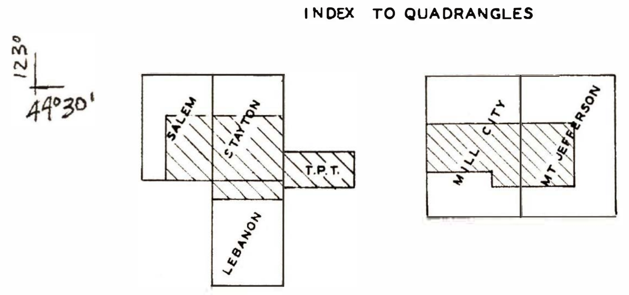
SCALE

1 ½ 0 1 2 3 4 5 Miles

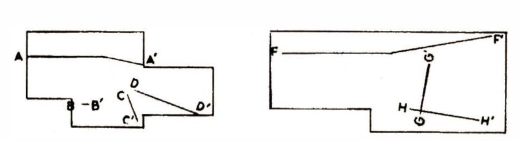
1 ½ 0 1 2 3 4 5 Kilometers

TOPOGRAPHIC BASE BY U.S.G.S & T. P. THAYER

INDEX TO QUADRANGLES



SECTIONS



EXPLANATION

SEDIMENTARY AND BEDDED VOLCANIC ROCKS

MAP SECTION

Qal	ALLUVIUM	RECENT
Qls	LANDSLIDE	RECENT
Qtg	TERRACE GRAVELS	PLEISTOCENE
Qgm	GLACIAL MORAINE	PLEISTOCENE
Qsb	SANTIAM BASALTS	PLEISTOCENE
Qol	OLALLIE LAVAS	PLEISTOCENE
TQm	MINTO LAVAS	PLIOCENE-PLEISTOCENE
Tb	BATTLE AX LAVAS	PLIOCENE-PLEISTOCENE
Tov	OUTERSON VOLCANICS	PLIOCENE
Tfr	FERN RIDGE TUFFS	MIOCENE
Tsl	STAYTON LAVAS	MIOCENE
Tss	SARDINE SERIES	OLIGOCENE-MIOCENE
Tbs	BREITENBUSH TUFFS	OLIGOCENE-MIOCENE
Ti	ILLAHE FORMATION	OLIGOCENE
Tmv	MEHAMA VOLCANICS	OLIGOCENE

INTRUSIVE IGNEOUS ROCKS

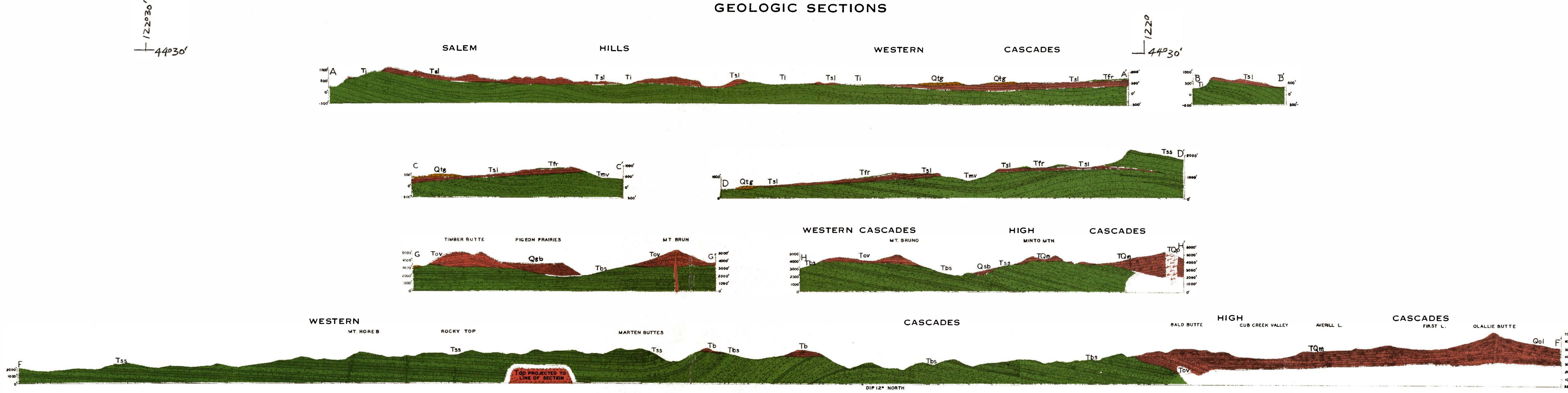
TQp	MINTO VOLCANIC PLUGS	PLIOCENE-PLEISTOCENE
Tdp	DIORITE PORPHYRY	UPPER MIOCENE

14° DIP AND STRIKE OF BEDS

6° APPARENT DIP OF LAVAS

UNCERTAIN BOUNDARY

GEOLOGIC SECTIONS



BUSHONG PROCESS, PORTLAND, OREGON