Late Quaternary sediments in the Willamette Valley, Oregon, include a unit of chiefly silt and fine sand, the Willamette Silt Formation. Previous workers have

(1) Assigned the Willamette Silt different ages which range from Sangamon interglacial to late Wisconsin glacial,

(2) Proposed that the Willamette Silt was deposited in a ponded body of water which was produced by

(a) a tectonic rise in sea level,

(b) icejam dams,

(c) a eustatic rise in sea level, or

(d) a "hydraulic dam",

(3) Attributed the Willamette Silt to

(a) one catastrophic flood--the Spokane Flood--in the Columbia River Valley,

(b) "normal" Columbia River floods supplemented by
locally derived sediments, or

(c) multiple large Columbia River floods.

The petrography and stratigraphy of the Willamette Silt and the geomorphology of the Willamette Silt surface have been investigated in the north Willamette Valley. The results of these investigations and the results of a radiocarbon dating program provide data for a new interpretation of the nature and sequence of late Quaternary geologic events in the Willamette and Columbia Valleys.

Petrography establishes:

(1) that the Willamette Silt was not derived from the local Willamette Valley provenance,

(2) that sediments mineralogically similar to the Willamette Silt are present in the Columbia Valley and in the Yakima and Walla Walla Valleys of southeastern Washington, and

(3) that the Willamette Silt contains no more locally derived heavy minerals than Columbia River sediment contains.

Stratigraphy indicates:

(1) that the Willamette Silt unconformably overlies weathered Tertiary bedrock and older Quaternary glacial outwash on the valley margins,

(2) that the silt conformably overlies locally derived fluvial-lacustrine sediments in deep central parts of the valley and conformably overlies young glacio-fluvial fan gravels,
(3) that deposition of the silt was accomplished during at least 40 large Columbia River floods into the Willamette Valley,

(4) that these floods carried heavy loads of chiefly silt and fine sand,

(5) that the silt, at least at lower altitudes, was emplaced in a continuously ponded water during a geologically short time span, and

(6) that ponded water was not stable at any altitude for long periods of time and that it drained rapidly from the Willamette Valley.

Geomorphology of the Willamette Silt surface shows:

(1) that deposition of the Willamette Silt was followed by rapid stream entrenchment,

(2) that a climactic Columbia River flood, larger than previous floods, entered the Willamette Valley after subaerial weathering and erosion of the Willamette Silt.

Stratigraphy, geomorphology, and radiocarbon dates show:

(1) that the last Cascade Mountains glaciation that resulted in a significant aggradation by Willamette River tributaries began more than $34,410 \pm 3,450$ years before present (B. P.),

(2) that the last climactic flood occurred about 19,000 years (B. P.), and

(3) that the age of the Willamette Silt is between 19,000 years (B. P.) and $34,410 \pm 3,450$ years (B. P.).

The writer proposes:
(1) that flooding was caused by repeated failures of the Lake Missoula glacial ice dam northeast of the channeled scablands,

(2) that floods, which sequentially eroded scabland tracts, scoured the Palouse Formation sediments from the scabland tracts, and redeposited part of the sediments in the Columbia River Valley and in major tributary valleys, and

(3) that ponded water was maintained in the Willamette Valley by more rapid aggradation in the Columbia Valley than in the Willamette Valley.
APPROVED:

Redacted for privacy

Professor of Geology

In Charge of Major

Redacted for privacy

Chairman of Department of Geology

Redacted for privacy

Dean of Graduate School

Date thesis is presented January 16, 1965

Typed by Barbara Glenn
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LATE QUATERNARY SEDIMENTATION AND GEOLOGIC HISTORY
OF THE NORTH WILLAMETTE VALLEY, OREGON

by

JERRY LEE GLENN

A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

June 1965
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LATE QUATERNARY SEDIMENTATION AND GEOLOGIC HISTORY OF THE NORTH WILLAMETTE VALLEY, OREGON

INTRODUCTION

Late Quaternary sedimentation and geologic history in the Columbia River Valley (Figure 1) have long been controversial topics among geologists. Bretz observed a complex system of abandoned anastomosing channels across the Columbia River Plateau in eastern Washington and ubiquitous fine-grained sediments and erratics along the Columbia River Valley. He postulated that a catastrophic flood--the Spokane Flood--had occurred in the upper Columbia River Valley (14, p. 607; 15, p. 618) and that the flood coincided with a tectonic submergence in the lower Columbia River Valley (13, p. 505-506). He believed that the flood originated when a lobe of the Cordilleran ice sheet which blocked the Clark Fork of the Columbia River abruptly retreated and released the ponded water in glacial Lake Missoula (26). Allison (2; 3, p. 676-677) agreed with Bretz that a flood had occurred, but he believed that the flood water was ponded behind a dam of combined glacial and river ice which began in the Columbia River Gorge and extended into the Columbia Plateau of eastern Washington. He also suggested that multiple floods produced by icejams would accomplish the same results as Bretz's catastrophic flood and that multiple floods were much more reasonable. Bretz (27, p. 967) later
FIGURE 1. Index map of part of the Columbia River Valley, Oregon, Washington, Idaho, Montana, and British Columbia.
reported evidence for seven or eight floods but continued to maintain that at least one of these was of unusual proportions and that the flood waters came from glacial Lake Missoula.

Lowry and Baldwin (59, p. 1-24), in a report on the Cenozoic geology of the lower Columbia River Valley, found no evidence that the fine-grained sediments of Bretz and Allison were related to abnormally large Columbia River floods. They postulated that these sediments were "normal" Columbia River flood deposits in a body of water which filled the lower Columbia and Willamette Valleys to the present 400-foot level. They believed that this body of water developed because of a eustatic rise in sea level during the Sangamon interglacial age. Lowry and Baldwin (59, p. 20-21) reported evidence for a large flood in the Columbia River Valley, but they believed that the flood post-dated the deposition of the fine-grained deposits.

Trimble (76, p. 1-119), in a recent report on the geology of the Portland area, suggested that Bretz's original Spokane Flood explained the nature and distribution of the fine-grained sediments and erratics. He found no evidence of either a tectonic or eustatic submergence in the lower Columbia Valley and proposed instead that ponded water developed because of a "hydraulic dam" below Portland.

The preceding discussion indicates four major problems related to late Quaternary sedimentation and geologic history in the Columbia River Basin. These are:
1) The cause of flooding.
2) The cause of ponded water.
3) The number of floods.
4) The chronology and time of flooding.

In the present study, the fine-grained sediments were investigated in one of the major Columbia River tributary valleys, the Willamette Valley of Oregon (Figure 1). The Willamette Valley was chosen for two reasons:

1) It contains a thick sequence of fine-grained deposits and excellent exposures, and
2) The lower end of the Willamette Valley lies only ten feet above present sea level; consequently, definite evidence of the proposed tectonic or eustatic submergence of the lower Columbia Valley should be present.

The fine-grained sediments in the Willamette Valley have not been treated in detail by previous investigators. Bretz did not mention specifically the Willamette Valley sediments although he was aware of the erratics (13, p. 489-506). Allison (2) was the first to suggest that the Willamette Valley sediments were related to an episode of Columbia River flooding. He (4, p. 615-632) studied the nature and distribution of erratics in the Willamette Valley and concluded that they were derived from the upper Columbia River Basin and that they were deposited during the late stages of Columbia River
flooding. Allison (8, p. 1-18) established a type section for the fine-grained deposits and named the sediments the Willamette Silt. Lowry and Baldwin, although correlating the Willamette Silt with "normal" Columbia River floods, thought that much of the silt was of local origin. Trimble correlated the Willamette Silt with Portland area "lacustrine" deposits which he believed were emplaced in the ponded water of his "hydraulically dammed" flood.

The present study was designed to accomplish the following objectives with respect to the Willamette Silt:

1) Establishment of the source of the Willamette Silt.

2) Differentiation of the silt from older and younger sediments in the Willamette Valley.

3) Correlation of the silt with similar silt deposits in the Columbia River Valley and in other valleys tributary to the Columbia River.

4) Determination of vertical and lateral changes in silt stratigraphy.

5) Description of the geomorphology of the silt surface and of the depositional basin in which the silt accumulated.

Finally, the writer hoped, and was not disappointed, that the results of this study would help to resolve conflicting interpretations of late Quaternary sedimentation and geologic history in the Columbia River Valley.
Location and Description of the Study Area

The Willamette Valley (Figure 2) is the southern part of a topographic low which includes the Puget Trough and the Chehalis Lowland of Washington. The valley is bordered on the west, east, and south by mountain ranges; the Oregon Coast Range, the Cascade Mountains, and the Calapooya Mountains, respectively. Most of the Willamette Valley floor lies below an elevation of 500 feet, mean sea level; the ridges of the Coast Range and Calapooya Mountains rise to 5,000 feet, and the peaks of the adjacent Cascade Mountains exceed 10,000 feet.

The climate of the Willamette Valley is mild because of the bordering mountain ranges and the influence of the nearby Pacific Ocean. The average monthly temperature ranges from 39 degrees Fahrenheit during the wet winter to 67 degrees Fahrenheit during the dry summer (49, p. 12). Precipitation ranges from 30 to 50 inches annually in the valley proper but is as high as 140 inches in some areas of the adjacent Coast Range.

The floor of the Willamette Valley and the adjacent foothills are used extensively for varied agricultural purposes. Small grains, fruits and nuts, and other special cash crops are the most prevalent. Truck farming is widespread near many larger cities. Soils are chiefly reddish brown latosols (49, p. 29) and are highly productive.
FIGURE 2. Index map of part of the Willamette Valley, Oregon
The adjacent mountains are covered with extensive Douglas fir forests, and the production of lumber products is the mainstay of Oregon's economy.

Nearly all of Oregon's large cities and almost 75 percent of the state's population are located in the Willamette Valley. Portland, the largest city, is situated at the northern end of the Willamette Valley. Smaller cities include Oregon City; Salem, the state capital; Albany; Corvallis; and Eugene and Springfield near the southern end of the valley.

The Willamette River is formed at an altitude of 435 feet by the junction of the Coast and Middle Forks near Eugene. From this junction, the river drops 400 feet along its northward course to Portland where it joins the Columbia River. Major tributaries of the Willamette are the Tualatin, Yamhill, Luckiamute, Marys, and Long Tom Rivers which flow eastward from the Coast Range, and the McKenzie, Calapooya, North and South Santiam, Molalla, and Clackamas Rivers which flow west-northwest from the Cascade Mountains (Figure 2).

The part of the Willamette Valley of interest to the present study extends southward from Portland to Eugene. South of Eugene the valley is narrow and the Coast Range and Cascade Mountains merge with the Calapooya Mountains. North of Eugene, three broad lowlands 10 to 30 miles wide lie between the Cascade Mountains and
the Coast Range and form the main part of the Willamette Valley lowland. Three ranges of hills, the Salem-Eola Hills, the Chehalem Mountains, and the Portland Hills, separate the individual lowlands. The northernmost of the broad lowlands is shared by the Columbia and Willamette Rivers and is named the Portland Basin. The middle and southern lowlands have not been named and are called the north and south Willamette Valley lowlands respectively in this report (Figure 2). The Tualatin Basin, not a part of the Willamette Valley lowlands, lies between the Chehalem Mountains and the Portland Hills.

Within the Willamette Valley, erratics and fine-grained deposits attributed to an episode of Columbia River "flooding" have been noted as far upvalley as Eugene, approximately 115 miles south of the mouth of the Willamette River and nearly 400 feet higher.

The summer of 1961 was spent in a reconnaissance of the Willamette Valley from Eugene to Portland. As a result of this survey and because of the magnitude of the area under consideration, it was decided to restrict subsequent work to the north part of the Willamette Valley (Plate 1).

In the area shown in Plate 1, detailed work was done in the extensive area which is underlain by Willamette Silt between the Salem-Eola Hills, the Cascade Range foothills, and the Chehalem Mountains. Field work in the Tualatin Basin was done on a reconnaissance basis except in the Onion Flat and Oswego Lake Gap.
localities where the sediments and geomorphic features were examined closely. The distribution of the silt in the Portland Basin was interpreted from published reports and maps (70, 76, 77) and has been only spot checked in the field. Small areas of deposits both older and younger than the Willamette Silt are included in the Willamette Silt map unit in the Portland Basin.
PREVIOUS WORK

The discussion of the previous work pertinent to the current study is divided into two parts. The first part describes the geologic setting and geologic history of the Willamette Valley through the Tertiary and early Quaternary. The second part deals with Quaternary events and geologic history in the Columbia River Valley. Additional references are reviewed as needed in the text of the report.

Geologic Setting

Rocks older than the Tertiary system do not crop out in or adjacent to the Willamette Valley. The description of Tertiary events leading up to the Quaternary period is taken from Lowry and Baldwin (59), Baldwin (9), Wells (84), and Trimble (76). These events are summarized and illustrated in a recent publication by Snavely and Wagner (71). The Tertiary geology is shown on maps by Baldwin (10); Felts (34); Harper (48); Thayer (73); Trimble (76); Vokes, Myers, and Hoover (78); Vokes, Snavely, and Myers (79); Warren, Norbistrath, and Grivetti (80); and Wells (84).

In early Eocene time, the Willamette Valley and the adjacent Coast Range were the site of a eugeosyncline (71, p. 2). The ancestral Cascade Mountains and Klamath Mountains bordered the eugeosyncline on the east, southwest, and south. The western border was
apparently marked by a series of islands west of the present Oregon coastline (71, p. 1).

On the floor of the eugeosyncline, submarine basalts were emplaced. Tuffaceous siltstones and sandstones, which are interbedded with the basalts, were derived from highlands south and east of the eugeosyncline. The rocks have been named the Umpqua Formation in the southern Coast Range, the Siletz River Formation in the central Coast Range, and the Tillamook Formation in the northern Coast Range.

In middle Eocene time, a thick sequence of marine arkosic and volcanic sediments was deposited, presumably by turbidity currents (71, p. 8), on and around the early Eocene submarine volcanic rocks. These sediments were derived from the metamorphic, igneous, and sedimentary rocks of the Klamath Mountains, and from volcanic rocks in the ancestral Cascade Mountains. In the part of the Coast Range adjacent to the Willamette Valley, the Tyee Formation and its fine-grained correlative, the Yamhill Formation (9, p. 7), contain the supposed turbidity current deposits.

Volcanic islands appeared and marked the partial filling of the Coast Range eugeosyncline in late Eocene time (71, p. 10). Fine and coarse volcanic sediments were deposited in basins between the islands and toward the open sea (west), argillaceous sediments of the Nestucca Formation (71, p. 13) accumulated. In the Willamette Valley, nearshore marine sediments of the Spencer Formation (71, p. 14)
were deposited in the late Eocene sea.

Uplift of the Coast Range began and was accompanied by intrusions of gabbroic sills during the Oligocene (71, p. 16). Marine sediments were deposited west of the uplift and form the Yaquina Formation. In the north part of the present Willamette Valley, marine sediments of the Keasy, Pittsburg Bluff, and Scappoose Formations were deposited (9, p. 38). Continued uplift and sedimentation resulted in the disappearance of the Coast Range eugeosyncline by middle Miocene time.

In the early and middle Miocene, small intermediate to basic volcanic intrusions (71, p. 20) into the rocks along the western flank of the present Coast Range occurred. The intrusive bodies form the prominent headlands along the Oregon Coast.

East of the ancestral Cascade Mountains during the middle Miocene, Columbia River Basalts were extruded through many fissures. These basalts extended westward down a lowland occupied by the modern Columbia River (76, p. 96) to the Pacific Ocean where they interfinger with the marine Astoria Formation. Columbia River Basalts also extended southward along the site of the present Willamette Valley where they are the ridge-forming rocks in the Chehalem Mountains and the Salem-Eola Hills.

The Cascade Mountains were broadly uplifted in late Miocene time, the Columbia River Basalts were gently warped, and locally,
volcanic rocks of late Miocene age were deposited over the Columbia River Basalts. These younger Miocene rocks, the forerunners of the Cascade Mountains volcanism to follow, are called the Rhododendron Formation (76, p. 96) in the Portland area.

During the remainder of the Miocene (59, p. 4) and into the early Pliocene (76, p. 96), an extensive lateritic soil formed on the Rhododendron and Columbia River Basalts surfaces west of the Cascade Mountains.

Renewed folding and uplift began in the Pliocene. Lacustrine deposits (76, p. 96) formed in broadly down-warped closed basins such as the Tualatin Basin, and fluviol gravel and sands were deposited in the Portland Basin. The lacustrine deposits are called the Sandy River Mudstone (76, p. 96) and the gravels and sands are named the Troutdale Formation (50, p. 873) in the Portland area. Correlative rocks (59, p. 14) along the eastern margin of the Willamette Valley between Portland and Salem are called the Molalla and Fern Ridge Formations.

Continued uplift of both the Coast Range and Cascade Mountains brought them to their present elevations during the Pliocene and early Quaternary. Volcanism in the Cascade Mountains and in the Portland area resulted in extensive deposits of intermediate and basic lava and pyroclastic debris. These deposits are called the Boring Lavas (76, p. 97) in the Portland area, and the Cascan Formation (50)
in the Cascade Mountains. Pleistocene central vent eruptions developed the present major volcanic peaks along the crest of the Cascade Mountains.

Downcutting resulting from continued regional uplift began in the Willamette Valley in late Pliocene time (76, p. 97) and continued into the Quaternary. The early and middle Pliocene lacustrine and fluvial deposits were eroded, and the Willamette and Columbia Rivers were superimposed into their present courses.

Periodically, during the Quaternary, alpine glaciation (73) resulted in deposition of extensive gravel fans where the glacial streams entered the Willamette Valley. Thayer (73, p. 1-40) recognized three stages of glaciation—Mehama, Detroit, and Tunnel Creek—in the North Santiam Valley. Allison (8, p. 9-12) described the glacial gravels in the Albany area (Figure 2) and named them from oldest to youngest, Lacomb, Leffler, and Linn. Trimble (76, p. 46-58) recognized deposits in the Portland area which he believed were correlative with Allison's gravel deposits. He named the deposits from oldest to youngest, the Springwater, Gresham, and Estacada Formations.
Quaternary Events in the Columbia River Valley

Early Work

The earliest published report on the Quaternary geology was by Condon (28, p. 54-72), who suggested that marine waters had extended up the Columbia River beyond the Columbia River Gorge. He speculated that sea level had been 330 feet higher than it is now and named this inland body of water "The Willamette Sound" because of its supposed resemblance to the modern Puget Sound. The submergence was correlated with the Champlain submergence on the Atlantic Coast.

Cobbles and boulders of foreign composition along the Columbia River and in the Willamette Valley were thought (32; 80, p. 81) to represent iceberg-rafted erratics in Condon's Willamette Sound. Bretz (13, p. 494) refuted Condon's idea on the age and marine character of Willamette Sound, but concurred that such a submergence must have occurred because of the erratics. He believed (13, p. 504-505) that the submergence was greater than Condon suggested and that it occurred during the Wisconsin glacial stage. The absence of marine fossils in the surficial sediments in the Willamette Valley led Bretz to suggest a fresh water rather than a marine submergence. He attributed the cause of the submergence to diastropic movements (13, p. 505) which were greater east than west of the Cascade
Mountains.

Bretz described (13, p. 502) a series of terrace gravels at Portland which he called the Portland Delta deposits. He stated that these gravels occur at elevations up to 300 feet and are disposed in foreset beds which dip west and northwest. Bretz at this time considered the gravels to be Columbia River deposits built out into the static or slowly falling waters of Condon's Willamette Sound.

The Channeled Scablands

Bretz (14, p. 573-608) later described the unusual characteristics of "scabland" drainage channels across the Columbia Plateau (Figure 1) of eastern Washington. He attributed the erosional and depositional features to glacial streams pouring over a 2000 square mile plateau area during the Spokane (14, p. 607) glacial stage. The Spokane glaciation was considered by Bretz (17, p. 342; 15, p. 648) to be early Wisconsin (Iowan) or perhaps Illinoian. The name "channeled scabland" was applied (15, p. 618) and the characteristic erosional and depositional features were described more fully by Bretz in 1923. In 1928, Bretz (20, p. 194) summarized the characteristics of the channeled scabland as follows:

The channeled scablands constitute the erosional part of the record. They cover almost 2,000 square miles, about one-sixth of the area of this part of the plateau. They are elongate tracts,
oriented with the gentle dip slope of the underlying basalt flows, mostly bare rock or with a thin cover of coarse basaltic rubble, commonly with canyons in them, and are bounded by steep slopes of the deep loessial soil of the plateau. They constitute a curious anastomosing pattern, the down-dip convergences inherited from an earlier normal drainage pattern and the divergences, equally numerous, produced by crossing of divides of this older pattern. There are hundreds of tracts of the higher loess-covered areas in the scablands, from a fraction of a square mile to many townships in area, all discontinuous and bounded by the scabland areas. The steep marginal slopes in loess are in striking contrast to the gentle slopes of the older drainage pattern surviving within each isolated loessial tract. Canyons in the scablands are multiple and anastomosing, amazingly so in some tracts; deep canyons and shallow ones uniting and dividing in a labyrinthine fashion about bare rock knobs and buttes unlike any other land surfaces on the earth. Certainly but few of these canyons are inherited from the older pattern.

The depositional land forms associated with channeled scabland are chiefly great mounded masses of little-worn basaltic gravel. They occur on the down-gradient side of eminences and in other protected places in the scablands, and in the Snake and Columbia valleys below the entrance of the scabland drainage routes. They are not eroded forms, they possess aggradational slopes, and they inclose depressions or by their position aid in inclosing depressions between themselves and adjacent rock walls. All attempts to interpret them as dissected remnants of terraces or originally continuous gravel deposits have failed. They are gravel bars of huge size.

Bretz suggested (15, p. 645) that many of the scabland tracts were simultaneously occupied during one flood of glacial water and applied the name "Spokane Flood" (18, p. 97) to this large volume of
water. He considered that many of the erratics were rafted by icebergs in the flood water but mentioned that others were rafted in during the late Pleistocene submergence which he had previously postulated (13, p. 504-505).

The effects of the Spokane Flood beyond the channeled scabland were described by Bretz (18, p. 97-115; 19, p. 236-259) in 1925. These effects included: 1) ponded water in the Yakima and Walla Walla Valleys (Figure 1) of Washington; 2) gravel bars which extended up many Columbia River tributaries; 3) small areas of scabland along the Columbia River from the Wallula Gateway to Portland; and 4) the construction of the Portland Delta. Bretz stated (19, p. 252) that the Spokane Flood:

entered an estuary of the Pacific whose surface stood more than 350 feet above present sea level. Here it built the Portland Delta... a subaqueous deposit, an affair of river bottom deposition and not a delta plain when constructed. The river was 100 feet deep over much of the surface when it was built.

Bretz estimated that the volume of the Spokane Flood at the Wallula Gateway was 66,132,000 second feet (38.9 cubic miles) (19, p. 258). By comparison the maximum historical flood at The Dalles (Figure 1), 100 miles downstream, was only 1,170,000 second feet. He suggested (19, p. 259) that either a climatic amelioration or volcanic activity beneath the Spokane ice cap caused the sudden release
of the Spokane Flood waters.

The catastrophic nature of the Spokane Flood induced many people to propose alternate hypotheses (20, 21) and motivated Bretz to collect more evidence in support of a flood. Part of this evidence consisted of deposits in the Yakima Valley (21, p. 324-328; 25, p. 412-422) and in all the tributary valleys (Palouse, Snake, and Walla Walla Valleys) which entered the scabland tracts from the east and from the southeast (23, p. 393-427; 24, p. 505-541). These deposits (23, p. 393; 22, p. 643-702) consisted of large gravel bars with foresets dipping away from the scabland and up the tributary valleys and variable thicknesses of poorly stratified and pebble-charged silt and sand.

The nature and distribution of the pebbly silts were described by Bretz (24, p. 505-541) in a later paper. He (24, p. 539) believed that these deposits were contemporaneous with scabland formation and that they recorded the existence of back water from the flood flowing up the tributary valleys. Lupher (60, p. 1431-1462) also described these deposits and suggested that the many clastic dikes present were formed during melting of blocks of ice.

Bretz (26) in 1930 proposed a new source for the volume of water needed for the Spokane Flood. Pardee (62, p. 376-386) had described deposits and features in the Clark Fork drainage basin (Figure 1) which he attributed to a body of water dammed by a
Cordilleran glacier. He named this body of water Lake Missoula. Bretz suggested that the Lake Missoula ice dam failed, releasing a wall of water 2100 feet high into the Spokane River and eventually into the Columbia River. A second ice dam near Lake Chelan, Washington, forced the water out of the Columbia Valley and across the Columbia River Plateau of Washington.

Many leading geologists viewed Bretz's concept of a Spokane Flood as a return to catastrophism. Most of the early critics (33, p. 200-211) suggested that less water over a longer period of time would result in many of the deposits and features which Bretz had described.

In 1933, Allison (3, p. 672-722) published new data on the characteristics of flood features along the Columbia River from the Columbia River Gorge upstream to the Yakima River Valley. He stated (3, p. 676-677):

The new data indicate that the flood rose to a consistently high level from the Wallula Gateway to the Columbia River gorge through the Cascade Mountains; that it left slack water deposits both in tributary valleys and on the uplands; hence, that it was virtually ponded. The data also prove that the flood was later than the major physiographic development of the region, as Bretz has continually insisted, so that a method of delaying or even entirely blocking the flow of the flood waters must be sought to explain the ponding. In spite of the obvious difficulties of such an explanation, the writer believes: that the ponding was produced by a blockade of ice in the Columbia River gorge through the Cascade Mountains;
that the rise of the Columbia River to abnormally high levels began at the gorge and not on the plateau of eastern Washington; that the blockade gradually grew headward until it extended into eastern Washington; that, as the waters were dammed to progressively higher levels, they were diverted by the ice into a succession of routes across secondary drainage divides at increasing altitudes, producing scablands and perched gravel deposits along the diversion routes, distributing iceberg-rafted erratics far and wide, and depositing pebbly silts in slack-water areas. This interpretation of the flood does not require a short-lived catastrophic flood but explains the scablands, the gravel deposits, diversion channels, and divide crossings as the effects of a moderate flow of water, now here and now there, over an extended period of time. It thus removes the flood from the "impossible" category.

Allison (3, p. 718-719) suggested that a general submergence, such as Condon (29, p. 54-72) and Bretz (13, p. 304-505) advocated, did not occur and that all the erratics are related to the Spokane Flood. He believed (3, p. 715-718) that the Portland Delta gravels, which Bretz indicated were deposited in an estuary during the Spokane Flood, were older than the flood and that their upper surfaces showed evidence of modification by the flood water.

In 1938 Flint (37, p. 461-524) examined and described one of the larger scabland tracts, the Cheney-Palouse tract. He rejected Bretz's contention that it was produced by an enormous proglacial discharge--Spokane Flood--and suggested a four stage evolution for an ideal scabland tract with filling of pre-scabland valleys and subsequent erosion as the principal themes. Flint (37, p. 461-524) thought
that the filling and erosion were caused by fluctuations in Lake Lewis. The concept of a Lake Lewis east of the Cascade Mountains was advanced by Symons (72, p. 108). Flint believed that the lake formed behind a more or less permanent dam across the Columbia River course through the Cascade Mountains. He rejected Allison's (3) ice dam as a cause of ponding and proposed instead (37, p. 503) a landslide dam or glacier ice in the Columbia River Gorge. Flint thought that the pebbly silt and erratics of Bretz (23, 24) and Allison (3) were deposits in the lake. The name "Touchet" beds (37, p. 494) was applied by Flint to these deposits in the Walla Walla River Valley. Diatoms in the Touchet beds indicated to Flint (37, p. 503) the fresh water nature of the lake.

Allison (7, p. 54) considered that Flint's fill and erosion hypothesis was insufficient with respect to the scabland problem in general even though it did allow these features to be formed by more conventional stream processes.

Bretz, Smith, and Neff vigorously refuted both Allison's and Flint's hypotheses and in 1956 (27, p. 957-1049) published new data and a revised interpretation of the glacial events in the Columbia River Basin. They abandoned the concept of a single Spokane Flood (27, p. 967) and recognized "the occurrence of several successive floods, the earliest recorded only in the Columbia Valley, the second involving perhaps the entire channeled scablands, latter ones restricted to
channels already deepened, and the last one again limited to the Columbia Valley". They maintained (27, p. 1035) that each flood had its inception in a sudden failure of an ice dam which released the waters of Lake Missoula (26, 62, 63), the presence of which had been verified recently (1). A late Wisconsin age (27, p. 1046-1047) was suggested for the periods of flooding.

The Spokane Flood in the Willamette Valley

The literature considered to date, with the exception of that on the Portland Delta, contains little data directly relating Willamette Valley events and deposits to those in the upper Columbia River Valley.

Allison (2) described erosional features similar to those in the scablands in three gaps—Oswego Lake Gap, Rock Creek Gap, and the modern Willamette River Gorge (Plate 1)—leading from the Columbia Valley into the Tualatin and Willamette Valleys and found upvalley foresets in gravels near these gaps. He (2) considered the gravels at Canby (Plate 1) to be continuous with Willamette Silt farther south in the Willamette Valley.

Allison (4) studied the nature and distribution of erratics in the Willamette Valley and concluded: 1) that they represented iceberg-borne debris brought into the Willamette Valley from the upper Columbia River drainage; 2) that they were brought into the
Willamette Valley when water stood as high as 250 feet above the present valley floor; 3) that ice jams in the Columbia River Gorge and below Portland produced the necessary water level; and 4) that they are younger than or contemporaneous with the main valley fill. He described (4) a deposit of gray, pebbly silt associated with the erratics and noted its similarity to the silts previously described by Bretz (23, 24).

Allison (4, p. 630-631) considered the age of the erratics to coincide with the Vashon (12) glacial stage in the Puget Sound region and with the Tahoe (11) stage of California.

In 1939 Allison (6) reviewed the evidence for Condon's Willamette Sound and concluded that, despite some major problems, the erratics were best explained by icebergs floating in a fresh water "sound".

The Willamette Silt was described by Allison (5, p. 442) as follows:

It is shaped like a wedge which is thickest at the north. Toward the south and about the edges it overlaps older rocks to elevations between 350 and 400 feet above sea level. The bulk of the material is silt and fine sand but it also includes blocks and smaller fragments of foreign rocks such as granite and quartzite, that evidently were brought in by icebergs that came down glacial Columbia River.

The composition of the valley fill was described briefly by
Felts (34, p. 66) who noted garnet, tourmaline, and other "foreign" minerals in the silt deposits. He concluded that the valley fill was deposited in an extensive open body of water.

Allison (8, p. 12) proposed the name Willamette Silt "to apply to the parallel bedded sheets of silt and associated material that cover the greater part of the Willamette Valley lowland". He noted their "foreign" composition and suggested that they were deposited by back flooding from the Columbia River into a fresh water lake which filled the valley to the 400-foot level.

Piper (65, p. 31), in a report on the ground-water resources of the Willamette Valley, noted an extensive body of semiperched water in the deposits of the main valley fill north of Salem (Plate 1). He described the Portland "delta" (65, p. 34) as "a stream-laid deposit on a gradually rising base level . . . not built in a single stage by progression of a delta into deep water".

Treasher (77, p. 13-14) suggested that the Columbia River was choked by its own load and that the Portland Delta deposits represent the resulting aggradational deposits. He denied both Bretz's and Allison's hypotheses of flood water in the Portland region.

The late Cenozoic geology of the Portland area has been described by Lowry and Baldwin (59, p. 1-24). They considered the Portland gravels to be correlative with the Canby gravels in the Willamette Valley (as did Allison) and with the Willamette Silt (59, p. 20).
They saw no evidence that either deposit was related to unusually large Columbia River floods and stated (59, p. 18): 

The wide distribution of the erratics, the topographic range of these incorporated in alluvial deposits, and the common maximum of the Portland gravels and Willamette Silt, as well as their included erratics, indicate the Portland gravels, Willamette Silt and at least part of the erratics were deposited in a body of water as it rose to a point represented by a present elevation of about 400. The evidence points to a rise in base level governed by a eustatic rise in sea level.

They also indicated (59, p. 21) that the scabland gravels and the Touchet beds were correlative with the eustatic submergence. They assigned the present elevation of these deposits and of the Portland area deposits to post-depositional uplift which in the Portland area would have amounted to 400 feet.

Lowry and Baldwin (59, p. 20) suggested that the Willamette Silt is higher on the Cascade Mountains side of the Willamette Valley because of greater deposition by Cascade Mountains streams entering the rising body of water.

Lowry and Baldwin (59, p. 20-21) did recognize evidence for a large post Portland gravel flood. They suggested that some erratics in the Portland region and in the upper Columbia River Basin were deposited in a fresh water lake that existed up through the last interglacial stage and until the Wisconsin glaciation and corresponding sea-level lowering caused downcutting.
The latest report on the geology of the Portland area is by Trimble (76, p. 1-119). He described (76, p. 58) "lacustrine" deposits which include the Portland Delta deposits of Bretz (19, p. 252), the Portland gravels of Lowry and Baldwin (59, p. 20), and the Willamette Silt of Allison (8, p. 12). He agreed with Bretz's early conclusion (15, p. 645) that these deposits were emplaced by a large flood but did not mention where they fit in the revised interpretation (27, p. 957-1049). Trimble (76, p. 64) considered that all the previous hypotheses (29, 13, 59) inadequately explained the lacustrine condition in the lower Columbia River, and suggested that a "hydraulic dam" on the Columbia River below Portland produced the lake. His concept of hydraulic damming assumed that more water reached the 1.5-mile wide "constrictions" near Longview, Washington, (Figure 1) than could pass through the constrictions and so a temporary backwater lake was formed. He thought that a volume of water large enough to cause hydraulic damming was present only during the original Spokane Flood.

Trimble (76, p. 68-71) recognized deposits of sand and silt younger than his lacustrine deposits. He described these deposits as stratified, erratic-bearing, and disconformably with the underlying lacustrine deposits, but he was puzzled over their origin.
NEW DATA

The data in this report are presented under three major subheadings: petrography, stratigraphy, and geomorphology. Additional data, based on the results of radiocarbon dating, are presented in the stratigraphy and the geomorphology sections.

Petrography

Petrographic studies involved an investigation of the heavy minerals in a composite size fraction from each sample. The selection of this size fraction was based on preliminary examination of size separates from the bulk of all samples to be analyzed. This examination revealed that the medium and coarse fraction of Willamette Silt samples contained high quantities of authigenic minerals (mostly iron oxides) and insufficient quantities of other heavy mineral grains. For this reason, the upper limit of the composite chosen for analysis was placed at 0.149 mm (U. S. number 100 sieve). The lower limit was selected at 0.053 mm (U. S. number 270 sieve), mainly because smaller grains are difficult to identify accurately.

All samples analyzed by petrographic techniques were similarly pre-treated. This pretreatment included either a complete or partial mechanical analysis followed by a procedure for removing iron stains. The latter consisted of boiling the samples for ten
minutes in a solution of ten grams of stannous chloride and 100 ml of five percent HCl. The heavy minerals were then separated from light minerals using tetrabromoethane (specific gravity 2.96) as the separating medium. Representative samples of the total heavy fraction were mounted in Canada balsam, and mineral frequencies were determined by grain count using standard petrographic techniques.

Samples collected for heavy mineral study were of three major types: 1) provenance samples, 2) Willamette Silt samples, and 3) correlation samples. A limited number of samples were collected to aid in the differentiation of the Willamette Silt from underlying sediments. The results of analyses on these samples are reported in the stratigraphy section.

Provenance Samples

The Willamette Silt has long been considered to contain a "foreign" mineral suite (34, 8). Although this has been accepted generally, no quantitative and very little qualitative work has been published on the "local" provenance mineralogy. For this reason, an attempt has been made to characterize the modern sedimentary influx. To accomplish this objective, one or two grab samples were collected from each major Willamette River tributary stream above the Willamette River Gorge (Plate 1). The Molalla River samples were not analyzed because this river enters the Willamette Valley near the
lower boundary of the study area and below all other Willamette Silt or Willamette River floodplain sample sites (Plate 1). The samples were obtained from either the stream bed or from the adjacent floodplain. All samples were collected above the 400-foot contour line to prevent possible contamination by erratics or "foreign" sediments.

Eighteen samples from ten different streams were analyzed; the streams sampled and the sample sites are shown in Figure 2. The sample sites are also located by Township and Range in Table 18, Appendix A.

In addition, 22 samples were collected from Willamette River floodplain deposits between Salem and Canby (Plate 1). This part of the floodplain is below all but one of the Willamette River tributaries which were sampled so that any variation in floodplain mineralogy due to a local source is minimized. The samples were collected by drilling two-inch diameter hand auger holes to a depth of six feet. All samples analyzed were a composite of the stratigraphic interval from four to six feet below the land surface. Each sample site was randomly selected using a grid system and a random number table in order to allow statistical treatment of the data if desired. The data from the samples were used not only to characterize the local heavy mineral suite but also to compare the suite with that in Willamette Silt samples.

Description of the modern sedimentary influx into the
Willamette Valley is facilitated by grouping the sediments according to the geologic character of their source areas. On this basis the Willamette Valley is bordered by two geologically distinct source areas, the Coast Range on the west and the Cascade Mountains on the east, and by a transition area between the two on the south.

**Coast Range Sediments**

The results of heavy mineral analyses of seven sediment samples from four different Coast Range streams are shown in Table 1. These data show that Coast Range sediments have a heavy mineral suite composed of augite, hornblende, and epidote group minerals. The augite is both the green diopsidic variety (51, p. 23) and the dusty or rosy-brown titanaugite (51, p. 23). The hornblende is chiefly green and brown, but a subordinate amount of the blue-green variety is noted. Lamprobolite (54, p. 329-330), the dark-brown to foxy-red variety of hornblende, is present in small quantities. Pistacite (54, p. 337-338) is the dominant epidote group mineral, but small amounts of zoisite and/or clinozoisite are noted in samples from some streams. Hypersthene, zircon, garnet, tourmaline, sphene, and rutile are widespread but minor components. Small quantities of muscovite and rare flakes of biotite comprise the mica group. The identifiable volcanic rock fragments are basaltic in composition. Much of the volcanic glass is palagonitic; however, grains of clear
TABLE 1. Heavy minerals in seven samples from four Coast Range tributaries of the Willamette River. Only the nonopaque minerals were counted. A "T" indicates that the minerals were in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>River</th>
<th>Little River</th>
<th>South Yamhill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Long Tom</td>
<td>Marys</td>
<td>Luckiamute</td>
</tr>
<tr>
<td></td>
<td>JLT-6</td>
<td>JM-1</td>
<td>JLL-5</td>
</tr>
<tr>
<td></td>
<td>JLT-8</td>
<td>JM-2</td>
<td>JSY-20</td>
</tr>
<tr>
<td>Hornblende</td>
<td>20</td>
<td>15</td>
<td>38</td>
</tr>
<tr>
<td>Lamproblolite</td>
<td>1</td>
<td>T</td>
<td>T</td>
</tr>
<tr>
<td>Augite</td>
<td>26</td>
<td>56</td>
<td>45</td>
</tr>
<tr>
<td>Hypersthene</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Epidote group</td>
<td>33</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Garnet</td>
<td>5</td>
<td>T</td>
<td>---</td>
</tr>
<tr>
<td>Sphene</td>
<td>3</td>
<td>3</td>
<td>---</td>
</tr>
<tr>
<td>Zircon</td>
<td>4</td>
<td>2</td>
<td>T</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>1</td>
<td>T</td>
<td>---</td>
</tr>
<tr>
<td>Rutile</td>
<td>T</td>
<td>3</td>
<td>---</td>
</tr>
<tr>
<td>Mica group</td>
<td>1</td>
<td>2</td>
<td>T</td>
</tr>
<tr>
<td>Volcanic glass and</td>
<td>1</td>
<td>4</td>
<td>---</td>
</tr>
<tr>
<td>rock fragments</td>
<td>4</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Unknown</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>


glass show low negative relief and are acidic (54, p. 420-423). The "unknown" category contains undifferentiated hornblende-, epidote-, and pyroxene-group minerals and less than one percent of other minerals.

In addition to the heavy minerals in Table 1, Coast Range streams supply significant amounts of black opaque minerals, chiefly ilmenite and magnetite. These heavy minerals were not tabulated because of the limited total number of grains counted and because the writer doubted that they would have any diagnostic value. In samples where a check was made, ilmenite-magnetite ranged from 7 to 64 percent of the heavy mineral suite and averaged 24 percent.

Although essentially the same heavy mineral suite is present in all Coast Range sediment samples, the abundance of the individual minerals differs in samples from the same stream and between samples from different streams. The differences in samples from the same stream are not unusually large considering the varied nature of the source area, the distance separating some samples, and differences in texture between samples. The differences between streams are fairly large and show a definite trend from northern (on the right side in Table 1) to southern streams. Augite is less and epidote group minerals are more abundant in the southern streams. Zircon and garnet, among the less abundant minerals, also are more common in the southern streams.
Qualitative differences are noted between samples from different streams. In the northern streams (to the right in Table 1), augite is chiefly of the titaniferous variety. Green diopsidic augite increases and titanaugite decreases in streams farther south. This trend appears in the Marys River samples and continues into the Long Tom samples where titanaugite is essentially absent. Southern streams also show an increase in minerals with euhedral crystal form and isotropic glass fringes. These minerals are chiefly hypersthene and minor amounts of green augite, and green hornblende.

The Long Tom River sediment heavy minerals differ in physical characteristics from those in other Coast Range stream sediments. Almost all heavy minerals in other Coast Range streams are angular to subrounded whereas those in the Long Tom River sediments are commonly well rounded. The Long Tom River sediments also contain most of the identifiably zoisite and/or clinozoisite.

Cascade Mountains Sediments

The results of heavy mineral analyses of seven samples from four streams which enter the Willamette Valley from the Cascade Mountains are shown in Table 2. These data indicate that the Cascade Mountains heavy mineral suite is dominated by augite and hypersthene; minor amounts of hornblende and epidote group minerals are the only other important constituents. Black opaque minerals are
TABLE 2. Heavy minerals in seven samples from four Cascade Mountains tributaries of the Willamette River. Only the nonopaque minerals were counted. A "T" indicates that the minerals were noted in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>McKenzie</th>
<th>Calapooya</th>
<th>South Santiam</th>
<th>North Santiam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>JMc-28</td>
<td>JCa-17</td>
<td>JCa-18</td>
<td>JSS-17</td>
</tr>
<tr>
<td>Hornblende</td>
<td>14</td>
<td>15</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Lamprobolite</td>
<td>1</td>
<td>1</td>
<td>T</td>
<td>--</td>
</tr>
<tr>
<td>Augite</td>
<td>28</td>
<td>44</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>Hypersthene</td>
<td>43</td>
<td>22</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>Epidote group</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Sphene</td>
<td>--</td>
<td>T</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Zircon</td>
<td>--</td>
<td>1</td>
<td>2</td>
<td>T</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Rutile</td>
<td>--</td>
<td>T</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Volcanic glass and rock fragments</td>
<td>--</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
common components of the Cascade Mountains sediment although no attempt was made to estimate or to determine their abundance.

Most of the augite in Cascade Mountains sediments occurs as subangular, prismatic grains of diopsidic augite. Titanaugite is widespread but is considerably less abundant than it is in most of the Coast Range sediments. The hypersthene is chiefly subhedral crystals and subordinate euhedral crystals. Numerous crystals of hypersthene and green augite and most of the zircon grains have fringes of volcanic glass or other volcanic debris. Green and brown hornblende are the only colored varieties of this mineral seen. The epidote group is almost exclusively granular pistacite. Volcanic rock fragments are chiefly andesitic and volcanic glass is both basic and acidic.

The data in Table 2 do not indicate significant differences in heavy mineral abundance either between streams or in samples from the same stream. The two centrally located streams (Figure 2) provide less hypersthene and more augite (Table 2) than do streams to the south (left side of Table 2) or to the north. The trend is not well established, however, particularly with respect to augite which is just as abundant in one of the North Santiam samples (Table 2) as it is in samples from the South Santiam and Calapooya Rivers.

Qualitatively, the only trend recognized was an increase from northern to southern streams in heavy minerals with volcanic glass rims.
Transition Area Sediments

The results of heavy mineral analyses of four samples from two transition area streams are shown in Table 3. These stream sediments should have a heavy mineral suite which is intermediate between that in the adjacent Cascade Mountains and Coast Range sediments. In actuality, the Coast Fork of the Willamette River lies more in the transition area, and the Middle Fork drains an essentially Cascade Mountains type source area.

The Coast Fork heavy mineral suite is not greatly different from that in the Coast Range sediments except for the quantity and character of the hypersthene. In the Coast Range sediments this mineral occurs commonly as euhedral crystals, some of which have fringes of volcanic glass. In the Coast Fork sediments this type of hypersthene is supplemented and largely replaced by subhedral, prismatic grains. The remaining components of the heavy mineral suite do not differ appreciably either in abundance or characteristics from the same minerals in Coast Range sediments. The accessory minerals (zircon, tourmaline, and rutile) show a decrease in abundance from the Coast Range to the transition area although the data are not conclusive.

The Coast Fork heavy mineral suite continues most trends previously noted in Coast Range sediments and begins some trends
TABLE 3. Heavy minerals in four samples from two transition area tributaries of the Willamette River. Only the nonopaque minerals were counted. A "T" indicates that the minerals were noted in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Middle Fork of the Willamette</th>
<th>Coast Fork of the Willamette</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>JMF-15</td>
<td>JMF-16</td>
</tr>
<tr>
<td>Hornblende</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Lamprobolite</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Augite</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>Hypersthene</td>
<td>37</td>
<td>40</td>
</tr>
<tr>
<td>Epidote group</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Garnet</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Zircon</td>
<td>T</td>
<td>T</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Rutile</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>Volcanic glass and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rock fragments</td>
<td>2</td>
<td>T</td>
</tr>
<tr>
<td>Unknown</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

which continue into the Cascade Mountains sediments. Chief among the latter are an increase in hypersthene and a decrease in accessory minerals.

Willamette River Floodplain Sediments

The results of heavy mineral analyses of 22 Willamette River floodplain sediment samples are shown in Table 4. Because a larger total number of grains were identified in these samples, the opaque minerals were counted.

The heavy mineral suite in Willamette River floodplain
TABLE 4. Heavy minerals in 22 Willamette River floodplain samples. The sample sites are shown in Plate 1. A "T" indicates that the minerals were noted in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>FMB1</th>
<th>FMB2</th>
<th>FMB3</th>
<th>FMB4</th>
<th>FMB5</th>
<th>FMB6</th>
<th>FMB7</th>
<th>FMB8</th>
<th>FMB9</th>
<th>FMB10</th>
<th>FMB11</th>
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</thead>
<tbody>
<tr>
<td>Hornblende</td>
<td>30</td>
<td>22</td>
<td>18</td>
<td>14</td>
<td>18</td>
<td>24</td>
<td>20</td>
<td>18</td>
<td>53</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>Lamprobolite</td>
<td>T</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>T</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Augite</td>
<td>93</td>
<td>96</td>
<td>106</td>
<td>79</td>
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<td>132</td>
<td>76</td>
<td>98</td>
<td>80</td>
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<td>111</td>
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<td>20</td>
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<tr>
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<td>--</td>
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<td>--</td>
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<tr>
<td>Sphene</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td></td>
</tr>
<tr>
<td>Zircon</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<td>--</td>
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<tr>
<td>Kyanite</td>
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</tr>
<tr>
<td>Tourmaline</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>T</td>
<td>--</td>
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<tr>
<td>Pyrophyllite</td>
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<td>--</td>
<td>--</td>
<td>T</td>
<td>--</td>
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</tr>
<tr>
<td>Rutile</td>
<td>--</td>
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<td>--</td>
<td>--</td>
<td>--</td>
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<td>--</td>
<td>T</td>
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</tr>
<tr>
<td>Mica group</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<td>16</td>
<td>16</td>
<td>9</td>
<td>3</td>
<td>8</td>
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<tr>
<td>Volcanic glass and</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>17</td>
<td>9</td>
<td>9</td>
<td>21</td>
<td>7</td>
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<tr>
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samples is dominated by pyroxenes, black opaque minerals, hornblende, and epidote group minerals. Green augite and euhedral to subangular grains of hypersthene are the principal pyroxenes. Ilmenite-magnetite are the abundant black opaque minerals, and green and brown hornblende are the principal amphibole varieties. The epidote group contains chiefly granular pistacite.

The nature and abundance of individual components in the Willamette River floodplain heavy mineral suite differ from what the tributary stream data indicate should be present. The qualitative differences include the presence of kyanite and pyrophyllite, neither of which was observed in any tributary stream sample. The floodplain sediments contain more hypersthene than augite, a reversal of the usual situation in the tributary stream sediments. The absence of appreciably amounts of titanaugite, blue-green hornblende, zoisite and/or clinozoisite, and the scarcity of garnet and tourmaline are unusual because these minerals occur in Coast Range stream sediments.

The nature and distribution of heavy minerals in Willamette provenance samples are summarized in the following section. Possible reasons for the differences between Willamette River floodplain and tributary stream mineralogy and for the large variation in heavy mineral content of floodplain sediments are also discussed.
Summary and Discussion

The qualitative and quantitative data on the heavy mineral suites in Willamette provenance samples are summarized in Tables 5 and 6 which show the average abundance of heavy minerals in all samples from the same source area and selected heavy mineral ratios for each source area respectively. The data show that the Willamette Valley is bordered by two source areas, the Coast Range and the Cascade Mountains, which supply different amounts of the same minerals, and by a transition area which supplies heavy minerals more like those in the Cascade Mountains sediments.

The definitive characteristics of the Coast Range heavy mineral suite are the dominance of augite, the sparseness of hypersthene, and larger amounts of garnet, tourmaline, sphene, and other accessory minerals than are found in sediments from the other source areas. The augite-hypersthene ratio (Table 6) most clearly separates Coast Range sediments from sediments in other source areas.

The Cascade Mountains heavy mineral suite is characterized by high percentages of augite and hypersthene, moderate amounts of hornblende and epidote group minerals, and very little else. Comparison of the average abundance (Table 5) of these minerals with the average abundance of the same minerals in the Coast Range indicates the completely different nature of the source rocks. The ratios in
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\textsuperscript{a} Not counted
\textsuperscript{b} Includes all 22 Willamette River floodplain samples
\textsuperscript{c} Not observed
\textsuperscript{d} 'T' = Average percent less than 0.1
Table 6. Heavy mineral ratios for samples from various sources. Ratios computed by summing all observations of the ratio components in samples from the source area specified.

<table>
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<tr>
<th>Sample Source</th>
<th>Augite Hypersthene</th>
<th>Pyroxene Hypersthene</th>
<th>Epidote Group Hypersthene</th>
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<td>8) Columbia River sediments</td>
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1 Amphibole: Includes hornblende and lamprobolite
2 Pyroxene: Includes augite and hypersthene

Table 6 show that the most important differences are in hypersthene and epidote group mineral abundance.

The transition area shows an increase in hypersthene over that in the Coast Range sediments, chiefly at the expense of augite and hornblende. The higher percentage of epidote group minerals in the
transition area is due chiefly to contributions from the Coast Fork which drains more Coast Range type rocks. The lower average percentage of augite in the transition area sediments reflects a continuation of the trend noted in Cascade Mountains samples north and south from the South Santiam and Calapooya Rivers. This trend shows increasing hypersthene at the expense of augite. The heavy mineral ratios (Table 6) do not indicate any significant differences between transition area and Cascade Mountains provenance.

The data in Tables 5 and 6 show that the Willamette River floodplain heavy mineral suite is not simply a composite of the suites in the adjacent source areas. If the observations on heavy mineral abundance in all Willamette River tributary samples are summed and ratios are computed using the sums, the values in row four (Table 6) result. The Willamette River floodplain samples should have a heavy mineral suite characterized by the same or nearly the same ratios if sediments from the tributary streams are equally represented.

Part of the discrepancy between heavy mineral abundance in Willamette River sediments and in sediments supplied to the Willamette River may be explain by derivation of the bulk of the floodplain sediments from the Cascade Mountains provenance where hypersthene and augite are more nearly equal. The Cascade Mountains streams have larger drainage basins and higher gradients than Coast Range streams; thus they supply more sediment to the Willamette River.
The absence or scarcity of some minerals, notably titanaugite, in the floodplain sediments also supports the derivation of most of the Willamette River sediments from the Cascade Mountains provenance.

Augite is more abundant (Table 5) than hypersthene in all Willamette River tributary stream sediments. This fact indicates that some way of selectively increasing or decreasing augite or hypersthene or both is necessary in order to explain the dominance of hypersthene in Willamette River floodplain sediments. Three possibilities are present: 1) solution has selectively removed augite from the floodplain sediments, 2) incorporation of Willamette Silt into floodplain sediments has affected the abundance of augite and hypersthene, and 3) hypersthene was once more abundant in tributary stream sediments. Even though augite is believed (51, p. 13, 23) to be slightly more susceptible to solution than hypersthene, the augite in the floodplain sediments is not more greatly altered than that in the tributary stream sediments. Thus the first possibility is unlikely. The Willamette Silt (see Table 8) contains about equal amounts of augite and hypersthene so that incorporation of Willamette Silt should not affect the relative abundance of these minerals in the Willamette River floodplain deposits. The last possibility is supported by the pyroclastic nature of much of the hypersthene and by recorded occurrences (42, 43, 44) of recent volcanic ash falls. Thin layers of crystal-bearing volcanic ash would probably be removed rapidly from
the rugged Cascade and Coast Range landscape and the erosion products and the ash would accumulate in low-lying areas such as the Willamette River floodplain.

Mixing of Willamette River floodplain sediments and Willamette Silt has affected the types and abundance of some heavy minerals in the Willamette River floodplain sediments. The presence of kyanite and pyrophyllite, minerals observed in the Willamette Silt (see Table 8) but not in tributary stream sediments, results from incorporation of Willamette Silt. In samples from the narrow Willamette River floodplain between Newberg and Canby (Plate 1), both hornblende and epidote are more abundant than they are in samples farther south in the Willamette River floodplain. These minerals are more abundant in the Willamette Silt (see Table 8) than they are in the Willamette provenance samples.

Sample FN19, which is from the narrow part of the Willamette River floodplain (Plate 1), has a heavy mineral suite which is not greatly different from that in nearby Willamette Silt samples (see Table 7). Possibly the sample came from an erosional remnant of Willamette Silt because samples (FS20 and FS21) farther downstream do not show as pronounced a Willamette Silt mineralogy.

Variation in texture between individual samples may be an important factor in causing the differences in heavy mineral abundance between Willamette River floodplain samples. Variation in both the
type and abundance of heavy minerals in samples from the same source has long been known (69, p. 3-29) to be related to sample texture. The data in Appendix B show that different floodplain samples range from coarse sands to heavy clays so that differences in heavy minerals are to be expected.

Willamette Silt Samples

Published work on the mineralogy of the Willamette Silt is incomplete. Felts (34, p. 66) and Allison (8, p. 12) indicated that the silt contained "foreign" minerals such as garnet and tourmaline, both of which are found in Coast Range sediments.

Thirty-six samples were analyzed during the study of Willamette Silt mineralogy. Twenty-two samples were collected from random sample sites (Plate 1) by using the method of site selection and sampling described for Willamette River floodplain samples. Because the silt samples collected in this manner were all fine-grained (Appendix B), 14 grab samples were collected from sands in widely scattered Willamette Silt outcrops. Seven of these samples have stratigraphic significance, and the results of heavy mineral analyses are reported in the stratigraphy section (see p. 86, 119). Heavy mineral analyses on the remaining seven samples and summary data for all samples are reported in the following section.
Heavy Minerals in the Willamette Silt

The results of heavy mineral analyses of the 22 Willamette Silt samples from random sample sites are reported in Table 7, and the average percentage of heavy minerals in these samples is shown in Table 8. These data show that hornblende dominates the Willamette Silt heavy mineral suite. Opaque minerals, epidote group minerals, augite and hypersthene are other major components. Volcanic glass and rock fragments, micas, garnet, zircon, sphene, kyanite, tourmaline, monazite, and pyrophyllite are important constituents in some samples and are present in small amounts in most samples. Less important components are hematite and leucoxene. The unknown fraction contains undifferentiated amphibole, pyroxene, and epidote group minerals and one to four percent of other minerals. Included among the latter are sillimanite and andalusite which were not identified in Willamette Silt samples until after their recognition in Columbia River sediments where they are more abundant. Apatite was also observed in Willamette Silt samples but was not counted because the acid pretreatment for iron removal may have affected its abundance.

The data in Table 7 show considerable intrasample variation in heavy mineral quantities. Part of the variation is due to the inclusion of volcanic detritus and micas as components of the heavy mineral suite. The specific gravity of the separating medium...
TABLE 7. Heavy minerals in 22 Willamette Silt samples. The sample sites are shown in Plate 1. A "T" indicates that the minerals were noted in the sample but did not come under the center of the cross hairs during the counting traverses.

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<td>T</td>
<td>--</td>
<td>--</td>
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<td>T</td>
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<td>--</td>
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<td>--</td>
<td></td>
</tr>
<tr>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
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</tr>
<tr>
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<td>--</td>
<td>1</td>
<td>T</td>
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</tr>
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<td>2</td>
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<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
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</tr>
<tr>
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<td>8</td>
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</tr>
</tbody>
</table>
TABLE 8. Average percentage of heavy minerals in fine- and coarse-textured Willamette Silt samples. A "T" indicates that the average percentage is less than 0.1.

<table>
<thead>
<tr>
<th>Heavy Mineral</th>
<th>Willamette Silt</th>
<th>Willamette &quot;Sands&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hornblende</td>
<td>39.0</td>
<td>32.3</td>
</tr>
<tr>
<td>Lamprobolite</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Augite</td>
<td>7.4</td>
<td>12.5</td>
</tr>
<tr>
<td>Hypersthene</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>Epidote group</td>
<td>8.8</td>
<td>15.7</td>
</tr>
<tr>
<td>Garnet</td>
<td>0.8</td>
<td>1.8</td>
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<tr>
<td>Sphene</td>
<td>0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Zircon</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Kyanite</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Pyrophyllite</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Staurolite</td>
<td>T</td>
<td>T</td>
</tr>
<tr>
<td>Rutile</td>
<td>T</td>
<td>T</td>
</tr>
<tr>
<td>Monazite</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Mica group</td>
<td>3.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Opaque minerals</td>
<td>10.4</td>
<td>13.7</td>
</tr>
<tr>
<td>Hematite</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Leucoxene</td>
<td>3.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Volcanic glass and rock fragments</td>
<td>6.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Unknown</td>
<td>7.8</td>
<td>8.1</td>
</tr>
</tbody>
</table>

1 Samples in Table 7
2 Samples in Tables 9, 13, 14

(tetrabromoethane) is high enough (2.96) so that most micas and much volcanic detritus should have remained in the light fraction. That they didn't may indicate occlusion by a heavy crop or excessive stirring of some samples during gravity separation of heavy minerals rather than actual differences in abundance. Part of the variation may be due to the "channel" method of sampling. This method does not always result in representative samples (61, p. 565-617) in
stratified deposits such as the Willamette Silt.

It is unlikely that textural differences between the 22 Willamette Silt samples (Table 7) caused significant intrasample variations in the abundance of heavy minerals. The particle size data (Appendix B) show that the samples are uniform in texture.

The results of heavy mineral analyses of seven "sand" samples from the Willamette Silt are shown in Table 9. The average percentage of individual heavy minerals in these samples and in seven additional coarse-textured Willamette Silt samples described in the stratigraphy section (see p. 86, 117) is shown in Table 8. Essentially the same heavy mineral suite is present in the coarse- and fine-textured samples. However, the coarse-textured samples contain more augite, opaque minerals, epidote group minerals, and minor constituents such as garnet and sphene. They contain less hornblende, volcanic debris, and micas than is found in fine-textured samples.

The differences in mineralogy between fine- and coarse-textured Willamette Silt samples is apparently due to texture alone. The writer expected that some differences could be traced to incorporation of locally derived sediment in the silt. The data show that incorporation was not significant. For example, local derivation of sediment could result in an increase in the quantity of augite and hypersthene in coarse-textured samples but not in the increase of
TABLE 9. Heavy minerals in sands within the Willamette Silt. The sample sites are shown in Plate 1. A "T" indicates that the minerals were noted in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Sample Designation</th>
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</thead>
<tbody>
<tr>
<td>Hornblende</td>
<td>84</td>
</tr>
<tr>
<td>Lamprobolite</td>
<td>T</td>
</tr>
<tr>
<td>Augite</td>
<td>7</td>
</tr>
<tr>
<td>Hypersthene</td>
<td>6</td>
</tr>
<tr>
<td>Epidote group</td>
<td>44</td>
</tr>
<tr>
<td>Garnet</td>
<td>4</td>
</tr>
<tr>
<td>Sphene</td>
<td>6</td>
</tr>
<tr>
<td>Zircon</td>
<td>3</td>
</tr>
<tr>
<td>Kyanite</td>
<td>T</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>2</td>
</tr>
<tr>
<td>Pyrophyllite</td>
<td>---</td>
</tr>
<tr>
<td>Staurolite</td>
<td>---</td>
</tr>
<tr>
<td>Rutile</td>
<td>---</td>
</tr>
<tr>
<td>Monazite</td>
<td>---</td>
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<td>28</td>
</tr>
<tr>
<td>Hematite</td>
<td>1</td>
</tr>
<tr>
<td>Leucoxene</td>
<td>4</td>
</tr>
<tr>
<td>Volcanic glass and</td>
<td>1</td>
</tr>
<tr>
<td>rock fragments</td>
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</tr>
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<td>Unknown</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>200</td>
</tr>
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</table>
augite alone.

Petrographic Comparison of Willamette Valley Sediments

The data presented in preceding sections show significant differences between heavy mineral suites in local provenance samples and Willamette Silt samples. Comparisons of the average percentages (Tables 5 and 8) and of heavy mineral ratios (Table 6) reveal that the Willamette Silt contains significantly more hornblende, epidote group minerals, garnet, sphene, and other accessory minerals and significantly less hypersthene and augite than are present in either Willamette River floodplain or Willamette River tributary samples. Coast Range streams (Table 1) could have supplied more of some more abundant minerals—for example, garnet and epidote group minerals—but the available data indicate that modern Coast Range sediments are masked by a greater sedimentary influx from the Cascade Mountains. Even if the Coast Range sediments were quantitatively more important during Willamette Silt time, the silt should contain more augite than is present because no change in Coast Range source rocks has occurred since the Willamette Silt was deposited.

Heavy minerals in the Willamette Silt are physically and optically different from their counterparts in Willamette provenance samples. The differences are outlined in Table 10.
TABLE 10. Physical and optical differences between Willamette Silt and Willamette provenance heavy mineral suites.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Willamette Silt</th>
<th>Willamette Provenance</th>
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</thead>
<tbody>
<tr>
<td>Degree of roundness</td>
<td>Mixture of well rounded and angular grains</td>
<td>Angular grains with rare rounded grains</td>
</tr>
<tr>
<td>Degree of solution</td>
<td>Augite shows prominent &quot;cockscomb&quot; terminations</td>
<td>Negligible</td>
</tr>
<tr>
<td>Euhedral crystals</td>
<td>Rare—most commonly hypersthene; also augite and hornblende</td>
<td>Common—hypersthene and zircon (except in Long Tom samples where it is rounded) and augite and hornblende less common</td>
</tr>
<tr>
<td>Crystals with volcanic glass fringe</td>
<td>Rare—usually hypersthene and rarely augite; never zircon</td>
<td>Common—hypersthene, augite, rarely hornblende; most zircon except that from Long Tom samples</td>
</tr>
<tr>
<td>Colored varieties of hornblende</td>
<td>Bluish-green common</td>
<td>Bluish-green rare</td>
</tr>
<tr>
<td>Epidote group minerals</td>
<td>Zoisite and/or clinozoisite common; epidote chiefly single crystals</td>
<td>Zoisite and/or clinozoisite rare; epidote granular aggregates</td>
</tr>
<tr>
<td>Garnet</td>
<td>Colorless, red, and yellow</td>
<td>Colorless only</td>
</tr>
<tr>
<td>Unique minerals</td>
<td>Kyanite, pyrophyllite, monazite, staurolite, andalusite, and sillimanite</td>
<td>None</td>
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</tbody>
</table>
Correlation Samples

The data presented in preceding sections show that the Willamette Silt differs from other Willamette Valley sediments in quantitative and qualitative aspects of its heavy mineral suite.

Previous workers (2, 3, 59, 76) have suggested that the silt was derived from the Columbia River drainage basin and have correlated it with sediments in other Columbia River tributary valleys. However, no published data on the types and quantities of heavy minerals in correlative sediments are known to the writer.

The last phase of the heavy mineral investigation involved correlation of deposits in the Columbia, Yakima, and Walla Walla Valleys with the Willamette Silt. For this purpose, six samples were collected from Columbia River deposits between Camas, Washington, and Hood River, Oregon (Figure 2). The samples were two grab samples from the modern river sediments and four from the modern river floodplain deposits or older fine-grained deposits. The stratigraphic position of these samples is uncertain because of the lack of any detailed study in the area. Six samples were collected from the Yakima and Walla Walla River Valleys of eastern Washington. These samples came from fine-grained deposits which underlie terraces above the modern stream levels, much as the Willamette Silt does in the Willamette Valley. The location of all 12 correlation samples is shown
in Figure 1 and is identified by Township and Range in Appendix A.

Columbia River Heavy Mineral Suite

Petrographic analyses of the six Columbia River samples are reported in Table 11. Five of the six samples contain a similar heavy mineral suite. The sixth, JGC-7, from a sand bar at the confluence of the Columbia and Hood Rivers, has a heavy mineral suite which reflects the influence of the latter stream.

Columbia River sediments have a heavy mineral suite which is comparable in many respects to that in the Willamette Silt (compare the data in Table 11 with those in Table 8). Each contains essentially the same total heavy mineral suite, and the same three groups of minerals are the most abundant constituents in both suites. In addition, heavy minerals in the Columbia River sediments are physically and optically similar to their counterparts in the Willamette Silt.

The average percentage of individual heavy minerals in the five Columbia River samples which have a similar heavy mineral suite is shown in Table 11, and selected heavy mineral ratios are included in Table 6. Comparison of these data with similar data for the Willamette Silt (Tables 8 and 6) shows that differences in average percentage of some minerals exist. The most significant differences are in hornblende, epidote group minerals, and garnet. Columbia River sediments contain less hornblende and more epidote and garnet than
TABLE 11. Heavy minerals in six Columbia River sediment samples. A "T" indicates that the minerals were noted in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
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<th>JGC-5</th>
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<td>1</td>
<td>7</td>
<td>1.5</td>
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<td>T</td>
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</table>

* Ferromagnesian minerals associated with orthoclase
do either the Willamette Silt or Willamette "sands". The largest differences are found between the fine-grained Willamette Silt samples and the Columbia River samples. The Willamette "sands" have a heavy mineral suite which is like that in the Columbia River samples. Because the latter are also sandy (Appendix A), textural differences again are responsible for part of the observed variations in abundance.

Examination of the hornblende in fine- and coarse-textured Willamette Silt samples reveals that the former contain more platy and equi-dimensional grains than the latter. This indicates that shape is a significant factor in the higher percentage of hornblende in fine-grained Willamette Silt samples. The higher percentage of micas in these samples is also due to the platy character of the mica group minerals.

**Heavy Minerals in Yakima Valley and Walla Walla Valley Sediments**

The types and distribution of heavy minerals in Yakima Valley and Walla Walla Valley sediments are shown in Table 12. The average abundance of heavy minerals in these samples and selected heavy mineral ratios are included in Tables 12 and 6. These data show that the heavy mineral suite is similar to that in Columbia River sediments and in the Willamette Silt. In addition, the data show that most components are present in essentially the same quantities. One notable exception is hypersthene, which is much less abundant in the
TABLE 12. Heavy minerals in samples from Yakima Valley and Walla Walla Valley deposits.

A "T" indicates that the minerals were noted in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Yakima Valley</th>
<th>Walla Walla Valley</th>
<th>Average Percent</th>
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<tr>
<td></td>
<td>JY-1</td>
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<td>JY-3</td>
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<td>Total</td>
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</tr>
</tbody>
</table>

*Ferromagnesian minerals associated with orthoclase
Yakima Valley and Walla Walla Valley sediments. The nearly fourfold increase in hypersthene in Columbia River sediments (Table 11) and in the Willamette Silt (Table 8) indicates derivation of this mineral from a local source during transport of the sediment down the Columbia River Valley. Data presented previously (sample JGC-7, Table 11; and Table 2) show that rocks in the Cascade Mountains contain abundant hypersthene.

Heavy minerals in Yakima Valley and Walla Walla Valley samples commonly have a light-colored surface coating or alteration product which the acid pretreatment did not remove. This explains the high percentage (Table 12) of unknown constituents in these samples.

Yakima Valley and Walla Walla Valley samples show considerable intervalley and intravalley variation in heavy mineral abundance. The data are inadequate to establish the reasons for either type of variation. Possibly, sediments not correlative with Willamette Silt were sampled. In this connection, samples JY-2 and JWW-6 are open to interpretation. Both (Appendix A) come from sediments which lack the chaotic cross-bedding, clastic dikes, and erratics found in sediments from which the remaining four samples were collected.
Stratigraphy

The stratigraphy of the Willamette Silt and certain underlying deposits in the north Willamette Valley lowland (Plate 1) was investigated during the present study. Fifty-two samples from shallow hand auger holes were collected to determine textural and mineralogic variations within the Willamette Silt. Additional samples for textural and mineralogical analyses were collected from outcrops. The stratigraphic sequence at many outcrops is described. The results of these investigations are reported below.

Description of Stratigraphic Sections

Post-Willamette Silt stream erosion and the activities of Man have resulted in many exposures of the Willamette Silt. Four sections which display the stratigraphic sequence were selected for detailed study. These sections, named from their geographic locations, are River Bend, Swan Island, Needy, and Deer Creek. The first three sections show different aspects of Willamette Silt stratigraphy beneath the main Willamette Valley lowland (Plate 1). The last section is located on the Coast Range flank of the valley and is typical of the Willamette Silt stratigraphic sequence marginal to and higher than the main Willamette Valley lowland.
The River Bend Section

The River Bend section, shown on Willamette River charts as Feaster's Rocks, is one of the better stratigraphic sections of Willamette Silt in the Willamette Valley. The section is in a reentrant cut into the silt by the Willamette River near the boundary between Dayton and St. Paul 7.5-minute topographic quadrangles (Plate 1). The section is named for River Bend Farm which is located near the river cut on the St. Paul to Fairfield road.

A nearly continuous section 1.5 miles long is exposed at River Bend. The base of the section lies at Willamette River low-water level at an altitude of approximately 75 feet, and the top of the section lies at an altitude of about 175 feet. The 100-foot section is well exposed except where local slumping or vegetation is present. The cliff faces westerly but it is semicircular in plan view so its trend ranges from N. 30° E. to N. 30° W. The photographs (Figures 3-17; 20, 21) which support the descriptions of stratigraphic units are taken looking due east.

Three stratigraphic units are recognized at River Bend. They are designated and are described in subsequent sections from bottom to top as Unit I, II, and III. The relationship between units and the general nature of the River Bend section are shown in Figure 3. Unit III is the Willamette Silt.
FIGURE 3. Stratigraphic units at River Bend.
Unit I. The basal unit is a conglomeratic sandstone which contains intercalated mudstone, sandstone, and conglomerate. The unit is a prominent ledge-former, and a particularly resistant ledge at river level forms Feaster's Rocks.

Twenty feet of the basal unit crops out at low-water Willamette River stages. The upper contact is marked by a paleosol along which many springs occur. Water from these springs drips over the basal unit and gives it a dark color (Figure 3) which sharply contrasts with the color of overlying units. The unit extends below the low-water level so that its maximum thickness is not known. Water well logs (68, p. 1-313) in the vicinity of the River Bend section show that sediments similar to those in Unit I are at least 240 feet thick.

The bulk of the conglomeratic sandstone is sand which ranges from one to two millimeters in diameter. Clasts larger than two millimeters and as much as 150 millimeters in diameter in part are distributed randomly through the sandstone and in part form pebble layers. The layers range in thickness from one to three inches and are variable in length. Most clasts over two millimeters in diameter are pebble size.

A fine sandy clay matrix coats the larger clasts and fills the pore spaces. The percentage of matrix increases upward in the section, and the matrix apparently represents weathered material carried downward from the paleosol by percolating ground water.
In addition to being bound by the sandy clay matrix, the conglomeratic sandstone is cemented partially by calcium carbonate. The degree of cementation increases upward; this increase suggests that the carbonate is authigenic and that it formed during the development of the paleosol. The paleosol contains a well-defined zone of carbonate accumulation (see Figure 5).

The conglomeratic sandstone is composed of well rounded rock fragments of various colors. The sand grains are not easily identified, but their prevailing dark color and fine texture indicate that they are basalts or andesites. Angular feldspar and quartz grains are subordinate constituents. The larger clasts are well rounded and are usually discoidal. They represent acid to basic igneous rocks, with basalt and andesite more abundant than rhyolite. Many clasts contain phenocrysts of feldspar and/or altered ferromagnesian minerals. Light-colored tuffaceous sandstone clasts are present as are multicolored agates.

Stratification and other sedimentary structures are poorly preserved in the conglomeratic sandstone although they are common in sandstone lenses. Pebble layers generally are nearly horizontal although some layers dip in various directions. The relationship of the latter to stratification in the enclosing sediments is obscured by the lack of well-defined strata except that of the layers. Isolated larger clasts and the pebbles locally are arranged in an imbricate structure,
but no uniform direction of current movement is shown.

Although conglomeratic sandstone forms the greater part of Unit I, mudstone, sandstone, and conglomerate are present locally and are more common toward the base of the section.

The mudstones are found in tabular bodies which vary in size. The largest body forms Feaster's Rocks and is a prominent ledge which extends 50 feet into the river and 300 feet along the river. The ledge disappears below the water level both upstream and downstream from Feaster's Rocks. A second mudstone body which occurs at the top of Unit I is eight feet thick and is traceable along the river for 200 feet. Slumping, which is widespread where the mudstone is the uppermost sediment in Unit I, prevents further definition of the extent of this body.

The color of mudstone beds varies from red and yellow to blue black and green. Within one bed the color varies according to local moisture conditions. Red and yellow mudstone units, on the basis of an absence of organic matter and on color, indicate oxidizing conditions. Blue-black and green beds contain abundant organic matter which, with an odor of sulfur on fresh break, indicates a reducing environment.

Many mudstone beds are locally sandy, and in some places, contain pebbles. Many also have abundant carbonate concretions, particularly along the upper boundary. The concretions are irregular
pebble- to cobble-size nodules; the largest concretion was four inches in diameter. Locally, the upper boundary of a mudstone bed is marked by a layer of calcium carbonate not exceeding one inch in thickness. The nature and occurrence of the carbonate suggest that it is secondary in origin.

The sandstone in Unit I occurs in lenticular bodies (Figure 4) which vary greatly in apparent dimensions. The lens in the middle of Figure 4 has a maximum thickness of four feet and a width of 32 feet; its length is unknown. The dark lens four feet below the Unit I paleosol in Figure 4 has a maximum thickness of one foot and is 16 feet long. The sand is fine to medium and is partially cemented with calcium carbonate. The dominant minerals are angular quartz and feldspar. Sandstone lenses are characterized by prominent cross-bedding, much of which is the festoon type (Figure 4). Scour-and-fill structures and horizontal or gently inclined bedding occur in some sand lenses. Variable directions of current movement are indicated by the cross-bedding.

The conglomerates in Unit I are found in lenses and in beds. The lenses are comparable in size to the sandstone lenses. The conglomerate beds are not well defined; generally, they grade vertically and laterally into conglomeratic sandstone. The thickest well-defined conglomerate bed is four feet thick and was traced 260 feet along the River Bend exposure.
FIGURE 4. Sandstone lens in Unit I, River Bend section. The dark zone below the vegetation in the upper center of the photograph is the paleosol which marks the upper boundary of Unit I. Note the "stringers" extending from the paleosol down into the parent material.

FIGURE 5. Paleosol developed on Unit I sediments, River Bend section. Note at the upper right a tilted block of paleosol clay surrounded by coarse sands of Unit II.
The conglomerate lenses and beds contain clasts of basalt, andesite, and rhyolite which range from pebbles to cobbles ten inches in diameter. The clasts are set in a sandy matrix, and the sediment is strongly cemented by hematite and limonite. More rarely, a black oxide--probably a manganese compound--is the cementing agent. Field examination did not reveal any carbonate cement in conglomerate lenses.

The top of the basal unit at River Bend is marked by a heavy clay and by a zone of calcium carbonate accumulation which represent the "B" and "B_{ca}" horizons of a paleosol (Figure 5). No evidence of a buried "A" horizon was noted along the River Bend exposure or in any other section investigated. The weathered zone of the paleosol is three to four feet thick. The lower boundary is transitional with the underlying parent material, and resistant pebbles in the parent material remain in the heavy clay of the paleosol.

The paleosol clay ranges in thickness from five to ten inches (Figure 5). The color of the clay varies from buff to blue black and depends on local oxidation-reduction conditions which, in turn, depend on the type of parent material and whether springs are present in the overlying coarse sands. The paleosol shows only weak structural development and locally is massive. Where the paleosol is developed on a mudstone lens, the clay has a subangular blocky to platy structure.
The zone of calcium carbonate accumulation is approximately 24 inches thick. The carbonate is found as well-defined vertical "stringers" (Figure 5) and as a white surface coating.

The Unit I paleosol and the parent material from which it is formed contain cylindrical tubes of dark-red sandy clay (Figures 4 and 6). These tubes are restricted to sandy parent materials and to places along the outcrop where the sands are well drained. The tubes extend at least three feet back from the face of the outcrop. Their size decreases downward from a maximum of two inches near the paleosol surface. The large tubes bifurcate downward from the paleosol into small tubes some of which run parallel to the paleosol surface.

The extent, size, and branching pattern of the tubes in the Unit I paleosol indicate that they are the sediment-filled root cavities of plants which grew on the paleosol prior to burial.

The Unit I paleosol shows no evidence of extensive pre-Unit II erosion along the mile or more of exposure. It is continuous along the cliff at nearly the same altitude except where modern streams have incised it, and it does not vary appreciably from its three-four-foot thickness.

Sheet erosion or local "plucking" accompanied the deposition of the black sands in Unit II. Small irregularities are apparent from an inspection of the contact shown in Figure 5, and Figure 7 shows
FIGURE 6. Cylindrical tubes of red sandy clay associated with the Unit I paleosol. The photograph was taken looking down at the top of a slump block so only the round ends of tubes are shown.

FIGURE 7. Blocks of clay plucked from the Unit I paleosol by the currents which deposited the overlying sands.
two blocks of paleosol clay which are separated from the paleosol surface. These blocks are as large as eight inches in diameter. The largest blocks are found near the paleosol surface and adjacent to sand-filled cavities from which they came.

Trimble (76, p. 55-56) described deposits along the Willamette River north and west of Canby (Plate 1) which the writer considers correlative with Unit I. Trimble assigned a middle Pleistocene age to the deposits, named them the Gresham Formation, and considered them correlative with the Leffler gravels of Allison (8, p. 9-11).

Unit II. Black sands and red silts form Unit II at River Bend where they unconformably overlie the paleosol of Unit I (Figure 5 and 7). The red silts are conformable (Figure 8) with the overlying buff to tan Willamette Silt of Unit III.

At one locality along the River Bend outcrop, a sharp contact (Figure 9) seems to separate oxidized Unit II sediments from the Willamette Silt. Heavy mineral studies (see p. 86) show, however, that the apparent contact is within locally derived sediments. The oxidation of these sediments is probably due to better local drainage. The sharp contact is caused by a textural and structural change in the local sediments; this change has caused the precipitation of secondary calcium carbonate in the sediments above the apparent contact.

The River Bend section contains a greater thickness of Unit II
FIGURE 8. Interbedded dark silts of Unit II and light silt of Unit III, River Bend section.
FIGURE 9. Apparent unconformable relationship between Unit II and Unit III silts, River Bend section.

FIGURE 10. Basal sand phase, Unit II, River Bend section.
sediments than is found in other exposures. The maximum measured thickness is 20 feet; however, near the upstream end of the River Bend section, only ten feet of Unit II is present. Part of the measured variation is due to uncertainty as to the position of the upper contact of the unit. The sands and silts which form the unit occur in irregular and lenticular bodies which show considerable local as well as regional variation in thickness. Only two to four feet of Unit II sediments are exposed across from Clark's Marina (Plate 1, SW1/4, Sherwood 7. 5-minute topographic quadrangle) and similar thicknesses are present in sections south (Plate 1, Durette's Landing and unnamed section five miles west of FMB7) of the River Bend locality. The Deer Creek, Needy, and Swan Island sections (Plate 1) do not contain pre-Willamette Silt sediments similar to those found in Unit II at River Bend.

Piper's (64, p. 49-52) report summarizes the water well log data on the distribution and thickness of Unit II type sediments. His upper confined-water-bearing zone occurs at elevations and has characteristics which indicate that the water comes from Unit II sediments. Piper (64, p. 50) believed that the zone became thinner west and north of the central part of the Willamette Valley north of Salem, and a similar distribution is shown above for the Unit II sediments.

Piper (64, p. 35) also noted a distinct difference in occurrence and nature of water-bearing zones in the south and north parts
of the Willamette Valley. The writer's observations of stratigraphic
sections and investigations of water well logs, many of which were
not available to Piper, indicate that Unit II sediments are confined to
the north Willamette Valley, or at least that they thin so as to be un-
important as a source of water south of Salem. Allison's (8, p. 12)
type section of the Willamette Silt at Irish Bend (Figure 2) has no
sediments similar to Unit II sediments, but rests on the presumed
equivalent of Unit I instead.

Unit II at River Bend is divided on the basis of texture and
sedimentary structures into three phases which are designated from
bottom to top as a basal sand, a middle sand and silt, and an upper
silt phase. One or more phases are recognizable in most other
stratigraphic sections along the modern lower Willamette River
course.

The basal sand (Figure 10) ranges from 2 to 12 feet in thick-
ness and is more variable in thickness than the overlying fine-grained
phases. The sand is blue when dry, black when moist. Particles
range from coarse sand to pebbles an inch in diameter. The latter
are rare but occur randomly scattered through the sand.

Hand-lens and binocular examination of the coarse sand frac-
tion shows a heterogeneous mixture of multicolored, angular to well
rounded, fine-grained volcanic and tuffaceous rock fragments and a
scattering of angular, clear plagioclase feldspar grains. Clasts
greater than two millimeters in diameter are principally light-colored tuffaceous sandstone fragments. Locally, pumice fragments predomi-
nate.

The dominant structures in the sand phase are cross-bedding and cut-and-fill channels. Contorted or disrupted bedding (Figure 11) and steeply dipping cross-beds are widespread. The cross-bedding is both large- and small-scale. Foreset beds have a measured length which ranges from 0.2 feet to 14 feet. The foreset beds indicate current movement in various directions but chiefly north. The foresets are locally marked (Figure 10) by accumulations of pumice frag-
ments or other tuffaceous and light-colored rock fragments.

The basal sand is overlain transitionally by the second phase which is characterized by complexly intercalated lenses of sand and red silt (Figure 12). This phase ranges from four to six feet in thick-
ness along the River Bend exposure. The boundaries between sand and silt are sharp and irregular (Figure 13), and, in the case of those in Figure 13, show post-depositional deformation of the sediments. The sand in the lenses is finer and is more uniform in size that the basal sand. Generally, thicker lenses of these sands are structure-
less although some lenses show contorted bedding. The silt lenses, in contrast to the sand, usually contain abundant sedimentary micro-
structures, chiefly cross-bedding (Figure 14) and irregular flow marks (Figure 12). Some silt lenses are surficially structureless.
FIGURE 11. Cross-bedding, cut-and-fill channels, and contorted bedding, basal sand phase, Unit II, River Bend section.

FIGURE 12. Intercalated black sands and red silts, middle phase, Unit II, River Bend section.
FIGURE 13. Contacts between sand and silt, middle phase, Unit II, River Bend section.

FIGURE 14. Sedimentary structures, middle sand and silt phase, Unit II, River Bend section.
The zone of intercalated sand and silt lenses is transitional upward into the third and upper phase of Unit II. The upper phase includes six to ten feet of red silt. In the transition zone between the upper phase and the underlying phase, the silt is interbedded with fine sand, and the bedding planes are nearly horizontal (Figure 15). Prevalent slumps in the overlying Willamette Silt prevent tracing individual beds for long distances; the longest continuous exposure of these beds was 25 feet.

A layer of volcanic ash (Figure 15) in the middle of the horizontal beds of silt and sand is less than 0.5 inch thick. The beds of sand and silt range in thickness from 0.5 inch to slightly over three inches, but most beds are less than one inch thick. Binocular examination of the ash reveals crystals of plagioclase, green ferromagnesian minerals, and many small red hematite masses with regular boundaries. The hematite grains apparently represent altered ferromagnesian minerals.

The ash layer occurs in the same stratigraphic position along most of the River Bend exposure and, in one locality, was traced for approximately 200 feet. Over this distance, the ash layer is concordant with the bedding of the silt and sand beds and shows only slight variation in altitude, most of which is due to post-depositional compaction or slumping. This observation is supported by locally contorted bedding which shows in the ash layer as small folds and by the
FIGURE 15. Ash layer in horizontal beds of silt and fine sand, upper silt phase, Unit II, River Bend section. A small clastic sand dike occurs near the right side of the photograph.

FIGURE 16. Contacts between beds, middle Willamette Silt section, River Bend exposure. The beds show normal grading.
presence of small clastic dikes (right side of Figure 15). The dikes contain coarse sand similar to that found in the basal phase of Unit II.

The percentage of sand decreases and the percentage of silt increases toward the top of the upper silt phase. The top four feet of the phase is laminated calcareous silt. Nodular carbonate concretions as large as one inch in diameter occur in the upper part of the silt phase. At the locality shown in Figure 9, a line of the concretions is present along the boundary between light and dark sediments. The sediments above the line are finer in texture and less regularly laminated than the underlying sediments.

The nature and distribution of heavy minerals in samples from the bottom, middle, and top phases of Unit II are shown in Table 13. Channel samples were collected from a one- to two-foot zone in each phase. The size fraction analyzed in these samples was the same as that analyzed in samples previously described (p. 29). Comparison of the heavy mineral suite in these samples with that found in local provenance samples (Tables 1, 2, 3) shows that Unit II sediments were derived from the local drainage basin.

The data in Table 13 also illustrate the problem of field definition of the boundary between Unit II and Unit III sediments. Sample JG63-40 was collected about a foot above the calcium carbonate zone shown in Figure 9 and from sediments which were thought to be stratigraphically and mineralogically Willamette Silt. Sample JG63-39
TABLE 13. Variation in heavy mineral suites with stratigraphic position, River Bend section. A "T" indicates that the mineral was noted in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
<thead>
<tr>
<th>Stratigraphic Position</th>
<th>Basal Black and red silt</th>
<th>Red Silt</th>
<th>Transition Unit II to Unit II</th>
<th>Transition Unit II to Unit III</th>
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cc 0'
came from a locality where no contact was apparent, but the sediments sampled, because of their light color, were thought to be Willamette Silt. The data in Table 13 show, however, that the heavy mineral suite in both samples is like that in Unit II sediments although some indication of a change in mineralogy is present. Sample JG63-RBII, which came from sediments four feet above JG63-40, contains a heavy mineral suite which shows that the contact between locally derived sediments and Willamette Silt lies in the interval between the two samples. Stratigraphically, however, no break is discernible, and the Willamette Silt conformably overlies local sediments.

**Unit III.** Bedded clayey silt sixty feet thick represents the Willamette Silt at River Bend. At its base, the silt conformably overlies the red silts of Unit II; its upper boundary is a present day erosion and weathering surface. The soil developed on Willamette Silt at the River Bend locality is mapped (74) as the Amity soil series. This series is an imperfectly drained member of the catena composed of Willamette (well drained), Woodburn, Amity (intermediate), and Dayton (poorly drained) soils.

Gray pebbly silts locally overlie oxidized Willamette Silt along the River Bend exposure. The gray silts range from 0 to 12 inches in thickness. Their thickness and distribution are controlled by local relief on the underlying Willamette Silt surface and by local erosion.
The stratification of the Willamette Silt is its most distinctive feature (Figure 3). It stands out conspicuously because small variations in texture cause differences in the ability of the sediment to retain moisture. Thus the dark bands in Figure 3 are more moist and contain finer sediment than the light bands. At least 40 distinct beds are visible in the River Bend Willamette Silt section.

The light and dark bands (Figure 3) vary locally in thickness. The total thickness of a bed does not appreciably change so that variations in thickness of coarse sediment are compensated by equal and opposite variations in the thickness of fine sediments. The individual beds are nearly horizontal, and many can be traced laterally for distances of 1,000 feet. Discontinuous exposures and prevalent slumping of the silt prevent tracing beds farther.

The bedding in the Willamette Silt differs in distinctness and in thickness with stratigraphic position. The beds in the lower five to ten feet are indistinct, and in many places, this part of the silt section is structureless (Figure 9). Locally, thin laminations and lenses or pockets of fine sand occur. The elongation of the lenses or pockets is parallel to bedding planes in the silt higher in the section. Most lenses and pockets are less than two inches thick, and they are seldom continuous for more than six to eight inches along the outcrop. The lenses or pockets do not occur randomly but instead crop out along certain zones. This indicates that they are part of an otherwise
obscure stratification in the basal Willamette Silt.

The middle 40 to 50 feet of the Willamette Silt (Figure 3) has sharply defined beds which range in thickness from 6 to 32 inches. The average bed thickness is about 14 inches. The beds thicken and contain more coarse sediment toward the top of the middle section so that the thickest and coarsest beds (Figure 3) occur about 12 feet below the upper boundary of the silt.

The top five to ten feet of Willamette Silt contains beds which average less than six inches thick. These beds are destroyed to varying depths by soil-forming processes.

Contacts between beds in the middle of the Willamette Silt section are shown in Figures 16 and 17. The contacts are sharp, only slightly irregular, and nearly horizontal. The irregularity consists of micro-scour marks (Figure 17) caused by currents which precede or which accompany deposition of the upper bed. These currents had little erosive force as neither large scour features nor truncation of beds occurs in the River Bend section.

No evidence of subaerial weathering or erosion between Willamette Silt beds is present in the River Bend section.

Individual beds at River Bend display one of two types of graded bedding. The first and more common type is the well known normal grading (Figure 16) in which coarse sediments grade into fine sediments higher in the bed. In the second type, called "double
FIGURE 17. Micro-scour marks along the contacts between beds, middle Willamette Silt section, River Bend exposure.
grading", the coarsest sediment is in the middle of the bed. Double grading does not occur in thin beds but is common in thick beds at the top of the middle section.

Cumulative curves for three composite samples from the bottom, middle, and top thirds of a Willamette Silt bed in the middle of the River Bend silt section are shown in Figure 18, and the variation in Inman (52) textural statistics for these samples is depicted in Figure 19. These data show that 1) the bed has double grading, 2) the bottom is coarser than the top, 3) the sorting decreases from bottom to top but is improved in the middle where the sediment is most coarse, and 4) skewness and kurtosis are more pronounced in the middle of the bed. The particle size distribution in samples from beds with normal grading in the River Bend Willamette Silt section is similar to that shown for the middle and top samples in Figures 18 and 19.

The data in Figures 18 and 19 show the texture of the Willamette Silt at River Bend. The silt contains between 69 and 86 percent silt. Even the coarse sample from the middle of the bed with double grading contains no appreciable amount of sediment larger than fine sand. Other Willamette Silt beds, regardless of their grading, are texturally similar. Near the bottom of the silt section, the lenses or pockets contain medium to coarse sand, but no sediment this coarse occurs in overlying beds.
FIGURE 18. Cumulative frequency curves for three samples from the bottom, middle, and top of a Willamette Silt bed with double grading, River Bend section.
FIGURE 19. Variation of texture with stratigraphic position in a Willamette Silt bed, River Bend section. Statistics after Inman (52); Md_\phi = phi median, M_\phi = phi mean, \sigma_\phi = phi deviation, \alpha_{1\phi} and \alpha_{2\phi} = first and second phi skewness, \beta_\phi = phi kurtosis.
In addition to their grading, Willamette Silt beds display other internal structures. The fine silts and clays show crude laminations, and the coarse silts and fine sands exhibit cross-bedding, scour-and-fill, ripple marks, and irregular tapered and elongate features (Figures 20 and 21). The last, for descriptive purposes, are called flow marks.

Ripple marks (Figures 20 and 21) are made up of foreset, topset, and bottomset beds arranged to form a series of asymmetrical anticlines and synclines. The length and slope of ripple mark foresets are similar to those of cross-bed foresets. The ripple marks in Figures 20 and 21 show sediment movement from right to left in the photograph or in a northward direction.

The cross-bedding is small in scale but very prominent despite the limited particle size range. The foresets are less than three inches long, and they slope less than 25 degrees.

The flow marks are well shown above the ruler in Figure 20. They consist of tapered and elongate lenses of clay and silt enclosed in fine sand. The lenses are less than six inches long and are no more than 0.5 inch thick. Their elongation is generally parallel to the horizontal bedding planes of the Willamette Silt. Locally, they are subparallel but their slope is no more than five degrees and is much less than that of other cross strata.

The basal part of Unit III and the upper part of Unit II at
FIGURE 20. Sedimentary structures in a Willamette Silt bed, River Bend section.

FIGURE 21. Detail of sedimentary structures shown in Figure 20.
River Bend contain a calcareous and nonleached zone. This zone has a horizontal extent of less than 200 feet and is apparently due to an unusual amount of impervious clayey silt beds in the overlying section. These covering beds effectively prevent leaching by downward percolating and normally slightly acid ground water.

The only invertebrate fossils known by the writer to occur in the Willamette Silt are preserved in the calcareous beds at the base of the River Bend section. The fossils are found in a zone six to ten feet thick, within which the contact between locally derived sediments (Unit II) and Willamette Silt (Unit III) occurs. Sample JG63-40, which contains a local provenance heavy mineral suite, and JG63-RBII (Table 13), which contains a Willamette Silt heavy mineral suite, are both collected from calcareous and fossiliferous sediments.

The fossils are macroscopic and microscopic. The former belong to the Phyla Gastropoda and Pelecypoda, and the latter belong to the Phylum Ostracoda. Ostracod tests are the most common fossils, and gastropods are far more abundant than pelecypods. Both the gastropods and pelecypods are small and are usually less than two millimeters in diameter. Rarely shells of both are as large as 0.5 inch in diameter. The shells are fragile and, if dry, will break into fragments when touched. The mollusks are distributed along the somewhat indistinct bedding planes which characterize this part of the silt. Toward the top of the fossil-bearing sediments, mollusks
are found in thinly laminated beds and along bedding planes.

Complete identification of all the fossils in the River Bend sediments has not been attempted. Dr. Ivan Pratt of the Department of Zoology, Oregon State University, has identified the gastropods and pelecypods as fresh-water pulmonate species similar to species which live in the Willamette Valley at present. The ostracods are also fresh-water forms similar to those in modern lakes and ponds.

The mollusks were sent to Dr. Joseph P. E. Morrison, at the United States National Museum, Washington, D. C., at the suggestion of Dr. Pratt. Dr. Morrison identified the following gastropod species:

- Gyraulus circumstriatus (Tryon)
- Armiger crista (Linnaeus)
- Stagnicola palustris nuttalliana (Lea)
- Fossaria perplexa (Baker and Henderson)
- Fossaria cooperi (Hannibal)
- Succinea gabbi (Tryon)

Dr. Morrison (letter dated 17 March 1964), stated that the environment indicated by these species was most probably a series of ponds on the flood plain of the river. In particular, the species Armiger crista (Linnaeus) is known typically from more or less shallow ponds that may be crowded with water weeds. The last three species on the list, that is, both species of Fossaria and the species of Succinea, are characteristic of silt or muddy sand margins of lakes, ponds, or streams. To me, these ponds would not have been temporary
ponds in the usual sense of the term. That is, they would not be drying up for a part of each year. They would be temporary in a geological sense or transient, as the sedimentation in the valley progressed or was cut away.

The pelecypods have not been positively identified, partly because they are scarce and usually somewhat badly broken during removal from the sediments. The shells appear to belong to species in the Sphaeriidiae family (64, p. 724) but they were not further identified.

The nature and distribution of heavy minerals in two Willamette Silt samples from the River Bend section are shown in Table 13. Sample JG63-RBII is from sediments near the base of the Willamette Silt section and only four feet above JG63-40. Sample JG63-35 is located near the middle of the section. Both of these samples contain a similar heavy mineral suite which differs considerably from that reported in the underlying sediments (Table 13) and which is not greatly different from that previously described in the section on petrography of the Willamette Silt.

Although the samples described above are the only ones on which grain counts were made, the silt section was examined thoroughly in the field, and numerous other samples were collected to determine if any beds with a local heavy mineral suite occur above the transition zone at the base of the silt. These samples were spot
samples of a restricted stratigraphic interval, usually less than a quarter of an inch thick. Particular attention was devoted to contacts between beds. This investigation revealed no field evidence which established local sediments above the base of the silt section nor was any evidence found which indicated significantly greater mixing of local minerals and Willamette Silt minerals near the contacts between beds.

Field investigation of the Irish Bend (Figure 2) type section of the Willamette Silt (8, p. 12) also failed to establish the presence of local sediments in the silt section.

Many other exposures are known where the sediments are similar to those at the River Bend section. These exposures are located on the western side of the north Willamette Valley lowland, and most are associated with undercutting of the Willamette Silt surface by the Willamette River. Good sections may be viewed at Durette’s and Weston Landings (Plate 1). One exception to the general location of these exposures is the excellent section across from Clark’s Marina (Plate 1). The full section here shows the same three units as are found at River Bend although Unit II is only two to three feet thick and the Willamette Silt has an exposed thickness of approximately 70 feet. This thickness is a minimum because the surface of the silt less than a quarter of a mile south is 30 to 40 feet higher than the surface is at Clark’s Marina.
The Needy Section

The Needy section is located four miles east of Hubbard and eight miles west of Molalla (Plate 1). The section is along the north-east bank of Rock Creek, a tributary of the Pudding River. The Needy Brick and Tile Company, from which the section is named, uses sand and silt from the Willamette Silt, and clay from the Rock Creek floodplain as raw materials for their products. The section was exposed during quarrying of these raw materials.

The Needy section (Figure 22) faces generally west but is semicircular in plan view so that north-facing and south-facing cuts are present. The base of the cut is the Rock Creek floodplain which stands at an altitude of 110 feet. The top of the section stands at an altitude of 180 feet. Because of slumping, only 62 feet of section is exposed.

Two units are distinguished at Needy. The lower unit resembles sedimentary rocks which crop out east of the Needy locality near the city of Molalla where they are called the Molalla Formation (48). The upper unit is Willamette Silt. For purposes of identification and description, the units are designated Unit I and Unit II respectively, but they should not be confused with units with the same designation in other sections.

Unit I. The base of Unit I is not visible at Needy, and only
FIGURE 22. Needy section, Needy Brick and Tile Company Quarry
the upper 12 feet is exposed. The top is marked by a paleosol similar to that on Unit I sediments at River Bend. Slumping covers all but the paleosol along most of the cut except at the north end of the exposure.

Unit I is a fine to medium sandstone which contains isolated pebbles and thin conglomerate beds. The sandstone is poorly cemented, and the grains are bound by a tuffaceous matrix. The latter gives the sandstone a white color and a tendency to flake when dry. Locally, irregular bands of hematite partially cement the sandstone.

The sandstone contains visible mica (mostly muscovite), feldspars, quartz, and larger grains of green, black, and red volcanic rock. Small organic fragments are also present. The conglomerate beds and pebbles are composed of different types of volcanic rock. Dark-colored, uniformly fine-grained basalts and porphyritic basalts are the most abundant; banded rhyolitic clasts and red and yellow agates are common.

The upper part of the sandstone and the lower part of the paleosol contain numerous cylindrical sediment-filled tubes which range from 0.25 to 0.5 inch in diameter. These tubes are filled with red sandy clay and resemble similar tubes described at the River Bend section.

The paleosol is deep red, almost maroon, where moist and a light orange red where dry. Water seeps occur along the top of the
paleosol, and the clay underlying these seeps is strongly reduced and blue black. On fresh break, the clay has an odor of hydrogen sulfide.

The Unit I paleosol shows two well-defined soil horizons (Figure 23). The lower horizon is a sandy clay 12 to 14 inches thick. It shows a strongly developed, coarse, prismatic to blocky soil structure and a zone of iron oxide. The upper horizon is 6 to 12 inches thick and texturally is a heavy clay. The horizon lacks any noticeable soil structure. Locally, a band of hematite 0.5 inch thick occurs at the top of this horizon.

Pebbles and cobbles occur in the paleosol. These are similar in distribution and characteristics to those in the underlying sandstone and are interpreted as incompletely weathered clasts of the parent material.

The top of the Unit I paleosol shows little evidence of pre-Unit II erosion. It is continuously exposed at nearly the same altitude along about 100 feet of the cut, and it crops out intermittently along the remainder of the cut. No changes in altitude or channels in the paleosol are noted.

**Unit II.** The Willamette Silt at Needy is 50 feet thick. The bottom and top of the section are marked by soil profiles; the former is the paleosol described above. The Willamette soil series (55) is formed on Willamette Silt in the vicinity of the Needy section.

Gray pebbly silts overlie oxidized Willamette Silt at Needy.
FIGURE 23. Paleosol developed on Unit I sedimentary rocks, Needy section.

FIGURE 24. Willamette Silt beds at the base of the Needy section.
A small exposure of gray silt is shown at the top of the Willamette Silt section on the left side of Figure 22. The gray silts are thin or absent at the level of the adjacent Willamette Silt surface (center of Figure 22) but thicken to more than two feet on the slope which leads from this surface to the Rock Creek floodplain.

The basal Willamette Silt (Figure 23) at Needy is represented by ten feet of sediment which ranges from silt to coarse sand. The sediments are crudely stratified and bedding planes are difficult to discern (Figure 24). The sands occur in pockets and lenses which are elongated parallel to stratification higher in the section (Figure 22). The pockets and lenses range from one inch to three inches in thickness and they crop out intermittently along certain zones (Figure 24). The fine sediments in a bed are crudely laminated. Individual beds are six to ten inches thick and are marked at the top and bottom by slight variations in texture and color (Figure 24). Pockets and lenses of coarse sediment are located in a medial position relative to the boundaries of a bed.

Distinctive features of the basal section at Needy are organic fragments and isolated pebbles or cobbles. The organic fragments are wood chips and bones. The wood chips contain little visible carbon and the organic structure is preserved by replacement by hematite. Attempts to obtain enough carbon for C\textsubscript{14} dating were unsuccessful. The bone fragments are well preserved but have not been
identified to date, and the specimens were found too late to be dated by radiocarbon methods. Bone fragments and complete bones of proboscidians have been found in the Willamette Valley. Most of these occur in sediments at or near the base of the Willamette Silt (Allison, personal communication) but some may be younger (47).

Pebbles and cobbles occur (Figure 25) in groups or pockets of two or three or more and in irregular or lenticular masses (Figure 26). The largest clasts are about four inches in diameter. The largest lens has a maximum thickness of four inches and has a visible length of six feet. The pebbles and cobbles are unusual because many are completely surrounded by fine-grained sediments. All the pebbles and cobbles are basalts or andesites and most are well rounded.

The basal Willamette Silt beds are overlain by alternating strata of sand and silt (Figures 24 and 27). Contact relationships show that some sand and silt strata represent normally graded beds. In these, the sand is sharply set off from the underlying silt and is transitional into the overlying silt. In other beds, both contacts are sharp and the beds are either sand or silt. Individual beds range in thickness from four to ten inches. The sands are coarse, much like those in the basal lenses and pockets, but are stratigraphically continuous (Figure 27). In addition, they show a characteristic, well-defined horizontal bedding (Figure 27) which is not present in the underlying sands. The silts are crudely laminated and locally contain
FIGURE 25. Isolated pebbles in the basal beds of the Willamette Silt, Needy section. The paleosol on Unit I sedimentary rocks crops out as the gray beds at the lower right.

FIGURE 26. Lens of pebbles and cobbles in the basal Willamette Silt beds, Needy section.
FIGURE 27. Horizontal beds of coarse sands and of laminated silts above the basal beds in the Needy Willamette Silt section.

FIGURE 28. Lower contact between Willamette Silt beds in the middle of the Needy section.
flow marks similar to those described in the River Bend section.

The zone of continuous sand and silt beds is 12 to 15 feet thick. The sediments in the next 20-foot interval, approximately the central part of the section (Figure 22), resemble those in the underlying zone. They differ chiefly in that the sand and silt beds are as much as three feet thick and lack continuity. Thickening, thinning, and lensing, and unconformable relationships between beds are displayed in Figure 22. The dark bands are fine-grained sediments. The sands are light-colored and show conspicuous horizontal bedding.

The contact relationships of a single bed in this part of the Willamette Silt section are depicted in Figures 28 and 29. The lower contact (Figure 28) is sharp, slightly irregular, and marked by a pronounced change from coarse sand to clayey silt. The upper contact (Figure 29) is also sharp, slightly more irregular, and marked by a change from coarse sand to clayey silt. The grading in this bed is discussed below.

The data in Figures 30 and 31 show the results of mechanical analyses of samples from the bottom, middle, and top thirds of a bed in the middle part of the silt section. These data also show the textural characteristics of the Willamette Silt and the nature of the graded bedding in the Needy section. The data show that 1) the bed has reverse grading from 94 percent silt at the bottom (JG63-31) to 86 percent sand at the top (JG63-33); 2) sorting is generally good
FIGURE 29. Upper contact of same bed shown in Figure 28.
FIGURE 30. Cumulative frequency curves for three samples from the bottom, middle, and top of a Willamette Silt bed with reverse grading, Needy section.
FIGURE 31. Variation of texture with stratigraphic position in a Willamette Silt bed, Needy section. Statistics after Inman (52); $\text{Md}_\phi$ = phi median, $M_\phi$ = phi mean, $\sigma_\phi$ = phi deviation, $\alpha_{1\phi}$ and $\alpha_{2\phi}$ = first and second phi skewness, $\beta_\phi$ = phi kurtosis.
and is slightly poorer at the top than at the bottom; 3) the samples are all skewed to the fines; 4) the middle of the bed is less skewed and the particle-size distribution is less peaked than at the top or bottom of the bed. A comparison of the River Bend data (Figures 18 and 19) with the Needy data shows that 1) the Willamette Silt at River Bend is finer than that at Needy even in the finest part of the latter; 2) the Willamette Silt is better sorted at Needy; 3) samples from both exposures are strongly skewed to the fines; and 4) skewness and kurtosis show opposing trends with stratigraphic position at the two exposures.

The fine sediments at the bottom of a bed in the middle of the silt section are crudely laminated or show flow marks (Figure 32). As the sediments become coarser toward the center of a bed (top of Figure 28 and middle of Figure 32), cross-bedding and cut-and-fill appear. The cross-beds have foresets which slope less than 25 degrees and generally about 20 degrees. The length of the foresets increases from two inches or less in the middle of a bed to as much as eight inches near the top of a bed. Comparison of the length of foresets in the upper left corner of Figure 33 with the length of those in the lower middle illustrates this point. The cross-beds in Figure 33 show current movement from left to right or toward the south and up the Willamette Valley.

Higher in the bed, cross-bedding is abruptly truncated to a
FIGURE 32. Cross-bedding, cut-and-fill, flow marks and horizontal bedding in the Needy Willamette Silt beds. Current movement is from left to right or nearly due south.

FIGURE 33. Large scour-and-fill structure, middle Willamette Silt beds, Needy section.
FIGURE 34. Cross-bedding and small cut-and-fill structures in the coarse sands near the base of the large scour-and-fill channel, Needy section.
nearly horizontal surface (Figure 32). On top of this surface lie horizontally bedded sands. The strata in these sands are less than 0.5 inch thick and more commonly are about one-sixteenth of an inch. Rarely, the thicker strata show steeply inclined cross-beds which are abruptly terminated at the top and bottom of the strata. In some beds, the horizontal strata do not reach the top of the bed but gradually die out in a structureless mass of coarse sand. The variable thickness of many beds in this part of the Needy section is related to the presence or absence of the structureless sand.

A major scour-and-fill structure (Figure 33) is associated with the middle Willamette Silt beds. Sediments in the scour-and-fill structure are at least 35 feet thick, and they extend 130 feet along the north-facing cut of the Needy exposure. Erosion during formation of the Rock Creek floodplain has truncated the north-facing cut so that the maximum extent of the scour-and-fill structure is unknown. The channel has a northwest trend as scour-and-fill sediments are not found on the south-facing cut of the Needy exposure. The scour-and-fill channel is cut into beds from the middle to near the bottom of the Willamette Silt section (Figure 33). The steepness of the channel boundary (Figure 33) and the fact that the channel can be traced to within three feet of the paleosol suggest that the channel may actually extend into the underlying paleosol. Slumping prevents tracing of the channel down to the paleosol.
The characteristics of the fill in the channel are well displayed in Figures 33 and 34. The bottom part of the fill is coarse black sand which is stratified in the lower part sub-parallel to the channel boundary (Figure 33); higher in the sand, bedding planes are nearly horizontal and cross-bedding and small scour-and-fill channels (Figure 34) occur. Horizontally bedded sands extend beyond the original channel boundary (Figure 33) and indicate that it was filled near the middle of the Willamette Silt depositional interval. Lenses of silt and coarse sand occur in a new channel cut in the horizontally bedded sands (Figure 33) above the original channel. These lenses are truncated in turn and are overlain by sand and silt beds which show no control by channel boundaries (Figure 33).

The top ten feet of Willamette Silt at Needy differs from that in underlying beds. The beds thin (Figure 22) from their maximum three-foot thickness in the middle part of the section to less than eight inches at the top of the section. The sediments are chiefly coarse silt and fine sand in the upper beds in contrast to the coarse sands and silts in underlying beds. Stratification is less distinct in the upper ten feet, partly because of soil-forming processes and partly because of more nearly uniform grain size. Variation in sedimentation conditions is indicated in the upper sediments (Figure 22) by lensing and truncation of beds.

Five samples were collected from the Willamette Silt in the
Needy section to determine variations in heavy mineral content with stratigraphic position. Two samples (JG-N1 and N) are from the silty sands at the base of the section (Figure 24); one (JG-26) is from the horizontal sands in the lower middle part of the section (Figure 27); one (JG-25) is from the black sands in the scour-and-fill channel (Figure 34); and the last (JG-24) is from the cross-bedded silts (Figure 32) in the middle of the section.

The results of heavy mineral analyses of these samples are shown in Table 14. These data indicate that all samples show elements of the "foreign" mineralogy which distinguishes the Willamette Silt from locally derived sediments. The high percentage of pyroxenes in the two basal samples suggests some mixing of local and foreign heavy mineral suites.

In addition to the samples described above, other samples were examined to determine whether the Needy section contained locally derived sediments. These were spot samples similar to those collected at River Bend for the same purpose. The samples failed to reveal any strictly locally derived sediments above the basal part of the section.

Other outcrops where the sediments are similar to those in the Needy section are found along Highway U. S. 99E at Aurora and east of Donald where the Donald Road crosses Senecal Creek (Plate 1). The base of the Willamette Silt is not exposed in either of these sections.
TABLE 14. Variation in heavy mineral suites in samples from Willamette Silt, Needy section. A "T" indicates that the mineral was noted in the sample but did not come under the center of the cross hairs during the counting traverses.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>JG-N1</th>
<th>JG-N2</th>
<th>JG-26</th>
<th>JG-25</th>
<th>JG-24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hornblende</td>
<td>38</td>
<td>45</td>
<td>27</td>
<td>73</td>
<td>76</td>
</tr>
<tr>
<td>Lamprobolite</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>--</td>
<td>1</td>
</tr>
<tr>
<td>Augite</td>
<td>50</td>
<td>33</td>
<td>25</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>Hypersthene</td>
<td>21</td>
<td>21</td>
<td>18</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Epidote group</td>
<td>13</td>
<td>14</td>
<td>16</td>
<td>19</td>
<td>41</td>
</tr>
<tr>
<td>Garnet</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Sphene</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Zircon</td>
<td>3</td>
<td>T</td>
<td>T</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Kyanite</td>
<td>T</td>
<td>1</td>
<td>--</td>
<td>1</td>
<td>T</td>
</tr>
<tr>
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<td>1</td>
<td>T</td>
<td>--</td>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>Pyrophyllite</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>--</td>
<td>T</td>
</tr>
<tr>
<td>Staurolite</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>T</td>
<td>--</td>
</tr>
<tr>
<td>Andalusite</td>
<td>T</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Rutile</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>--</td>
</tr>
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<td>T</td>
<td>--</td>
<td>--</td>
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<td>T</td>
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<td>2</td>
<td>3</td>
<td>T</td>
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<tr>
<td>Opaque minerals</td>
<td>34</td>
<td>45</td>
<td>72</td>
<td>38</td>
<td>26</td>
</tr>
<tr>
<td>Hematite</td>
<td>T</td>
<td>T</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Leucoxene</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Volcanic glass and rock fragments</td>
<td>T</td>
<td>T</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>25</td>
<td>18</td>
<td>22</td>
<td>21</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

1 Basal silty sands
2 Basal sandy "pocket"
3 Lower horizontal sands
4 Coarse micaceous sand at base of large scour-and-fill channel
5 Cross-bedded silts near middle of the Willamette Silt section
The Swan Island Section

The Swan Island section is along a north-trending 200-foot long erosional escarpment which forms the east bank of the Molalla River near Canby (Plate 1). The exposure is best approached from the east on the road which leads to Swan Island farm, from which the exposure is named.

A section 70 feet thick is exposed at Swan Island (Figure 35). The section begins at river level at an altitude of approximately 65 feet during low-water stages and extends upward to an altitude of 135 feet. Two units are identified: Unit I, the lower unit, is correlated with Unit I at River Bend. Unit II is the Willamette Silt.

Unit I. The lower unit at Swan Island is a conglomeratic sandstone with interbedded mudstone and conglomerate. The maximum thickness of Unit I sediments is unknown but well logs from water wells in the Canby area show more than 180 feet of similar sediments. The exposed thickness ranges from 12 feet at the north end of the outcrop to 35 feet at the south end (Figure 35).

The contact between lower unit sediments and Willamette Silt is not marked by a paleosol. Instead the contact is an erosional surface which has a total of 23 feet of relief along the outcrop and as much as six feet of local relief where the underlying sediments have been channeled. Texture and degree of cementation (see below) are
FIGURE 35. The Swan Island section, Molalla River.
the most reliable criteria for establishing the contact between Willamette Silt and underlying sediments.

The lower part of Unit I is a conglomeratic sandstone which contains interbeds of mudstone. The mudstone beds range in thickness from two to four feet and form a ledge (Figure 35) at water level along most of the outcrop. Near the south end of the outcrop (below the "ladder" in Figure 35) the ledge is displaced upward approximately three feet along a normal fault. The fault does not cut overlying Willamette Silt beds.

The conglomeratic sandstone contains clasts as large as six inches in diameter. The clasts are dark, dense to porphyritic volcanic rocks, mainly basalts. Weathering rinds on the clasts are 0.25 to 0.5 inch thick, and many phenocrysts are altered to hematite. The coarse clasts are set in a sandy matrix and locally are coated with silt and clay. Iron oxides are the principal cementing agents although the induration and low permeability of the sediments are caused chiefly by the fine-grained matrix. The sediments are not calcareous.

The mudstone beds are sandy and locally contain pebbles. The color of the mudstone varies from red and brown to blue black depending on local moisture conditions. Organic fragments, including twigs and branches, are abundant in the mudstone beds.

At the north end of the Swan Island outcrop a two-foot thick
conglomerate bed overlies the conglomeratic sandstone and mudstone. This bed thickens and thins southward along the outcrop and is not present at the south end (Figure 35). Because of slumping, the bed is poorly exposed along much of the outcrop. Pebble and cobble clasts, chiefly basalts, are the principal constituents. The clasts are set in a red silty clay matrix which serves as the only binding agent.

The upper part of Unit I is a tuffaceous conglomeratic sandstone which ranges in thickness from six feet at the north end of the outcrop to 30 feet at the south end. The variation in thickness is due to erosion prior to deposition of the overlying Willamette Silt. The conglomeratic sandstone is characterized by clasts which range in size from pebbles to boulders and by an almost total lack of stratification (see the right side of Figure 35). Many clasts are vesicular, gray volcanic rocks which contain greenish-brown phenocrysts which are probably olivine. Clasts of comparable nature are not found in the overlying Willamette Silt. A fine-grained tuffaceous matrix serves as the binding material around clasts.

Unit II. The Willamette Silt at Swan Island ranges in thickness from 35 feet at the south end of the section to 58 feet at the north end. The sediments in the silt section are dominantly uncemented sands in contrast to the cemented and tightly bound conglomeratic sandstones and mudstones in Unit I.

The basal Willamette Silt is a well stratified, reddish-brown
sand which ranges in thickness from 10 feet at the south end of the outcrop to 25 feet at the north end. The strata range in thickness from 1/16 inch to as much as six inches. Bedding planes are sub-parallel to the underlying erosion surface and, in local relief features, terminate against the erosion surface. The sand is coarse and locally contains basalt pebbles as much as two inches in diameter. Quartz, feldspars, and micas are abundant constituents in the sand.

The reddish-brown sands are overlain by gray and black sands which grade into light-colored silty sands at the top of the section. The upper sands are poorly stratified in comparison to the underlying sands. Bedding planes are intermittent and somewhat chaotic. Locally, cross-bedding is present, and a large cut-and-fill structure occurs near the middle of the outcrop. The extent of the cut-and-fill structure is unknown as only one channel boundary is present. The sands in the channel have a maximum thickness of four feet and are traceable for 25 feet along the outcrop before they are obscured by vegetation. The channel sands are well stratified and the strata run sub-parallel to the channel boundary.

The soil developed on Willamette Silt at Swan Island differs from that at River Bend. Neither structural nor textural development is as great at Swan Island and the solum is only 18 inches thick. The 1926 Soil Survey of the Swan Island area shows this soil as Sifton sandy loam (55) instead of one of the Willamette catena of soils. The
Willamette soil series does occur on a small knoll half a mile north of Swan Island (55), and the present investigation reveals that it underlies a small hill half a mile south of Swan Island. The knoll rises to an elevation of 165 feet and the hill reaches 190 feet. The presence of these isolated remnants of Willamette Silt adjacent to the Swan Island locality indicates that the Willamette Silt was 55 feet thicker in the Swan Island area than it is now.

Other sections where the Willamette Silt has the characteristics it displays at Swan Island are limited to the southwest quarter of the Canby 7.5-minute topographic quadrangle and to the northwest quarter of the adjacent Yoder 7.5-minute topographic quadrangle (Plate 1). The better exposures are adjacent to the Highway U. S. 99E bridge across the Molalla River at Canby; at Pat's Acres, 2.5 miles due west of Canby; and along the new section of Highway U. S. 99E north of Aurora (Plate 1). None of these exposures shows the base of the Willamette Silt although some have a more complete upper-silt sequence. Access to many of these sections and the Swan Island section, is limited by the nearly vertical faces of the exposures.

Heavy minerals have not been investigated in samples of the Swan Island sediments. Samples JG-22, 23, and 29, from similar sediments at Pat's Acres and along Highway U. S. 99E at the Molalla River bridge were analyzed, and the results are reported in Table 9. The data show that Swan Island type sediments contain the same heavy
mineral suite found in other Willamette Silt samples.

The Deer Creek Section

The Deer Creek section is on the south bank of Deer Creek, a small tributary of the South Yamhill River (Plate 1). The section is along a road cut through the escarpment which separates the Willamette Silt surface from the Deer Creek floodplain surface. The cut extends north-south for about 100 feet. The top of the section is 175 feet above sea level, and the Deer Creek floodplain is at an altitude of 120 feet. Only the upper 30 feet of the section is exposed; the remainder lies below the road level or is covered by vegetation and slump.

Three stratigraphic units, two of which are beneath the Willamette Silt, are exposed at Deer Creek. The lowest unit crops out only in the banks of Deer Creek where ten feet of fine-grained tuffaceous sandstone and intercalated clay is present. The surface of the outcrop is weathered and displays a variety of red, yellow, and white colors. The sediments are similar in nature and in weathering pattern to Tertiary rocks (10) which occur in the area.

A covered section 15 feet thick lies between the sandstone and the overlying gravel unit. At the base the gravels are fresh, and about equal amounts of coarse sediment and sandy clay matrix are present. Toward the top the gravels are intensely weathered, and many clasts are easily cleaved with a small shovel. The gravels are
dominantly pebbles and a few cobbles. The larger clasts are chiefly fine-grained basic volcanic rocks. Gabbroic rock clasts and tuffaceous sandstone clasts are subordinate constituents. The decomposed rock fragments and the sandy clay matrix are red to maroon. At the top of the unit, the sandy clay has a coarse prismatic to blocky structure and is darker than stratigraphically lower sediments.

Willamette Silt 15 feet thick overlies the weathered gravels. The contact separating gravels and silt is sharp and is marked by a change in color, texture, and consistency. The silt is buff to tan, chiefly silty clay, and friable. The top of the gravel unit is a sandy pebble-bearing clay which is deep red to maroon and not friable. Stringers of silt extend down into the weathered gravels, and locally, the basal silt contains small clasts of red silty clay from the underlying weathered gravels. The contact between the silt and gravel, although not exposed along the entire section, generally occurs at a uniform altitude.

A channel sample was collected from the middle eight feet of the Willamette Silt. The particle size distribution in this sample is shown in Figure 36. These data show that the sediment is chiefly silt and clay but contains a little sand. Inman and Trask textural statistics indicate that the sediment is poorly sorted and is strongly skewed toward the fines.

The Willamette Silt section is crudely stratified. In the basal
FIGURE 36. Cumulative frequency curve for a channel sample from Willamette Silt, Deer Creek section.
part, the strata are as much as one inch thick, but the average thickness is less than 0.25 inch. The contacts between strata are sharp but are irregular or slightly wavy. The stratification is caused by slight changes in texture which result in varying moisture retention. The middle and upper parts of the silt section are characterized by obscure laminations. Laminations show best on the surface of the outcrop where the sediments are exposed to differential drying. Toward the top of the section, the strata thin and are poorly defined. Mixing by soil-forming processes has resulted in homogeneous non-laminated silt at the top of the section.

The upper part of the silt section contains a red oxidized zone which extends to depths of three to four feet. Published soil maps (56) show Willamette silt loam in this area.

A layer of structureless, gray sandy silt six to eight inches thick overlies the oxidized zone. Scattered pebbles of quartzite, vein quartz, and granitic and metamorphic rock are found in the gray silts and as float on the slopes of the cut.

Many other outcrops show the stratigraphic relationships and characteristics as the Willamette Silt at Deer Creek. In localities closer to the center of the South Yamhill Valley, as at the South Yamhill River bridge (SE1/4, sec. 32, T. 5 S., R. 5 W.) on the Bellevue to Ballston road, the silt is underlain by more than 30 feet of gravel similar to that at Deer Creek. All gravels which underlie Willamette
Silt in the Yamhill Valley probably are part of the same stratigraphic unit. In sections higher in altitude than the Deer Creek section or closer to the Coast Range foothills, the silt rest unconformably on decomposed bedrock. Road cuts along Highway 18 between Sheridan and Newberg (Plate 1) generally show the Willamette Silt on bedrock.

Willamette Silt sections along the Cascade Mountains foothills adjacent to the north Willamette Valley lowland are similar to sections along the Coast Range foothills. Good outcrops are present along the upper part of Rock Creek (Plate 1) in the Yoder and Scotts Mills 7.5-minute topographic quadrangles. A particularly good section occurs near the center of sec. 23, T. 5 S., R. 1 E. In many sections along the Cascade Mountains foothills, weathered gravels form a thin veneer over bedrock, and in other sections, no gravels are present. Gravels more than 20 feet thick underlie Willamette Silt along the Molalla River Valley east of Molalla (Plate 1).

Textural Data

The particle size distribution of 52 Willamette Silt and 22 Willamette River floodplain samples has been determined. The objectives of these determinations were 1) to define the general particle size characteristics of the Willamette Silt, 2) to determine variations in the particle size in the Willamette Silt with geographic, topographic, and stratigraphic position, and 3) to compare the
Willamette Silt to modern Willamette River floodplain deposits.

Twenty-two Willamette Silt (TMB1-TSP22) and 22 Willamette River floodplain samples (FMB1-FSP22) were obtained from random sample sites, and the remaining silt samples were collected from sample sites along an east-west transverse profile across the Willamette Valley (Plate 1). All samples were obtained by drilling shallow hand auger holes to a depth of six feet. A composite sample from the four- to six-foot depth interval was analyzed for particle size.

Textural Characteristics of the Willamette Silt

The particle size distribution in the 52 Willamette Silt samples is summarized in the cumulative curves in Figure 37 and in the accompanying bar graph (Figure 38). Cumulative curves for all other Willamette Silt samples fall in the area outlined by the two curves in Figure 37. These data show that 1) the range in median diameter in all samples is from coarse clay to coarse silt, and the average median diameter is in the fine silt class, and 2) 64 percent of the samples are in the silty clay textural class. The data point out that the Willamette Silt is remarkably uniform in texture over much of the north Willamette Valley.

The percentage of sand, silt, and clay and the Inman and Trask textural statistics in all Willamette Silt samples are shown in Appendix B. These data indicate that, in the depth interval
FIGURE 37. Range in cumulative frequency curves of 52 Willamette Silt samples. Average median diameter is 0.014 mm.
FIGURE 38. Percentage of 52 Willamette Silt samples in each of the U. S. Bureau of Roads textural classes. The sand-silt-clay boundaries are $>0.074 - <0.074$ to $>0.005 - <0.005$ mm respectively.
represented by the samples, the Willamette Silt is composed dominantly of silt and clay particles. In all samples except one (TMB2), the percentage of silt is greater than the percentage of any other size, and in all samples except two (TMB2 and JG67), the percentage of silt is equal to or greater than the percentage of sand and clay combined. The Inman and Trask textural statistics show that, in addition to being fine-grained and skewed toward the fines, the Willamette Silt is poorly sorted.

**Topographic and Stratigraphic Variation in Willamette Silt Texture**

The Molalla-Sheridan drilling traverse begins one mile west of Molalla (Plate 1) at an altitude of 310 feet. The traverse extends westward across the north Willamette Valley lowland where the silt surface ranges from 150 to 200 feet in altitude and up the South Yamhill River Valley to an altitude of 225 feet 2.5 miles east of Sheridan (Plate 1). A more detailed description of the topography of the Willamette Silt surface is contained in the geomorphology section (see p. 163-179).

The topography of the Willamette Silt along the Molalla-Sheridan traverse is shown at the top of Figure 39. Inspection of the profile reveals that five topographically distinct subareas (see p. 163) are crossed in obtaining samples along the profile. The line graphs below the profile (Figure 39) show the variation in selected Inman and
Figure 39. Profile of Sheridan-Molalla sample traverse with variations in selected Inman (phi measures using phi scale) and Trask (quartile measures) textural statistics and sand-silt-clay percentages of Willamette Silt samples (locations shown on geologic map, Plate 1).
Trask textural statistics and the variation in the percentage of sand, silt, and clay between sample sites. These data show that the Willamette Silt varies in texture along the profile. The significance of textural variations is shown by grouping the data according to the topographic subarea from which it comes (Table 15). The following conclusions are indicated: 1) the coarsest and most poorly sorted sediments occur in the Canby channeled plain and in the French Prairie rise subareas; 2) the Willamette Silt in the eastern terrace subarea is coarser than the silt is in the western terrace subarea; 3) the variation is due chiefly to changes in the percentage of sand and clay; 4) skewness shows no significant trend along the profile; and 5) the Willamette Silt in a topographic subarea is texturally transitional into the silt in adjoining areas. The last point is significant because it establishes the relationship between fine-grained silt higher on the flanks of the Willamette Valley and Willamette Silt nearly 150 feet lower in the north Willamette Valley lowland.

Despite the uncertainty concerning the relative stratigraphic positions of samples along the Molalla-Sheridan traverse, the data presented in Figure 39 and Table 15 correlate well with observations in stratigraphic sections. Three of the sections, Deer Creek, River Bend, and Needy, are less than half a mile from the Molalla-Sheridan traverse (Plate 1). The Deer Creek section in the western terrace subarea and the River Bend section in the Dayton basin subarea
TABLE 15. Average and range in particle size distribution statistics for Willamette Silt samples in the same topographic sub-area along the Molalla-Sheridan traverse. The range is given in parentheses.

<table>
<thead>
<tr>
<th>Topographic Area</th>
<th>% Sand</th>
<th>% Silt</th>
<th>% Clay</th>
<th>Median (Md_φ)</th>
<th>Inman's Sorting (σ_φ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern terrace</td>
<td>(1-13)</td>
<td>(52-68)</td>
<td>(20-45)</td>
<td>(5.06-6.72)</td>
<td>(2.12-2.89)</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>61</td>
<td>31</td>
<td>5.76</td>
<td>2.49</td>
</tr>
<tr>
<td>Canby channeled plain</td>
<td>(11-22)</td>
<td>(47-58)</td>
<td>(21-31)</td>
<td>(4.68-6.14)</td>
<td>(2.72-3.09)</td>
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<tr>
<td></td>
<td>21</td>
<td>54</td>
<td>25</td>
<td>5.35</td>
<td>2.91</td>
</tr>
<tr>
<td>French Prairie rise</td>
<td>(11-23)</td>
<td>(53-65)</td>
<td>(22-24)</td>
<td>(4.92-5.66)</td>
<td>(2.48-2.99)</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>59</td>
<td>23</td>
<td>5.15</td>
<td>2.75</td>
</tr>
<tr>
<td>Dayton basin</td>
<td>(1-6)</td>
<td>(58-67)</td>
<td>(30-41)</td>
<td>(5.81-6.77)</td>
<td>(2.14-2.91)</td>
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<tr>
<td></td>
<td>2</td>
<td>63</td>
<td>35</td>
<td>6.40</td>
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<tr>
<td>Western terrace</td>
<td>(1-5)</td>
<td>(53-63)</td>
<td>(36-44)</td>
<td>(6.40-6.94)</td>
<td>(2.37-2.74)</td>
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<tr>
<td></td>
<td>2</td>
<td>58</td>
<td>40</td>
<td>6.71</td>
<td>2.60</td>
</tr>
</tbody>
</table>

contain little coarse sediment (see p. 128 and 18). The Needy section, farther east in the Canby channeled plain subarea, (see p. 111 ) contains much interbedded sand and silt. Thus the textural trends between the stratigraphic sections are the same as the trends shown by the data in Figure 39 for near-surface Willamette Silt samples.

The variations in texture of Willamette Silt along a north-south profile down the north Willamette Valley lowland have been investigated by Pomerening (66, p. 94-100). His data show that the B2 horizons of soils developed on Willamette Silt contain coarser sediment northward along the crest of the French Prairie rise to the vicinity of
Donald (Plate 1). From Donald north to three miles due east of La Butte, where Pomerening's sampling program ended, the B<sub>2</sub> horizons became finer.

**Textural Comparison of Willamette Silt and Willamette River Floodplain Sediments**

The data from the 44 random Willamette Silt and Willamette River floodplain samples are used in the textural comparison of sediments from the two deposits. The particle size distribution statistics for these samples are shown in Appendix B, and the data for selected statistics are summarized in Table 16. The data show that the Willamette Silt is finer and better sorted than Willamette River sediments and that the silt is less variable in particle size than Willamette River sediments.

A plot (Figure 40) of mean phi against sigma phi for the 44 silt and floodplain samples illustrates the last point. The less variable nature and the textural distinction between Willamette Silt and Willamette River floodplain sediments are indicated by the grouping of the Willamette Silt data. Plots of other particle size distribution statistics show a similar textural separation of Willamette Silt from Willamette River floodplain sediments.
TABLE 16. Summary of selected particle size distribution statistics for 22 Willamette Silt and 22 Willamette River floodplain samples from random sample sites. The original data are shown in Appendix B.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Willamette Silt</th>
<th>Willamette River Floodplain</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Sand</td>
<td>Average 4</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Range 1-12</td>
<td>1-72</td>
</tr>
<tr>
<td>% Silt</td>
<td>Average 62</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Range 42-69</td>
<td>19-61</td>
</tr>
<tr>
<td>% Clay</td>
<td>Average 34</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Range 19-47</td>
<td>9-70</td>
</tr>
<tr>
<td>Mdφ</td>
<td>Average 6.35</td>
<td>5.41</td>
</tr>
<tr>
<td></td>
<td>Range 4.99-7.92</td>
<td>2.70-9.24</td>
</tr>
<tr>
<td>σφ</td>
<td>Average 2.60</td>
<td>2.87</td>
</tr>
<tr>
<td></td>
<td>Range 1.72-3.15</td>
<td>1.72-4.35</td>
</tr>
</tbody>
</table>
FIGURE 40. Plot of $M_\phi$ (phi mean) and $\sigma_\phi$ (phi deviation) for 22 Willamette Silt samples and 22 Willamette River floodplain samples.
General Distribution and Nature of the Willamette Silt

The Willamette Silt has been mapped for differing reasons by previous investigators. Piper's (65) map of water-bearing formations shows the distribution of the silt in the Willamette Valley where he called the silt "older alluvium and related deposits". Soil scientists have mapped related soils developed on Willamette Silt, and their maps (55, 56, 74, 75, 83) also show the distribution of the silt.

Data from the present investigation show that the floor of the Willamette Valley below an elevation of about 350 feet is underlain by a varying thickness of Willamette Silt. As a mappable unit, the silt does not extend higher than 325 feet on the valley margins although six feet of Willamette Silt was observed at one exposure near the 325-foot level on the Cascade Mountains flank. In the north Willamette Valley, the silt is thicker at higher altitudes on the Cascade Mountains flank than it is on the Coast Range flank. In the south Willamette Valley, however, silt sections are equally thick at comparable altitudes along both valley flanks.

Isolated hills (Mt. Angel, La Butte) of Tertiary sediments or intrusive rocks interrupt the continuity of the Willamette Silt fill, and modern streams have cut through and removed the silt from other areas.

The Willamette Silt is thickest beneath the main lowland of the
Willamette Valley between Salem and Wilsonville (Plate 1) where approximately 70 feet of silt was observed and as much as 100 feet may be present. The silt thins east and west from the crest of the French Prairie rise (Plate 1) and southward along the crest of the rise. The thinning east, west, and south is caused by increased altitude of the pre-silt surface and by the east, west, and south slope of the silt surface from and along the crest of the rise. These relationships and the relationships between stratigraphic sections are depicted in Figures 41 and 42 which contain schematic profiles along lines of traverse determined by the locations of the stratigraphic sections. The profile in Figure 39 gives a truer picture of the magnitude of the east-west slopes even though the vertical exaggeration in that profile is about 80.

Two silt surfaces are shown in Figures 41 and 42. The upper surface is a reconstructed surface based on the elevation of small remnants (see p. 125) of Willamette Silt which occur adjacent to the Swan Island section. Post-Willamette Silt erosion (see p. 193) has removed the silt in the Swan Island and Needy localities so that the second and lower surface represents the present silt surface. The southward slope of the silt surface along the crest of the French Prairie rise is approximately the same as that of the reconstructed silt surface slope in Figure 42.

Allison's description (5, p. 442) and name (8, p. 1-18)
FIGURE 41. Schematic profile showing the relationships between stratigraphic sections and showing the thickening and thinning of the Willamette Silt along an east-west traverse, north Willamette Valley.
FIGURE 42. Schematic profile showing the relationships between stratigraphic sections and showing the thickening and thinning of the Willamette Silt along a north-south traverse, north Willamette Valley.
indicate the general nature of the Willamette Silt. In the north Willamette Valley, coarse sands are intercalated with silt in the Needy section, and farther north, in the Swan Island section, gravels are present in the Willamette Silt. The relationships between stratigraphic sections are shown in Figures 41 and 42. The data show that the coarser sediments are found farther north and beneath the French Prairie rise (Plate 1). East and west from the crest of the rise (Figure 41) and south along the crest of the rise the sands grade into progressively finer sediments.

Trimble (76) mapped a gravel phase, a sand phase, and a silt and clay phase in Portland area sediments which he considered correlative with Willamette Silt. He found that these phases are arranged concentrically about the mouth of the Columbia River Gorge much as the Willamette Silt is arranged about the head of the Willamette River Gorge near the Swan Island locality (Plate 1).

The profiles in Figures 41 and 42 show that the Willamette Silt, dependent on locality, either unconformably overlies or conformably overlies older deposits. On the valley margins the silt unconformably overlies strongly weathered terrace gravels (Deer Creek) or Tertiary bedrock. In the center of the Willamette Valley, strongly weathered deposits at River Bend are overlain by locally derived sediments which are conformable with the overlying Willamette Silt. In Figure 41, the locally derived sediments are depicted as
transitional with Willamette Silt and as pinching out east and west of a pre-Willamette Silt Willamette River channel. The exact position of this channel is unknown although it is shown (Figure 41) to lie east of the modern Willamette River course.

The upper boundary of the Willamette Silt is a modern erosion and weathering surface. No locally derived sediments overlie Willamette Silt in the Willamette Valley nor do local sediments occur above the base of the silt section. Topographically lower and stratigraphically younger sediments do occur in the floodplains of modern streams incised below the silt surface.

Erratics and gray pebbly silts (4, 5) overlie oxidized Willamette Silt. The oxidized zone indicates that the contact is unconformable and that time elapsed before the gray silts and erratics were deposited. Pebbles of vein quartz and granitic and metamorphic rock fragments in the gray silts indicate that they, like the Willamette Silt, were derived from outside the local drainage basin.

**Geomorphology**

The geomorphic phase includes descriptions of the Willamette Valley, the Willamette River and its floodplain, and the Willamette Silt surface. These descriptions furnish information on the characteristics of the basin in which the Willamette Silt accumulated and are helpful in interpreting the origin of the silt and the post-silt geologic history.
The Willamette Valley

The Willamette Valley lies at the southern end of a structural and erosional lowland which extends from the Puget Sound of Washington to Eugene. The Cascade Mountains border the lowland on the east, and the Coast Range-Olympic Mountains form the western boundary. The Willamette Valley (Figure 2) part of the lowland begins on the north at the confluence of the Willamette and Columbia Rivers and ends south of Eugene where the Cascade Mountains and the Coast Range merge with the Calapooya Mountains. Gradual slopes separate the Willamette Valley from the foothills of the bordering mountain ranges. Topographic profiles show that the valley is asymmetrical and that the Cascade Mountains slopes are much steeper than those of the Coast Range.

The Willamette Valley has a length of 125 miles and a width which ranges from less than a quarter of a mile to slightly more than 30 miles. The average width is difficult to determine because of the irregular valley margins, but it is probably between 10 and 15 miles.

Three ranges of northwest-trending hills capped by resistant Columbia River Basalts (84) form the "narrows" of the Willamette Valley where they are crossed by the Willamette River in its general northward course. The hills are named (Figure 2) the Portland Hills, the Chehalem Mountains, and the Salem-Eola Hills; the
intervening lowlands are called the Portland Basin and the north and south Willamette Valley lowlands. A fourth lowland, called the Tualatin Basin (Figure 2) lies west of the Portland Basin in a syncline (84) between the Portland Hills and the Chehalem Mountains. The north Willamette Valley lowland and the Portland Basin also are located in synclinal structures.

Profiles were drawn along ridges which lead from Tertiary bedrock on the flanks of the Willamette Valley into the valley proper. These profiles show that no consistent breaks in ridge slopes occur between 300 and 600 feet in altitude. Many ridges and stream valleys were examined closely during field mapping of the upper limit of the Willamette Silt in the north Willamette Valley lowland. This examination revealed no evidence of shorelines, deltas, or beach deposits which could be related to standing water levels in the Willamette Valley during Willamette Silt time.

The North Willamette Valley Lowland

The north Willamette Valley lowland (Figure 2 and Plate 1) is an irregular 500 square mile area which is underlain chiefly by Willamette Silt. The lowland is roughly triangular in shape; the apex of the triangle is near Salem, and the base is along the west to northwest-trending front of the Chehalem Mountains. Gentle dip slopes (84) lead from the crest of the Salem-Eola Hills and from the western
foothills of the Cascade Mountains (84) toward the center of the low-
land. A steeper slope forms the south-southwest facing front of the
Chehalem Mountains. Small bedrock hills, the largest of which are
Mt. Angel and La Butte (Plate 1) are surrounded by younger sediments
in the north Willamette Valley lowland.

The Willamette River enters the north Willamette Valley low-
land through a water gap approximately 1.5 miles wide near the apex
of the triangular area. A small water gap (Plate 1) less than half a
mile wide and east of the Willamette River Gap passes water from
Mill Creek to the north Willamette Valley lowland. Two other small
gaps, Holmes’ Gap and Salt Creek Gap, are cut through Coast Range
foothills west of the Willamette River Gap. These gaps contain only
intermittent streams or none. The entrances to the north Willamette
Valley range in altitude from 135 feet in the modern Willamette River
Gap at Salem to 200 feet in the Salt Creek Gap.

The Yamhill River enters the north Willamette Valley through
a large gap between the northwest end of the Salem-Eola Hills and the
foothills of the Coast Range (Plate 1). The present course of the
Yamhill River parallels the base of the lowland triangle. The Molalla
River, the only other large stream to enter the north Willamette Val-
ley, rises in the Cascade Mountains and comes into the lowland near
the northeast corner of the triangle. Small streams, including Rock
Creek, Butte Creek, Abiqua Creek, Silver Creek, and Pudding River,
enter the north Willamette Valley lowland along the Cascade Mountains side of the triangle.

The Willamette River exits from the north Willamette Valley lowland through a rock-walled gorge at the northeast corner of the triangle (Plate 1). At its narrowest point near the south end, the gorge is less than half a mile wide between 400-foot contour lines. Columbia River Basalts border the gorge on the west and generally floor the gorge, and Boring Lava and Columbia River Basalts crop out along the east wall (84, 76). The west wall of the Willamette River Gorge increases in altitude from south to north up to the point where the river passes the crest of the Portland Hills structure. From about Oregon City north, the Willamette River flows along the trend of the Portland Hills. The east wall of the Willamette River Gorge decreases in altitude north of the crest of the Portland Hills and is overlapped by Quaternary alluvium in the Portland Basin.

Three gaps occur in the walls of the Willamette River Gorge. The Tualatin River enters through one gap, and the Clackamas River passes through a second gap (Plate 1). The third gap contains no permanent stream and has been dammed to produce Oswego Lake.

The Tualatin River Gap is at the southeast end of a narrow lowland or neck which connects the Willamette Valley and the Tualatin Valley (Plate 1). The lowland trends N. 45° W. or nearly parallel to the strike of the Portland Hills. The Oswego Lake Gap also lies at
the end of a narrow channel which connects the Willamette Valley and the Tualatin Valley, but, in contrast to the Tualatin River lowland, the Oswego Lake channel trends N. 25° E. or across the trend of the Portland Hills.

Both the Oswego Lake Gap (76, 2) and the modern Willamette River Gorge contain unusual erosional and depositional features. The erosional features include isolated hills or knobs of bare basalt, undrained depressions in basalt, and benches which locally have a veneer of unconsolidated coarse sediments. The depositional features include isolated large boulders and masses of unstratified bouldery rubble, most of which is found near the southwest end of the Oswego Lake Gap. Along the narrow part of the Willamette River Gorge, similar erosional and depositional features are present. Neither bare bedrock nor isolated boulders extend higher than 350 feet in altitude along either the Willamette River Gorge or the Oswego Lake Gap.

Two other bedrock-floored gaps extend around or through the Chehalem Mountains and connect the north Willamette Valley lowland with the Tualatin Basin (Plate 1). These gaps are called the Chehalem and Rock Creek Gaps.

The Chehalem Creek Gap skirts the Chehalem Mountains (Plate 1) and connects the head of the Tualatin Basin with the northwest corner of the north Willamette Valley lowland. The gap is 0.5 mile wide at the narrowest point between 400-foot contour lines.
Two streams, Chehalem Creek and Ayers Creek, flow in opposite directions from a low divide at an altitude of 210 feet near the middle of the gap. Chehalem Creek, the larger stream, flows southeast into the Willamette River near Newberg, but its barbed entrance (Plate 1) to the Chehalem Creek Gap and the presence of barbed tributaries along Chehalem Creek suggest that the main flow was northwest into the Tualatin Valley.

The walls of the Chehalem Creek Gap are smoothly rounded and are covered by a variable but usually thin soil. No unusual erosional or depositional features are associated with the Chehalem Creek Gap although its width and curvature are larger than the present streams require or are capable of producing.

The Rock Creek Gap (Plate 1) has been described or noted by previous workers (76, 2) because of its unusual erosional and depositional features. The gap is located seven miles west of the Willamette River Gorge and in a low broad saddle between two ridges of the Chehalem Mountains. Interstate Highway 5 runs along the east side of the saddle.

The Rock Creek Gap is not bordered by abrupt walls such as those which flank the Chehalem Creek Gap and the modern Willamette River Gorge. Instead, its boundaries coincide with the maximum extent of unusual erosional and depositional features (Sherwood, 7. 5-minute topographic quadrangle) at the north end of the gap. The
features occur in an area slightly less than 1.5 miles wide and 2 miles long along the Rock Creek Gap. A large part of this area is characterized by bedrock slopes, isolated bedrock hills, and channels cut into bedrock. The bedrock is a dense north-dipping basalt which is mapped (84) as part of the Columbia River Basalts.

The bedrock slopes typically lack all but a surficial veneer of basalt rubble set in a red silt matrix. In areas adjacent to the Rock Creek Gap, ten feet of red silt overlies weathered basalts. The silt has been scoured from both steep and gentle slopes in the Rock Creek Gap leaving the basalt rubble and red silt as lag deposits.

The basalt hills are located within channels and on divides between channels. The hills have as much as 50 feet of relief and typically show steep north-facing slopes and gentle south-facing slopes. South-facing slopes are underlain by basalt gravels which rapidly become finer south of the hills. Some basalt hills in channels which head at low altitudes also have gravel deposits which extend northward from the steep slope. The gravels in these deposits are generally finer than the gravels on the south slopes.

Bedrock channels have a broad floor characterized by considerable irregular local relief, scattered large basalt boulders, and vertical walls. The largest channel is 500 feet wide. Bare basalt walls of the channel range from 50 to 100 feet high, and small intra-channel bare basalt hills protrude 40 feet above the floor of the
Rock Creek flows northwest along the large channel and is separated by a low divide at 140 feet in altitude from an unnamed creek which flows southeast toward Wilsonville. Smaller channels which are cut in basalt east of the largest channel extend northwest into the Tualatin Valley or southeast into the Willamette Valley. Channels which open to the southeast are larger than the channels which open to the northwest. Many channels end in nearly vertical bedrock walls at the divide separating Tualatin and Willamette Valley drainages.

Closed depressions occur adjacent to basalt hills in some channels. The depressions are usually less than 10 feet deep; the largest is 22 feet deep, 1000 feet long and 200 feet wide. Small closed depressions in basalt as much as 15 feet deep are located on the divides between channels.

Seven and possibly eight divides are found between bedrock channels which lead either into the Willamette Valley or into the Tualatin Valley. The divides range in elevation from 140 to 270 feet. The divide at 330 feet through which Interstate Highway 5 passes contains none of the erosional or depositional features which characterize other Rock Creek Gap divides at lower altitudes. Bare basalt and isolated basalt hills reach altitudes as high as 350 feet in the center of the Rock Creek Gap.

Bedrock channels which drain southeast into the Willamette
Valley unite into one broad channel south of the small community of Mulloy (Plate 1). This channel is one mile wide and has a maximum relief of 60 feet. The relief decreases toward the south until in the vicinity of Wilsonville and across the Willamette River only a broad lowland is present. Soil maps (55, 76) and field observations indicate that the channel is cut into and is younger than Willamette Silt. The broad lowland with which the channel merges south of Wilsonville is underlain by Willamette Silt.

Channels draining northward from the Rock Creek Gap also combine into a single broad channel. This channel runs from the northwest end of the Rock Creek Gap to the southwest end of the Oswego Lake Gap (Plate 1). The channel ranges from 1 one wide and 60 feet deep at the Rock Creek Gap end to 1200 feet wide and 70 feet deep at the Oswego Lake end. The sediments adjacent to the channel and forming the channel boundaries are sands and silts similar to those in Willamette Silt at Swan Island and Pat's Acres (Plate 1). Soil maps (83) show that the channel is cut into Willamette series soils.

Small low swells and elongate closed depressions with generally less than 20 feet of relief occur on the floor of the broad channel and on the adjacent Willamette Silt surface (Beaverton and Sherwood 7.5-minute topographic quadrangles). The elongation direction of the ridges and depressions is N. 7° E. or nearly parallel to the trend of the broad channel. Shallow borings to a depth of six feet in
sediments beneath both the ridges and depressions show that they are underlain by Willamette Silt.

Well-defined ridges and depressions (NE1/4 Sherwood 7.5-minute topographic quadrangle) higher than those described above and due east of the north end of Rock Creek Gap have a maximum of 30 feet of relief. These ridges and depressions are covered to depths of six feet by Willamette Silt except near the north end of Rock Creek Gap where the silt is thin or lacking from some ridges and the depressions are floored by basalt rubble.

Onion Flat, a larger than normal depression, is located at the southwest end of the broad channel and at the head of the Rock Creek Gap (Plate 1). This depression formerly contained a lake (43) in which approximately 40 feet of organic sediments have accumulated. A radiocarbon date of 12,240 ± 330 years (B. P.) (Appendix C) was obtained from peat at a depth of 16 feet. An ash layer similar to that noted at 6.6 feet in the Labish Channel peat is found less than 0.2 feet below the surface at Onion Flat.

Smaller multiple channels, cut into Willamette Silt and higher than the broad channel described above, extend up the Tualatin Valley from the Rock Creek-Oswego Lake Gaps to the vicinity of Hillsboro and Forest Grove where they merge with the general level of the Willamette Silt surface in the Tualatin Valley.
The Willamette River and Floodplain

The Willamette River begins at the junction of the Coast Fork and Middle Fork near Eugene. The river flows north-northeast through the Willamette Valley a distance of 190 miles to its confluence with the Columbia River near Portland. The Columbia River empties into the Pacific Ocean approximately 100 miles northwest of the mouth of the Willamette River.

The major tributaries (Figure 2) of the Willamette River are the Tualatin, Yamhill, Luckiamute, Marys and Long Tom Rivers from the Coast Range; the Coast and Middle Forks of the Willamette, which together form the headwaters of the Willamette River; and the McKenzie, Calapooya, South Santiam, North Santiam, Molalla, and Clackamas Rivers from the Cascade Mountains. The larger Willamette River tributaries enter from the Cascade Mountains. Discharge data (28) for streams in the Willamette River drainage basin show that only 15.8 percent of the total Willamette River discharge at Wilsonville comes from Coast Range streams.

The Willamette River is one of the larger northward flowing rivers in the world. The average discharge ranges from 5,453 cfs (28, p. 130) near Eugene to 30,110 cfs (28, p. 181) at Wilsonville. The width of the river varies from 200 to 1000 feet and the average width is probably 500 feet. The gradient (Figure 43) from the junction
FIGURE 43. Willamette Valley slope data (compiled from U. S. Geological Survey topographic quadrangle maps).
of the Coast and Middle Forks to the mouth averages 2.2 feet per mile. The gradient decreases downvalley from 4.2 feet per mile between Corvallis and the junction of the Coast and Middle Forks to less than 0.04 feet per mile from Newberg to Oregon City. Back water from the 40-foot falls of the Willamette River at Oregon City affects the latter reach. The falls are caused by a resistant lava flow of Columbia River Basalts (84, 76). The pool above the falls stands 50 feet above sea level, and the Willamette River below the falls fluctuates as much as two feet during a tidal cycle.

The profile in Figure 43 shows local variations in Willamette River slope. These variations are found where the river has entrenched itself close to the margins of the valley, as near Albany where basalt crops out along the river. Similar basalt ledges cause rapids along the Willamette River east of the Salem-Eola Hills. None of the tributaries of the Willamette River, except the McKenzie River, supplies enough load to cause any noticeable change in Willamette River slope.

The Willamette River along its course displays features of a braided or of a meandering regimen. From Eugene to Harrisburg, flow is typically around numerous islands, and the stream is braided. From Harrisburg to the mouth, flow is restricted to one channel, and meandering reaches alternate with straight reaches.

Willamette River deposits (Figure 44) are typically coarse
FIGURE 44. Typical Willamette River point bar gravels, Matheny Bar, one mile west of sample site FMB9 (Plate 1).

FIGURE 45. Fine-grained topstrata overlying Willamette River gravels at the toe end of lower Martine Bar one mile west of sample site FMB9 (Plate 1).
gravels (41) which are deficient in sand probably because of the high gradient of the stream and the prevailing dense volcanic rocks in the adjacent source areas. As the river migrates to a new course or abandons a meander loop, the gravels are covered by laminated silts and interbedded thin sands (Figure 45).

The floodplain of the Willamette River ranges from one to four miles wide and generally slopes more steeply than the Willamette River (Figure 43). Steep, nearly vertical escarpments, as much as 100 feet high in the north Willamette Valley separate the floodplain surface from the Willamette Silt surface. The relief of the escarpments decreases toward the south and near Harrisburg (Figure 2) the floodplain surface and the silt surface merge. The geomorphic features of the floodplain are chiefly abandoned channels (see Figure 47), arcuate point bar ridges, and swales. In one abandoned channel near bore hole FG16 (Plate 1) an ash layer was found in organic clay. Organic clay below the ash layer gave a radiocarbon date of 7,010 ± 220 years (B. P.).

In the north Willamette Valley, surfaces are found between the Willamette River floodplain escarpments which are generally higher than the local floodplain level. These surfaces do not show abandoned meander channels or point bar ridges but are flat or show smoothly rounded elongate ridges and troughs. The sediments (Figure 46) underlying these surfaces are fine-grained silts and sands which show
FIGURE 46. Well stratified silts and sands underlying a surface slightly higher than the adjacent Willamette River floodplain surface between River Bend and Weston Landing (Plate 1).
a much more well-defined bedding than is typical of topstrata in low-lying floodplain areas. The bedding (Figure 46) is not horizontal but follows local relief in the underlying sediments.

Allison (4, 5) describes "first and second bottoms" in the Willamette River floodplain, the latter of which normally are not flooded. The writer's observations indicate that the well stratified silts and sands are confined to deposits underlying the higher level and that this is the level into which the slope data (Figure 43) show that the modern river is entrenched from Newberg to Oregon City. Samples FS20 and FS21 and possible FN18 (Plate 1) are from second bottom deposits. These samples contain (Table 4, page 41) a heavy mineral suite similar to that found in other Willamette River floodplain samples. Allison (5, p. 629-630) also indicated that the second bottom sediments contained a heavy mineral suite different from that in the Willamette Silt.

The Willamette Silt Surface

The Willamette Silt surface is described for the north Willamette Valley lowland where good large scale topographic maps and aerial photographs are available. In this area the silt surface (Figure 39) has about 200 feet of relief. The main lowland in the center of the valley lies between 150 and 200 feet in altitude. The silt extends higher than the lowland on the flanks of the valley and pinches
out against older Tertiary deposits between 325 and 350 feet.

Within the north Willamette Valley lowland, the area underlain by Willamette Silt is divided on the basis of geomorphology into five subareas. The subareas are named from their geographic location and geomorphic expression: 1) The western terrace, 2) The Dayton basin, 3) The French Prairie rise, 4) The Canby channeled plain, and 5) The eastern terrace. The location and boundaries between the subareas are shown in Plate 1.

**The Western Terrace**

The western terrace includes all the area underlain by Willamette Silt between the Dayton basin and the upper altitude of the silt. A gradual change in slope from steeper in the terrace area to less steep in the basin is used as the boundary between the two areas. The slope change generally occurs at about 160 feet in altitude except in the Dundee and Newberg areas (Plate 1) where the slope changes at approximately 150 feet.

The silt surface in the western terrace subarea has a regional eastward slope (Figure 39) into the Willamette Valley and north and south subarea slopes toward the Yamhill River. Road cuts and water well logs show that the silt surface reflects to a certain extent the slope of the underlying bedrock. The bedrock slopes are greater than the silt surface slopes, and so the silt thickens toward the center of
the Yamhill Valley and of the Willamette Valley.

Hills and ridges of Tertiary bedrock and modern drainage valleys are the principal topographic features in the western terrace sub-area.

The bedrock hills are either highs in the pre-silt surface which have not been overlapped by the silt or highs from which the silt subsequently has been eroded. In both instances, the hills are isolated from bedrock in the adjacent Coast Range foothills.

The ridges are continuations of bedrock ridges beneath Willamette Silt. Highway 18 between McMinnville and Newberg is cut through several of these ridges. The road cuts show that the silt thickens in both directions from the ridge crests.

The Willamette Silt is drained by permanent and intermittent streams. The former extend into the adjacent bedrock hills and have well-defined broad valleys which are larger than the present streams require. The valley slopes are rounded, and, unless recently scalloped by the stream, the slopes have a mantle of Willamette Silt. Intermittent streams do not cut into adjacent bedrock and usually occupy only a narrow vertical-walled channel in the center of a broad swale.

The Dayton Basin

The Dayton basin is a topographic low in the Willamette Silt surface which is centered around the town of Dayton and which extends
along most of the west side of the north Willamette Valley lowland (Plate 1). A gradual slope leads into the basin from the adjacent French Prairie rise. The boundary (Plate 1) between the basin and the rise is arbitrarily set at 175 feet. Water well logs and outcrops show that 50 to 100 feet of Willamette Silt underlie the basin and the rise. The thickness of silt and the absence of local relief except that of incised Yamhill and Willamette River tributaries indicate that the rise slope is depositional in origin. The slope ranges from one to two feet per mile between highest and lowest points in areas not affected by recent erosion.

The most conspicuous topographic features in the Dayton basin are the escarpments which separate the Willamette Silt surface from the modern floodplain surfaces of the Yamhill River and of the Willamette River. The Willamette River floodplain escarpments are typically nearly vertical with as much as 100 feet of relief. One exception is the terraced-appearing scarp in the vicinity of sample number FN19 (Plate 1, Newberg and St. Paul 7.5-minute topographic quadrangles). Yamhill River escarpments near the mouth of the river also appear to be terraced.

Two abandoned channels of streams which flowed on the Willamette Silt are present in the Dayton basin. One channel is an abandoned meander loop of the Yamhill River (McMinnville 7.5-minute topographic quadrangle) south of McMinnville. The floor of the
meander loop is 40 feet higher than the nearby Yamhill River floodplain and is between 10 and 15 feet lower than the adjacent Willamette Silt surface. The minimum width of the meander loop channel is 500 feet, and the radius of the meander is 1200 feet. These dimensions are considerably greater than similar dimensions for modern Yamhill River channels and for present meander loops. This fact may indicate that the river which cut the meander loop had a greater discharge (58, p. 63-65) than the modern river or it may be a reflection of the difference between Willamette Silt and sediments in the modern Yamhill River floodplain. Larger rivers during and immediately after Willamette Silt deposition would not be unexpected if the silt is glacial in age as previous workers have indicated and as data from this investigation affirm.

The second abandoned channel lies north of the mouth of the Yamhill River (Dundee and Dayton 7.5-minute topographic quadrangles). The channel width—nearly 1600 feet—indicates that the channel is a former Willamette River channel. The channel floor is at an altitude of 110 feet, about 50 feet higher than the modern river level nearby, and about 30 feet lower than the adjacent Willamette Silt surface.

Many small tributaries of the Willamette River and of the Yamhill River cross the Willamette Silt in the Dayton basin. Almost all tributaries enter along east-flowing courses of the two rivers.
The Willamette River along its north-flowing course from Salem to Newberg has only two tributaries and one of these is the pirated headwaters of Champoeg Creek (Plate 1). The tributary streams typically have steep walls and flat floors; the latter are much too wide for the small streams.

Barbed tributaries are common along many small streams. Champoeg Creek (St. Paul 7.5-minute topographic quadrangle), for example, has many intermittent tributaries which drain into it from the northeast as well as intermittent tributaries which enter from the southwest. The barbed tributaries of Champoeg Creek almost all enter the creek from the northeast.

Champoeg Creek Valley shows (St. Paul 7.5-minute topographic quadrangle) an intravalley terrace. The remnants of the terrace are found almost exclusively along the northeast side of the valley. The surface of the terrace is gently sloping and is bordered by steep slopes which lead to the valley floor and to the adjacent Willamette Silt surface. The altitude of the terrace does not vary noticeably from about 140 feet although the relief of the terrace surface above the valley floor increases from 30 to 55 feet in a downvalley direction. Shallow borings and road cuts indicate that Willamette Silt underlies the terrace surface. Soil maps (74) show Willamette silt loam on the terrace sediment and on the adjacent Willamette Silt.

Aerial photographs (Figure 47) show a characteristic mottling
Figure 47. Photomosaic showing characteristic nature of the Willamette floodplain and the Willamette Silt surfaces.
pattern on the Willamette Silt surface in the Dayton basin. The pattern is particularly evident in that part of the basin west of the Willamette River. East of the river, the mottling pattern is poorly defined (Figure 47) in the Dayton basin subarea, but the pattern is again conspicuous along the southern end of the French Prairie rise (Figure 47). The mottling pattern consists of dark areas and of bordering light areas (Figure 47). In some places, the dark areas are enclosed by light areas and are circular or oval. The circular and oval dark areas cover from 600 to 1200 square feet of silt surface. Field examination of the mottled areas shows that in some the dark areas are poorly drained swales and the light areas are better drained swells. The relief between swells and swales is no more than one to two feet. In other mottled areas no relief is visible, and the mottling pattern probably reflects variations in surface texture of the Willamette Silt.

The French Prairie Rise

The French Prairie rise is a gradual rise in the Willamette Silt surface toward the center of the north Willamette Valley lowland. The crest of the rise trends about N. 45° E. and is located slightly east of the center of the lowland. The crest ranges in altitude from 197 feet near the north end to 180 feet at the south end. The slopes to the west and south of the crest are regular, smooth slopes and have little local relief. The slope to the east is steeper than the west and
south slopes and shows a series of low step-like swells, most of which are discontinuous and lack sufficient relief to appear on the available topographic maps. The boundary between the rise and the Canby channeled plain (Plate 1 and Figure 47) is drawn where the east slope begins to steepen and the first swells appear. The western boundary was arbitrarily set at 175 feet.

Two deeply incised streams, Senecal and Mill Creeks, drain most of the French Prairie rise. The stream valleys, like Champoeg Creek Valley in the Dayton basin, have steep walls and flat floors. The drainage pattern (Woodburn 7.5-minute topographic quadrangle) of the streams is conspicuously rectangular with alternating north-flowing and east-flowing reaches. Where the two streams parallel one another, intermittent streams and small tributaries continue the right angle trends. The lower part of Mill Creek Valley near Aurora (Plate 1) contains an intravalley fill similar to that in the Champoeg Creek Valley.

A low broad channel (Plate 1) cuts through the north end of the rise (Sherwood and Canby 7.5-minute topographic quadrangles) and isolates a remnant of the rise surface (Canby 7.5-minute topographic quadrangle). Between 190-foot contour lines, the channel is approximately one mile wide and 35 feet deep. The channel can be traced northwest across the Willamette River (Plate 1) (Sherwood 7.5-minute topographic quadrangle) into the Rock Creek Gap channel previously
described (p. 152-156). Toward the southeast and east the channel joins a second broad channel and together they form the Canby channeled plain.

The Canby Channeled Plain

The Canby channeled plain extends from near Canby at the head of the Willamette River Gorge southwest to the vicinity of Salem (Plate 1). The boundaries of the channeled plain coincide with an increase in the slope of the silt surface which leads into the trough from the east and from the west.

Two broad channels unite to form the channeled plain in the Canby area. One channel, the larger and deeper channel, extends northeast from Canby toward the head of the Willamette River Gorge. In this channel, isolated remnants of the French Prairie rise stand 60 feet above the floor of the channel, and the channel is nearly three miles wide. The second channel trends northwest into the Rock Creek Gap. This channel is about one mile wide, and the floor of the channel is 30 feet below the level of the adjacent French Prairie rise. The depth and width of the combined channels decreases toward the southwest, and, near Salem, the channeled plain is less than 20 feet below the adjacent silt surface and is less than two miles wide.

In addition to the increased steepness of Willamette Silt slopes which lead into the channeled plain, the silt surface in the plain shows
topographic features unlike those in adjacent subareas. These features consist of northeast-southwest trending swells and swales with a maximum of 25 feet of relief, and isolated closed depressions with 10 feet or less of relief. Good examples of these features are found near the southwest corner of the Yoder 7.5-minute topographic quadrangle.

The Willamette Silt surface in the Canby channeled plain shows a mottling pattern which is distinctly different from that on the adjacent French Prairie rise. The dark areas in the rise are typically circular or are oval (Figure 47), whereas the dark areas in the channeled plain are typically elongated parallel to the general northeast-southwest trend of the plain (Figure 47). The mottling pattern in the channeled plain is caused by drainage differences due to relief. The lighter areas mark better drained swells.

The Labish Channel, the most prominent geomorphic feature in the Canby channeled plain subarea, is a deep inner trough cut below the general level of the plain. The trough trends nearly parallel to the course of the channeled plain, but on the north it bisects the two broad channels near Canby (Plate 1). The floor of the Labish Channel is flat and ranges from 1200 feet to 4000 feet in width. The slope of the channel is northeastward and averages 1.5 feet per mile. In the Aurora area, the channel joins the Molalla River floodplain, and the channel and the floodplain are nearly three miles wide.
The walls of the Labish Channel are formed by Willamette Silt and are generally steep, except in the Aurora area, where gradual slopes lead down from the channeled plain level to remnants of an intrachannel terrace. The terrace extends nearly halfway across the channel from the west bank near Aurora and from the east bank two miles south of Aurora. The channel width in this vicinity is constricted to 1200 feet where the terrace is present; where the terrace is absent the width averages nearly 2000 feet.

The upper end of the Labish Channel above the entrance of the Pudding River contains no permanent stream, and the floor of the channel in this area is underlain by a peat deposit nearly 22 feet thick (43). A radiocarbon date of 11,000 ± 230 years (B.P.) (Appendix C) was obtained from the basal peat. Peat immediately above and below a thin ash layer about six feet below the surface of the peat has a radiocarbon age between 6,820 ± 200 and 7,125 ± 160 years (B.P.) (Appendix C).

The lower part of the Labish Channel is occupied by the Pudding River and other small Cascade Mountains streams (Plate 1). The Pudding River flows in a circuitous channel cut into coarse sands and fine gravel where the river enters the channel and into heavy clays and cemented gravels north of Aurora. Carbonized organic fragments in unconsolidated sands and silts overlying cemented gravels adjacent to the Pudding River near Pat's Acres (Plate 1) have a
radiocarbon age of 4,150 ± 125 years (B. P.) (Appendix C). The size, slope, and curvature of the Labish Channel above the Pudding River and the tortuous course of the Pudding River indicate that a large stream cut the Labish Channel. Presumably, the channel is a former course of the Willamette River.

The Canby channeled plain is drained by many steep-walled and flat-floored tributaries similar to those noted in adjacent subareas. Many of these tributaries make barbed or nearly right-angle entrances into the Labish Channel. Barbed tributaries are particularly common in the reach of the channel above the entrance of the Pudding River (Plate 1). In this reach, 11 tributaries enter the Labish Channel; eight of them make barbed entrances from the northeast, and three enter at right angles to the trend of the channel.

The small streams draining eastward from the French Prairie rise into the Labish Channel have intermittent tributaries along linear trends oriented at right angles to their courses and parallel to the trend of the Canby channeled plain (Gervais 7.5-minute topographic quadrangle). Inspection of the tributary streams in the field indicate that they flow in the low swales between the equally low swells which characterize (p. 170) the channeled plain subarea. The swells and swales are particularly prominent south and southwest of Gervais (Figure 47) where the swells show as linear, light-colored areas.
The Eastern Terrace

The eastern terrace is a broad tract along the east side of the north Willamette Valley lowland. The tract is bordered on the west by the Canby channeled plain and on the east by the upper limit of Willamette Silt. On the north, the eastern terrace is separated from the western terrace by channels near Canby. Both the eastern and western terrace subareas are slightly higher areas adjacent to the main Willamette Valley lowland and underlain by thin Willamette Silt.

The silt surface in the eastern terrace slopes northwest and is divided into upland ridges separated by stream valleys. Northwest-trending ridges near the north end of the eastern terrace (Yoder 7.5-minute topographic quadrangle) are separated from swells and swales which trend northeast in the Canby channeled plain by an erosional scarp which locally shows 40 feet of relief. Water well logs and road cuts in the eastern terrace area show that the Willamette Silt is thin. This thinness and the local relief of as much as 100 feet in the eastern terrace area indicate bedrock control of the silt surface.

Many small streams drain the Willamette Silt in the eastern terrace area or flow across the eastern terrace from the adjacent Cascade Mountains foothills. As in nearby areas, the stream valleys are typically flat-floored and steep-walled. The drainage is well integrated, and the streams, unlike those farther west, show no right
angle tributaries or barbed tributaries. No mottling pattern similar to that in either the Canby channeled plain subarea or in the French Prairie rise-Dayton basin subareas is present. Some of the streams, notably Butte Creek and Rock Creek (Silverton and Yoder 7.5-minute topographic quadrangles), have remnants of an intravalley terrace. Borings into the Rock Creek terrace and road cuts through it show that it is a bedrock bench rather than an alluvial terrace. The Butte Creek terrace, however, is underlain by Willamette Silt which is separated from adjacent higher Willamette Silt by a steep, irregular escarpment. The few logs from water wells on and adjacent to the terrace suggest that the Willamette Silt in the valley overlies a pre-silt bedrock terrace.

The Mill Creek floodplain at the southwest end of the eastern terrace is a broad gravel plain which slopes gently northward. The boundary between the floodplain and the eastern terrace is an erosional scarp with 10 to 30 feet of relief. The relief decreases and the scarp becomes less steep from south to north along the Mill Creek floodplain although the scarp is not exceedingly steep anywhere. The scarp does not appear to have been undercut by Mill Creek in the recent geologic past.

The Mill Creek floodplain is floored by coarse gravels (41) which extend southward through the Mill Creek Gap (Plate 1) and up the North Santiam River Valley where they form the lowest fan level.
North of Salem, gravels in the floodplain of the Willamette River near the southwest end of the Labish Channel (Plate 1) are similar to the exposed Mill Creek floodplain gravels and are correlated with them. Similar gravels are not found north and west of the southwest end of the Labish Channel.

The Mill Creek-North Santiam fan gravels have a thickness of 50 feet in gravel pits in the Salem area. Water well logs show that the gravels have a maximum thickness of about 150 feet near the center of the Mill Creek Gap. The base of the gravel thus lies at about 113 feet in altitude.

The Mill Creek floodplain gravels apparently represent a fan deposit from an earlier North Santiam River which drained through the Mill Creek Gap into the Willamette River. Piper (65, p. 48-49), in his report on the ground water of the Willamette Valley, noted that water-bearing gravels similar to those in the Mill Creek floodplain extend north and east of the floodplain boundary. Thus the gravels underlie Willamette Silt. A log about three feet in diameter and of unknown length was found 20 feet below the surface of the gravels in the Mill Creek floodplain. A radiocarbon date of $34,410 \pm 3,450$ years (B. P.) (Appendix C) was obtained on wood from the log.

The Molalla River occupies a floodplain one to two miles wide near the north end of the eastern terrace. The floodplain slopes northwest and is veneered by coarse gravels. Coarse gravel fans,
covered by varying thicknesses of Willamette Silt, are present adjacent to the Molalla River floodplain in the Molalla area. The fan gravels decrease in thickness and disappear northwest of Molalla as the Willamette Silt thickens toward the center of the Willamette Valley.

Two fan levels, all overlain by Willamette Silt, are present along the Molalla River. Fifteen feet of gravels crops out in the lowest fan at Wagonwheel Park 3.8 miles due north of Molalla. In this locality, the gravels overlie a truncated bedrock surface 40 feet higher than the present bedrock floor of the adjacent Molalla River. The gravels are not strongly weathered in the lower fan, but they are highly decomposed in the higher fan.

Gravel deposits similar to those in the Molalla area are not found in stratigraphic sections beneath Willamette Silt in much of the north Willamette Valley lowland. The farthest downvalley occurrence of glacial outwash gravels is at Goods Bridge 1.2 miles due south of Canby where less than eight feet of gravels is exposed. The total thickness of the gravels is unknown, but they are probably less than ten feet thick.
RESULTS AND DISCUSSION

Petrography

Petrographic data establish that the Willamette Silt was not derived from the local Willamette Valley provenance. This provenance is characterized by heavy minerals which originated chiefly from basic to intermediate volcanic rocks in the Cascade Mountains and by heavy minerals derived from basic volcanic rocks and from sedimentary rocks in the Coast Range. Heavy minerals in the Coast Range streams show that detritus in some sedimentary rocks originated during weathering and erosion in granitic and metamorphic terranes. The data indicate that sedimentary rocks from these terranes become quantitatively more important in the Coast Range section toward the south end of the Willamette Valley.

Petrographic data show that sediments with a heavy mineral suite similar to that in the Willamette Silt occur in the Columbia Valley above the mouth of the Willamette Valley and in terrace deposits in the Yakima and the Walla Walla Valleys of southeastern Washington. These facts, when combined with the provenance indicated by the heavy mineral suite in the silt, show that the source of the Willamette Silt lies east of the Yakima and Walla Walla Valleys and probably in the extensive area of granitic and metamorphic rocks in northeastern Washington and western Idaho.
The petrographic data also show that the Willamette Silt contains no more minerals typical of the local provenance than Columbia River sediment above the mouth of the Willamette Valley contains. The absence of significantly higher average percentages of augite and hypersthene--dominant minerals in the local provenance--in the silt than in the Columbia River sediment indicates that deposition of the Willamette Silt took place during a geologically short time span. A short time span is affirmed by stratigraphic data which establish the absence of recognizable locally derived sediments above the base of the Willamette Silt section.

Stratigraphy, Geomorphology, and Radiocarbon Dates

Stratigraphy, geomorphology, and radiocarbon dates permit an interpretation of the nature and of the sequence of late Quaternary geologic events in the north Willamette Valley lowland. These events are summarized in Table 17 and are discussed below.

The Willamette Valley began to form in the late Tertiary and early Quaternary because of continued regional uplift and erosion (76, p. 97). During the formative stage, the north Willamette Valley lowland was carved to a little below its present depth. Pediments formed along the flanks of the lowland where they now stand as dissected, Willamette Silt-covered, and gravel-veneered slopes.

Periodically, during the early and middle Quaternary,
<table>
<thead>
<tr>
<th>Geologic Event</th>
<th>Approximate Age (years before present)</th>
</tr>
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<tbody>
<tr>
<td>Erosion of Tertiary and early Quaternary rocks to form Willamette Valley</td>
<td></td>
</tr>
<tr>
<td>Deposition of Yamhill River gravels and of high Molalla River fan gravels</td>
<td></td>
</tr>
<tr>
<td>Weathering and erosion; formation of River Bend paleosol and cutting of the</td>
<td></td>
</tr>
<tr>
<td>Mill Creek-North Santiam Valley</td>
<td></td>
</tr>
<tr>
<td>Deposition of Mill Creek lowland-North Santiam River fan gravels and low Molalla River terrace gravels</td>
<td>34,000</td>
</tr>
<tr>
<td>Deposition of fluvial-lacustrine locally derived sediments in deeper central</td>
<td></td>
</tr>
<tr>
<td>part of north Willamette Valley lowland</td>
<td></td>
</tr>
<tr>
<td>Deposition of Willamette Silt</td>
<td>&lt;34,000</td>
</tr>
<tr>
<td>Stream entrenchment and weathering of Willamette Silt; initial occupation of</td>
<td></td>
</tr>
<tr>
<td>modern Willamette River course</td>
<td></td>
</tr>
<tr>
<td>Climactic post-Willamette Silt flood</td>
<td>&gt;19,000</td>
</tr>
</tbody>
</table>

Inflowing water

Modification of Oswego Lake Gap, Rock Creek Gap, and Willamette River Gorge by erosion
Cutting of shallow multiple Tualatin Valley channels
Scouring of Willamette Silt from Canby channeled plain and re-deposition of the silt as intra-valley fills
Deposition of ubiquitous gray pebbly silt and erratics
TABLE 17. Continued.

<table>
<thead>
<tr>
<th>Geologic Event</th>
<th>Approximate Age (years before present)</th>
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</thead>
<tbody>
<tr>
<td>Blockade of Willamette River channel at Wilsonville and in Portland area with flood deposits</td>
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<tr>
<td>Outflowing water</td>
<td></td>
</tr>
<tr>
<td>Erosion of the Onion Flat lake bed and cutting of a low broad channel from Rock Creek Gap to Oswego Lake Gap</td>
<td></td>
</tr>
<tr>
<td>Beginning of peat deposition in Onion Flat</td>
<td>19,000</td>
</tr>
<tr>
<td>Deposition of &quot;second bottom&quot; sediments in the Willamette River floodplain</td>
<td></td>
</tr>
<tr>
<td>Erosion to form Labish Channel</td>
<td></td>
</tr>
<tr>
<td>Abandonment of the Labish Channel and beginning of peat formation; modern Willamette River course reoccupied</td>
<td>11,000</td>
</tr>
<tr>
<td>Deposition of volcanic ash in Labish Channel, Onion Flat, and abandoned Willamette River channel</td>
<td>6,800-7,100</td>
</tr>
<tr>
<td>Deposition of modern floodplain sediments; carbonized wood at Pat's Acres</td>
<td>4,100</td>
</tr>
</tbody>
</table>
glaciation resulted in aggradation by Willamette River tributaries which drained into the north Willamette Valley lowland. Downcutting, during the interglacial ages, dissected the glacial outwash deposits. Glacial deposits are found in the Mill Creek-North Santiam River Valley and in the Molalla River Valley where outwash gravels may be traced to glaciated headwater areas. The Yamhill River gravels show no conclusive evidence of a glacial origin, and the Coast Range probably was not glaciated extensively, if at all.

Because the gravels are all overlain by and are thus older than Willamette Silt, no attempt to determine exactly the relative ages of gravel deposits in the north Willamette Valley was made. The decomposed state of the Yamhill River gravels indicates that the presilt surface, which they underlie, was dissected and was weathered extensively prior to deposition of the Willamette Silt. The gravels probably are correlative with the higher level decomposed fan gravel deposits adjacent to the Molalla River. The lower level fan gravels in the Molalla Valley are correlated with the Mill Creek-North Santiam River fan gravels. This correlation is based on the similar topographic position of the gravels in the respective river valleys.

Either Quaternary glaciation did not result in a significant aggradation by the Willamette River in the north Willamette Valley lowland or the glacial deposits were removed during the interglacial ages. Unit I at River Bend and similar deposits elsewhere along the
the west and north sides of the north Willamette Valley lowland are
too variable in texture, too strongly cemented, and too thick to be
correlative with known glacial outwash. The textural variability and
sedimentary structures in the Unit I beds indicate that the beds were
deposited in fluvial and in fluvial-deltaic environments. The distribu-
tion and thickness of the sediments show that they were deposited
in a downwarp in which the base lies more than 120 feet below the
present base level of the Willamette River and more than 70 feet be-
low modern sea level.

The writer believes that the Unit I deposits are older than
known Pleistocene glacial deposits in the north Willamette Valley low-
land and that they probably are correlative with Troutdale Formation
deposits in the Portland Basin. Lowry and Baldwin (59) suggest that
Troutdale correlative sediments filled the Willamette Valley to a level
above the present top of the Salem-Eola Hills; thus Troutdale sedi-
ments below younger sediments in the valley are not unexpected.

Trimble (76, p. 55-56) reported that pollen in deposits near
Swan Island, which are correlated by the writer with Unit I deposits,
indicated a "nonglacial rather than a glacial climate". Although
Trimble (76, p. 55-56) assigned the deposits to a "middle (?) Pleisto-
cene age", similar pollen could be found in early Quaternary or late
Tertiary deposits. The C14 date from the deposits near Swan Island
establishes only that they are older than 37,000 years (B. P.).
The data do not establish whether or not the Willamette River aggraded the north Willamette Valley lowland during the Quaternary glacial ages. If the slope of the lowest fan gravel surface is extended down the Molalla Valley from the outcrop of the gravels at Wagonwheel Park, the gravels would enter a Willamette River which was ten feet higher than the present Willamette River. This fact may indicate either that the Willamette River of the lowest fan gravel age was aggraded to the higher level or that the falls of the Willamette River at Oregon City were ten feet higher then than now.

Glacial outwash does not crop out along the west and north sides of the lowland where Unit I type sediments underlie Willamette Silt. The depth and intensity of weathering of Unit I sediments are less than that of the Yamhill River gravels and of the high Molalla River fan gravels, and they are also less than that which Trimble (76, p. 50-58) and Allison (8, p. 9-11) describe for gravels in the Portland and Albany areas. These facts show that the surface of the Unit I sediments is younger than the high gravel surfaces, and they suggest that any glacial gravels which may have been deposited on Unit I sediments were subsequently eroded. Erosion, however, would not be accomplished without leaving some remnants of the glacial gravels or without leaving floodplain and channel deposits of the eroding stream; none of these remnants or deposits is present.

Despite the younger age of the Unit I sediment surface, the
writer is not convinced that any glacial gravels were deposited along the north and west sides of the north Willamette Valley lowland. The Molalla River gravels thin into the Willamette Valley from the apex of the fans to less than 15 feet thick at Wagonwheel Park. The thickness of the Mill Creek-North Santiam gravels in the Mill Creek Gap indicates that they were deposited in a deep inner-valley cut into Tertiary and early Quaternary bedrock. The edges of the valley are covered by Willamette Silt in the north Willamette Valley lowland, and the depth and position of the inner-valley in this area are not known. The inner-valley was deep enough so that Unit I sediments at River Bend and elsewhere were exposed subaerially and were not covered with fluvial deposits until the beginning of Willamette Silt time.

After aggradation in the Mill Creek-North Santiam Valley and after weathering to form the River Bend paleosol, sediment-charged Columbia River water entered the lower part of the north Willamette Valley lowland. The inflowing water eroded any Molalla River glacial outwash that may have been deposited in the Swan Island area and also cut away any evidence of a paleosol on Unit I deposits. Sand, which accompanied the inflowing Columbia River water, was deposited on the erosion surface. The north end of the pre-silt Willamette River Valley was filled by the Columbia River flood-derived sand, and Willamette River water spread laterally over an adjacent low terrace onto sediments similar to Unit I at River Bend.
The contact between Unit I and Unit II sediments at River Bend and the variation in thickness of Unit II sediments in the north Willamette Valley lowland indicate that unchanneled Willamette River water spread over the lowland, here, depositing a few feet of sediment, and there, 20 feet or more. Initial deposits consist of locally derived fluvial black sands of the basal Unit II phase at River Bend. The change in textures and in sedimentary structures toward the top of Unit II indicate a rather abrupt shift from fluvial to fluvial-lacustrine and finally to lacustrine sedimentation in the Willamette Valley. A thin layer of volcanic ash in the lacustrine sediments attests to volcanism in the Cascade Mountains and to standing water in the River Bend area. Water-dwelling pulmonate mollusks, ostracods, sedimentary structures, and mineralogy indicate slow deposition of local sediments in shallow water near the end of Unit II time. Oversteepened cross-beds, irregular and contorted bedding, which is not truncated by overlying beds, and clastic dikes indicate post-depositional movement of saturated Unit II sediments, perhaps caused by compaction due to the weight of overlying Willamette Silt.

Deposition of Willamette Silt began at River Bend without any interruption in established lacustrine conditions. The relatively "pure" local mineralogy of sands and silts in Unit II indicate that the first floods brought very little fine sediment into the Willamette Valley. During at least 40 subsequent floods, a volume of chiefly silt
and fine sand was deposited. This volume is estimated at nearly three cubic miles in the north Willamette Valley lowland alone. The water and sediment moved up the Willamette Valley along the French Prairie rise and the Canby channeled plain subareas. Coarse sediments were deposited close to the head of the Willamette River Gorge and beneath the rise and channeled plain. Fine sediments were deposited in subareas marginal to or higher than the rise and channeled plain—Dayton basin, eastern and western terraces. In back eddy areas near the Willamette River Gorge but away from the path of incoming flood water—such as the Clark's Marina area—fine sediments also were deposited. Because the eastern terrace subarea lies adjacent to the path along which Columbia River sediments traveled up the Willamette Valley, greater thicknesses and coarser sediments were deposited at comparable altitudes in that subarea than in the western terrace subarea. Columbia River deposits, by the end of Willamette Silt time, had established a depositional southward slope which extended from the Columbia Valley into the Willamette Valley nearly to the Salem area.

Fresh water fossils, nearly horizontal and continuous bedding, and absence of subaerial weathering or erosion between beds show that the Willamette Silt was deposited in a continuously ponded body of water at River Bend and at other lower altitude exposures. Greater depths of oxidized Willamette Silt at its higher altitude exposures
than elsewhere may indicate either intermittent subaerial exposure of
the silt during deposition or better post-silt drainage. The absence
of shorelines, deltas, or beach deposits related to stable ponded water
levels indicates that the water surface fluctuated. Coarse sediments,
truncation and lensing of beds, and large cut-and-fill channels in the
Needy and Swan Island areas show that ponded water was shallow.

Texture, sedimentary structures, and contacts in a Willamette
Silt bed at River Bend show that floods began there with gentle cur-
rents which scoured the underlying beds and deposited coarse silt.
The preservation of ripple marks in the coarse silt indicates that the
flood waters carried a large load and that deposition was rapid. Finer
sediments toward the top of a bed show a return to quiet water sedi-
mentation. In some beds, quiet water sedimentation took place during
both early and late flood stages. Northward-dipping foreset beds of
ripple marks and of cross-beds within some beds at River Bend show
that flood waters, which flowed upvalley along the French Prairie rise
and the Canby channeled plain, circulated back into quiet water in the
Dayton basin.

Textural differences and contacts between Willamette Silt beds
at Needy show that periods of high energy transportation of sediment
up the Willamette Valley ended abruptly and were followed by periods
of quiet water sedimentation. Within Willamette Silt beds related to
one flood, quiet water sedimentation gradually changed to high energy
sedimentation during the flood.

The widespread distribution of the Willamette Silt, its occurrence nearly 150 feet higher on the flanks of the valley than in the center of the valley, and its presence more than 100 miles south in the Willamette Valley from the Columbia Valley show that the floods were large and that the inflowing waters were highly turbulent.

The thickness of Willamette Silt beds shows that flood waters carried heavy loads, and the variation in bed thickness with stratigraphic position indicates that flooding began slowly, built up to maximum proportions near late middle Willamette Silt time, and gradually diminished. The absence of locally derived sediments above the base of the Willamette Silt section indicates that the interval between floods was short and that the Willamette Silt was deposited during a geologically short time span.

The fact that the Willamette Silt unconformably overlies older glacial gravels and is conformable with the youngest known glacial gravels indicates that deposition of the silt took place near the end of the last major stage of Cascade Mountains glaciation. A radiocarbon date from a log in the Mill Creek-North Santiam gravels shows that this glaciation began more than 34,410 ± 3,450 years (B. P.).

Ponded water drained from the Willamette Valley immediately after the last Columbia River flood. The absence of shorelines, deltas, or beach deposits related to ponded water levels in the
Willamette Valley shows that the water did not stand at any one level for a long period of time. The absence of locally derived sediments over Willamette Silt and rapid post-silt downcutting indicate that ponded water drained rapidly from the Willamette Valley.

Subaerial weathering and erosion of the Willamette Silt began as ponded water drained from the Willamette Valley. The large abandoned channel near the mouth of the Yamhill River indicates that the Willamette River established an initial course in the Dayton basin and along the north side of the north Willamette Valley lowland. The Yamhill and Molalla Rivers established courses near their present routes. Pudding River, Abiqua Creek, and Rock Creek reoccupied courses in pre-silt valleys across the eastern terrace and northward along a low between the French Prairie rise and the eastern terrace. Barbed tributaries along the southwest end of the Labish Channel indicate that initial drainage of the southward-sloping rise was southwest and into the Willamette River north of Salem.

Downcutting in the river valleys and in small tributary valleys progressed rapidly until the streams cut through Willamette Silt into the underlying bedrock. Because of the indurated nature of the bedrock and because the bedrock lies near the present base level of the Willamette River, lateral planation ensued and flat-floored but steep-walled stream valleys formed.

After weathering of the Willamette Silt and after dissection of
the silt surface, a climactic Columbia River flood larger than any previous floods entered the Willamette Valley. Part of the floodwater passed through the Oswego Lake Gap where it scoured the bedrock walls and left the basalt rubble noted in the gap. Flood water, which continued up the Tualatin Valley from Oswego Lake Gap, eroded high level, shallow, multiple channels in Willamette Silt. At Rock Creek Gap, flood water spilled over the divide between Tualatin Valley and Willamette Valley drainages and formed the unusual erosional and depositional features noted in this gap. Flood water, which entered the Willamette Valley through the Willamette River Gorge, combined with that from the Rock Creek Gap to scour the upper Willamette Silt from the Canby channeled plain.

The largest Columbia River flood, unlike previous floods, deposited little "foreign" sediment in the Willamette Valley. Gray pebbly silts and erratics, which overlie oxidized Willamette Silt, are deposits of the last flood. The common occurrence of the gray silts and the erratics up to 400 feet in altitude and the presence of scoured bedrock in Rock Creek Gap at 350 feet in altitude indicate that the last flood inundated the Willamette Valley to at least the 400-foot altitude.

The last flood, unlike previous floods, left a record of the flood water leaving the Willamette Valley. Flood water spilled northward over the basalts in Rock Creek Gap and eroded the Onion Flat lake bed and the broad channel between Rock Creek Gap and Oswego
Lake Gap. This channel is lower and larger than smaller Tualatin Valley channels, and the position of the channel at the north end of Rock Creek Gap is such that the channel would have been filled by sediments if it had been present during the inflowing flood stage.

Trimble (76, p. 65) noted evidence for high energy westward-flowing water followed by low energy eastward-flowing water in sediments at the southwest end of Oswego Lake Gap. Although Trimble (76, p. 65) correlated these sediments with Willamette Silt, sedimentary structures in the silt in the Willamette Valley show no evidence of water rapidly flowing out of the valley, and the writer believes that the Oswego Lake Gap sediments should be correlated with post-silt flood deposits.

The last Columbia River flood extensively modified pre-flood Willamette Valley drainages. Willamette Silt, locally scoured by the flood, was redeposited in favorably oriented stream valleys where it now occurs as remnants of intravalley terraces. Local sediments and eroded Willamette Silt also accumulated in the pre-flood Willamette River channel at Wilsonville and in the Willamette River channel between Oregon City and Portland. The flood-derived fill caused an aggradation by the Willamette River which resulted in deposition of "second bottom" sediments in the Willamette River floodplain. The well-defined stratification of these sediments and the mantling of underlying floodplain topography indicate that the aggradation occurred
in essentially ponded water. Ponded water in the Willamette River floodplain rose to an altitude which allowed all or part of the river flow to be diverted around the Wilsonville blockade and down the flood-scoured Canby channeled plain. During subsequent entrenchment, the Labish Channel was cut to its present depth. Later the channel was abandoned, possibly because higher pre-silt bedrock along the channel than along the modern river course resulted in conditions which favored piracy. A radiocarbon date from peat at the base of the Labish Channel indicates that the channel abandonment was completed about 11,000 ± 230 years (B. P.).

After abandonment of the Labish Channel, the Willamette River reoccupied its initial post-Willamette Silt course. Erosion and lateral planation by the river dissected and partially removed "second bottom" deposits and locally widened the floodplain. Small tributary streams such as Champoeg Creek and Mill Creek near Aurora reestablished their courses in partially filled valleys and rapidly eroded the intravalley fills. The Pudding River, a small stream in a channel carved by a larger stream, began to flow in a circuitous course down the Labish Channel.

About 7,000 years (B. P.), a widespread ash fall covered much of the Willamette Valley and probably much of the adjacent mountains (47, p. 463; 42; 67). The ash in the Labish Channel peat, in the abandoned Willamette River channel near sample site FG16, and in the
Onion Flat peat (43, p. 268-269), records this pyroclastic eruption. The difference (Appendix C) in the ages of organic sediments immediately above and below the ash may be due to differences in sample treatment by the two laboratories which processed the samples, or, more likely, the difference is due to contamination during sampling. The age, distribution, and petrography of the ash (42, 43, 46, 67) indicate that the ash was derived during the eruption of Mount Mazama and the formation of Crater Lake.

The age of the last Columbia River flood can be interpreted from the results of radiocarbon dating combined with the results of pollen analysis (43, p. 268-269). Organic sediments began to accumulate in Onion Flat after the last flood water drained from the Willamette Valley so that a date from the basal sediment would give the time of flooding. Organic sediments in the Labish Channel are younger than those in Onion Flat because the channel was not cut and was not abandoned until after the Willamette River aggradation caused by flood deposits.

Basal organic sediment from Onion Flat was not submitted for dating, but the age can be estimated from rates of organic sediment accumulation based on available dates. These dates show that organic sediments in the Labish Channel between the ash and the bottom of the channel accumulated at a rate of one meter per 930 years. Hansen's data (43, p. 268-269) show that the ash layer in the Labish
Channel is synchronous with that in Onion Flat. Thus, the rate of peat accumulation between the ash and the $12,240 \pm 330$ years (B. P.) date from peat at 16 feet in Onion Flat is one meter per 1,048 years. At an average rate of organic sediment accumulation of one meter per 1,000 years the age of the basal peat at Onion Flat is about 19,000 years (B. P.).

Pollen (43, p. 268) in the basal organic sediment at Onion Flat shows that the basal sediment was deposited during a cooler and more moist climate (43, p. 278) than the present climate. This fact indicates that the basal sediment accumulated during a glacial stage. The 19,000 years (B. P.) date lies well within the age range assigned by Crandell (30, p. 9) to the Vashon glacial stage in the Puget Sound region of Washington.

The 19,000 years (B. P.) date also is the minimum age of the Willamette Silt. The exact age of the silt is unknown although in many areas where the post-silt flood scoured Willamette Silt, soil scientists note soil development no different from that on adjacent uneroded Willamette Silt. This suggests that the upper part of the silt is not greatly older than the last climactic flood. The $34,410 \pm 3,450$ years (B. P.) date from a log in pre-silt gravels is a maximum age of the basal silt. Although these gravels are correlated with unweathered fan gravels in the Molalla River Valley, the log is 20 feet below the present Mill Creek floodplain, and an unknown thickness of gravels
could have been eroded by Mill Creek. Thus the maximum age of the Willamette Silt could be less than the 34,410 ± 3,450 years (B.P.) date.

Origin of the Willamette Silt

Data from the present investigation establish the following pertinent facts relative to the origin of the Willamette Silt:

1) The silt was derived from the Columbia River Basin east of the Yakima and Walla Walla Valleys and from sediments originally derived chiefly from granitic and metamorphic terranes.

2) Deposition of the silt took place near the end of the last Quaternary glaciation that caused a significant aggradation in Cascade Mountains Willamette River tributaries. This glaciation began more than 34,000 years (B.P.).

3) Deposition of the silt immediately followed or caused lacustrine conditions in the Willamette Valley.

4) Deposition of the silt was accomplished by at least 40 rapidly recurring Columbia River floods that transported heavy loads chiefly of silt and fine sand into the Willamette Valley.

5) Deposition of the silt, at least at lower altitudes, occurred in a ponded body of water in which the water level fluctuated.

6) Deposition of the silt was followed by an abrupt end of lacustrine conditions in the Willamette Valley and by vertical
entrenchment of streams.

7) After entrenchment of the streams and after weathering of the silt, a climactic Columbia River flood scoured the bedrock entrances between the Columbia and the Willamette and Tualatin Valleys, eroded large tracts of the silt surface, deposited ubiquitous gray pebbly silts and erratics on the Willamette Silt, eroded the Onion Flat lake bed and the broad channel between Rock Creek Gap and Oswego Lake Gap, and caused an aggradation by the Willamette River. This flood occurred about 19,000 years (B. P.).

The facts outlined above indicate that previous correlations of the Willamette Silt with one Columbia River flood (76) or with "normal" Columbia River floods (59) are incorrect.

The data show that the largest Columbia River flood, presumably the one to be "hydraulically dammed" and the one to be called the Spokane Flood, occurred after the Willamette Silt was deposited. The writer correlates Trimble's "lacustrine" deposits with Willamette Silt, as Trimble did, although the proposed method of origin (see p. 203-207) of the silt and "lacustrine" deposits is different from that which Trimble envisioned. Trimble's (76, p. 68-71) "upper (?) Pleistocene sand and silt deposits", which Trimble states (76, p. 68) disconformably overlie "lacustrine" deposits, are correlated by the writer with gray pebbly silts and erratics in the Willamette Valley. Trimble's (76, p. 71-72) "Recent (?) terrace deposits" in the
Clackamas Valley are believed to be in part the same as the "upper (?) Pleistocene sand and silt" and in part the same as "second bottom" deposits in the Willamette River floodplain. The upper (?) Pleistocene deposits and part of the Recent (?) terrace deposits, where examined by the writer, are probably locally scoured and redeposited Willamette Silt or its "lacustrine" correlative. The distribution of the sand and silt and the Recent (?) terrace deposits, as mapped by Trimble, indicates such an origin.

Lowry and Baldwin's (59) "normal" Columbia River floods into a body of water produced by a eustatic rise in sea level during an interglacial age fails to explain the origin of the Willamette Silt for the following reasons:

1) The age range for the silt falls in a period of low sea levels (31, p. 1708) and high lake levels (31, p. 1708) indicative of a glacial age.

2) No evidence of an aggradation of the type (35, 40) which accompanies a eustatic rise in sea level is present.

3) The lack of stability of ponded water, as shown by the absence of shorelines, deltas, and beach deposits, is not typical of either the rate or nature of eustatic sea level change.

4) "Normal" Columbia River floods, which were confined to the Columbia Valley, probably would not have repeated access to the requisite silt and sand load.
5) A modern Columbia River flood of about two weeks duration, if it deposited all its load in a triangular area the size of the north Willamette Valley lowland, would result in a bed only approximately 0.01 foot thick (data from unpublished U. S. Geological Survey Records; computations by W. L. Haushild, U. S. Geological Survey, Portland, Oregon).

Lowry and Baldwin (59, p. 20-21) did recognize evidence in the Portland Basin for the climactic post-Willamette Silt flood which data from the present investigation establish.

A tectonic submergence of the lower Columbia Valley, such as Bretz (13, p. 502; 19, p. 252) advocated, is also refuted by reasons 2) and 3) above.

Any hypothesis which explains the origin of the Willamette Silt must provide the following:

1) A mechanism to produce multiple large Columbia River floods over a geologically short time span,

2) An easily and continuously accessible supply of silt and fine sand, and

3) A mechanism to produce continuously ponded water, at least at lower altitudes, in the Willamette Valley.

Allison's icejams provide a mechanism for multiple floods, but icejams alone are inadequate to produce continuous ponding or to provide fine-grained sediments. Icejams produced by combined
glacial and river ice probably would be annual. Although data from this investigation do not establish the frequency of flooding, the absence of local sediments in the silt section indicates that flooding occurred more often than annually.

The stratigraphic record of Willamette Silt floods contains little evidence of floating ice. The erratics that were observed by the writer either lay on Willamette Silt or were buried in silt scoured and redeposited during post-silt erosion. The isolated pebbles and cobbles at the base of the Needy section may be erratics although this is not definitely established.

Fine-grained sediments mineralogically similar to Willamette Silt are not available locally in the Columbia River Gorge. This fact, and the fact that sediments similar to the silt occur in Columbia River tributary valleys upstream from the gorge, indicates that icejam-produced floods depend on floods in the upper Columbia River Basin for a supply of Willamette Silt-type sediments.

Multiple floods caused by Missoula dam failures (27) also fulfill part of the necessary requirements for an explanation of the origin of the Willamette Silt. Floods produced by this mechanism cross the Columbia River Plateau of eastern Washington where a thick sequence of early Pleistocene eolian silts and fine sands--the Palouse Formation--would serve as an excellent and easily scoured source for Willamette Silt. However, the number of floods and the
chronology of flooding favored by Bretz, Smith, and Neff (27) is not compatible with that established by Willamette Valley data, and without a tectonic submergence, no mechanism of producing ponded water in the Willamette Valley is provided.

The writer believes that multiple floods produced by repeated Missoula dam failures, perhaps seasonally supplemented by floods due to icejams, most nearly satisfy Willamette Valley data. This conclusion implies that more floods occurred than Bretz and coworkers (27) recognized and that scabland tracts were initially occupied sequentially or by smaller floods rather than simultaneously, as Bretz favored, by a large flood. The fact that Bretz, Smith, and Neff (27) did not recognize more floods is understandable because their conclusions are based chiefly on the erosional record of flooding. This record is not nearly so reliable as the depositional record of flooding in the Willamette Valley, particularly because the last climactic flood probably extensively modified the records of earlier floods across the scablands.

A sequential development or a progressive widening of scabland tracts is necessary to insure a continuing supply of Palouse Formation sediments to later floods. Descriptions (82, 36) of Pleistocene glacial deposits in eastern Washington show that the glaciers of Willamette Silt time did not carry great amounts of fine-grained sediments. This fact, and the fact that the Willamette Silt was
deposited during a geologically short time span indicates that the glaciers could serve only as a supplemental source for Willamette Silt. An early flood of the magnitude of Bretz's Spokane Flood (19, p. 258) or of the magnitude of the last climactic flood in the Willamette Valley would have eroded much of the Palouse Formation from the scablands. Willamette Valley data show, however, that floods near the end of Willamette Silt time deposited greater thicknesses of fine-grained sediments than either earlier or later floods.

Relative to the sequence of floods in the Columbia Valley, the absence of heavy loads of silt and fine sand in early Willamette Valley floods, as shown by the local mineralogy in Unit II sediments at River Bend, indicates that these floods were confined to the Columbia Valley. This fact supports Bretz, Smith, and Neff's conclusions (27, p. 967), based on data from the scabland area, that the earliest floods did not cross the scablands. The relatively minor deposits from the last climactic flood may be due in part to nonponded conditions in the Willamette Valley prior to the flood, but, more likely, the scarcity of deposits indicates the earlier floods had scoured nearly all the easily available Palouse Formation sediments from the scabland tracts.

The frequency of floods produced by Missoula dam failures is a point about which the data available do not give a satisfactory answer. It is probably safe to say, however, that such floods would
be less controlled by annual climatic fluctuation than floods produced by combined river and glacial ice jam dams.

One last point relative to the origin of Willamette Silt--ponded water--remains to be discussed. The writer observed no evidence that ponded water ever stood continuously in the Columbia Valley during Willamette Silt time. The "lacustrine" deposits of Trimble, where they could be definitely differentiated from deposits emplaced during the last climactic flood when ponded water was present for a short time, are poorly stratified in comparison to the conspicuous stratification of the Willamette Silt. Trimble (76, p. 63) also noted the difference in stratification between Columbia Valley and Willamette Valley "lacustrine" deposits.

The writer believes that the most satisfactory explanation for continuous ponding in the Willamette Valley is a more rapid aggradation in the Columbia Valley than in the Willamette Valley. Treasher (77, p. 13-14) suggested that the Portland area deposits are the result of an aggradation by a Columbia River "choked by its own load". The writer's observations and previous descriptions by others (13, p. 502; 19, p. 252; 65, p. 34) suggest that the aggradation was unusually rapid.

The Columbia River aggradation, in part, preceded the beginning of flooding in the Columbia Valley, and it probably coincided with the growth and advance of the Cordilleran Glacier Complex.
(38, p. 303-313) northeast of the channeled scablands. Waters (82, p. 763-820) described a coarse gravel terrace which extends down the Columbia Valley from Lake Chelan, Washington (Figure 1). He attributed the terrace gravels to the advance of the Okanogan lobe of the Cordilleran Glacier Complex to and eventually across the Columbia Valley. The growth of the Cordilleran ice cap probably coincided with the beginning of the alpine glaciation that caused the deposition of the Mill Creek-North Santiam Valley and low Molalla Valley fan gravels.

After the Okanogan lobe blocked the Columbia River and scabland flooding began, aggradation progressed more rapidly in the lower Columbia Valley than in the Willamette Valley, and a ponded body of water formed in the Willamette Valley. Repeated floods across the scablands and down the Columbia Valley then entered the Willamette Valley and deposited the Willamette Silt. Entrance to the valley was facilitated, as Allison (4, p. 625-626) suggested, by an aggradational slope into the Willamette Valley. Icejams (4, p. 625-626) may also have been important in deflecting the flood water into the Willamette Valley, and possibly in producing ponded water at higher altitudes, but aggradation during flooding was the most important factor in maintaining continuously ponded water at lower altitudes.

Downcutting began when the Pend Oreille lobe (27) retreated from across the Clark Fork and when scabland flooding ended. In
the lower Columbia Valley, a continued low stand in sea level resulted in immediate entrenchment and in drainage of ponded water from the Willamette Valley. A readvance of the Pend Oreille lobe about 19,000 years (B.P.) would have created conditions favorable for a new glacial Lake Missoula which, when its ice dam failed, resulted in the largest Columbia River flood ever to enter the Willamette Valley.
BIBLIOGRAPHY


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APPENDICES
**Appendix A**

**TABLE 18. Location of local provenance and correlation sample sites.**

<table>
<thead>
<tr>
<th>River</th>
<th>Sample Number</th>
<th>Public Land Survey</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yamhill</td>
<td>JSY-20</td>
<td>Grand Ronde 15' quadrangle&lt;br&gt;SW1/4 sec. 10,&lt;br&gt;T. 5 S., R. 8 W.</td>
<td>Adjacent to Highway 18 bridge over Rogue River, a tributary of the South Yamhill River. River sediment.</td>
</tr>
<tr>
<td></td>
<td>JSY-19</td>
<td>Grand Ronde 15' quadrangle&lt;br&gt;SE1/4 sec. 33,&lt;br&gt;T. 5 S., R. 8 W.</td>
<td>South Yamhill River bridge 3/4 mile west of the junction of Crooked Creek with South Yamhill River. Floodplain sediment.</td>
</tr>
<tr>
<td>Luckiamute</td>
<td>JLL-5</td>
<td>Dallas 15' quadrangle&lt;br&gt;SW1/4 sec. 13,&lt;br&gt;T. 5 S., R. 8 W.</td>
<td>Near Black Rock County Park on Little Luckiamute River. River sediment.</td>
</tr>
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<td></td>
<td>JM-1</td>
<td>Marys Peak 15' quadrangle&lt;br&gt;SW1/4 sec. 26,&lt;br&gt;T. 11 S., R. 7 W.</td>
<td>Near Alder. Floodplain sediment.</td>
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<tr>
<td>River</td>
<td>Sample Number</td>
<td>Public Land Survey</td>
<td>Remarks</td>
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<tr>
<td>Long Tom (con't)</td>
<td>JLT-8</td>
<td>Elmira 15' quadrangle</td>
<td>By Long Tom River bridge.</td>
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<td></td>
<td></td>
<td>Sec. line secs. 28-33,</td>
<td>Floodplain sediment.</td>
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<td>T. 16 S., R. 6 W.</td>
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<tr>
<td>Coast Fork</td>
<td>JCF-10</td>
<td>Cottage Grove 15' quadrangle</td>
<td>River sediment.</td>
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<td></td>
<td></td>
<td>SW1/4 sec. 3,</td>
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<td>T. 20 S., R. 3 W.</td>
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<td></td>
<td>JCF-11</td>
<td>Cottage Grove 15' quadrangle</td>
<td>Near Walker.</td>
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<td></td>
<td>NW1/4 sec. 10,</td>
<td>Floodplain sediment.</td>
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<tr>
<td></td>
<td></td>
<td>T. 20 S., R. 3 W.</td>
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<tr>
<td>Middle Fork</td>
<td>JMF-16</td>
<td>Lowell 15' quadrangle</td>
<td>At gaging station at Jasper.</td>
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<td></td>
<td></td>
<td>SW1/4 sec. 15,</td>
<td>River sediment.</td>
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<td></td>
<td>T. 18 S., R. 2 W.</td>
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<tr>
<td></td>
<td>JMF-15</td>
<td>Lowell 15' quadrangle</td>
<td>One mile south of Jasper.</td>
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<td></td>
<td>SE1/4 sec. 23,</td>
<td>River sediment.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T. 18 S., R. 2 W.</td>
<td></td>
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<tr>
<td>McKenzie</td>
<td>JMc-28</td>
<td>Marcola 15' quadrangle</td>
<td>At Henricks bridge.</td>
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<td></td>
<td></td>
<td>NE1/4 sec. 32,</td>
<td>River sediment.</td>
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<td></td>
<td></td>
<td>T. 17 S., R. 1 W.</td>
<td></td>
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<tr>
<td>Calapooya</td>
<td>JCa-18</td>
<td>Brownsville 15' quadrangle</td>
<td>Half a mile above gaging station near Holley.</td>
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<tr>
<td></td>
<td></td>
<td>SW1/4 sec. 14,</td>
<td>River sediment.</td>
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<td>T. 14 S., R. 1 W.</td>
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<tr>
<td>River</td>
<td>Sample Number</td>
<td>Public Land Survey</td>
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<tr>
<td>Calapooya (Con't)</td>
<td>JCa-17</td>
<td>Brownsville 15' quadrangle SE1/4 sec. 15, T. 14 S., R. 1 W.</td>
<td>At gaging station near Holley. River sediment.</td>
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<td>South Santiam</td>
<td>JSS-17</td>
<td>Brownsville 15' quadrangle NW1/4 sec. 28, T. 12 S., R. 1 W.</td>
<td>At Waterloo bridge. Point bar.</td>
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<td>JSS-18</td>
<td>Lebanon 15' quadrangle NE1/4 sec. 29, T. 12 S., R. 1 W.</td>
<td>One mile due south of Reed School. Floodplain sediment.</td>
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<tr>
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<td>JNS-20</td>
<td>Lyons 15' quadrangle SW1/4 sec. 15, T. 9 S., R. 1 W.</td>
<td>A quarter of a mile south of State Highway 22. Floodplain sediment.</td>
</tr>
<tr>
<td></td>
<td>JGC-1</td>
<td>Camas, Wash. - Oreg. 15' quadrangle SE1/4 sec. 9, T. 1 N., R. 4 E.</td>
<td>Adjacent to Orchard Hills Golf Course. Older silt or high floodplain sediment.</td>
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<tr>
<td>River</td>
<td>Sample Number</td>
<td>Public Land Survey</td>
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<td>(Con't)</td>
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<td>15' quadrangle</td>
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<td>SW1/4 sec. 21,</td>
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<td>T. 2 N., R. 6 E.</td>
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<td>15' quadrangle</td>
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<td>SW1/4 sec. 25,</td>
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<tr>
<td>JGC-5</td>
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<td>Bonneville, Wash. - Oreg.</td>
<td>One mile east of Cascade Locks. Older sand or high level floodplain sediment.</td>
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<tr>
<td></td>
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<td>15' quadrangle</td>
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<tr>
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<td>SE1/4 sec. 6,</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>T. 2 N., R. 8 E.</td>
<td></td>
</tr>
<tr>
<td>JGC-7</td>
<td></td>
<td>Bonneville, Wash. - Oreg.</td>
<td>Sandbar at mouth of Hood River.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15' quadrangle</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. sec. 25,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>T. 3 N., R. 10 E.</td>
<td></td>
</tr>
<tr>
<td>Yakima</td>
<td>JY-1</td>
<td>Yakima East, Wash.</td>
<td>One mile southeast of Union Gap in terrace deposits. Coarse gravels abruptly overlain by chaotically bedded silts and sands with large erratics near top of section.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.5' quadrangle</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>NW1/4 sec. 21,</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>T. 12 N., R. 19 E.</td>
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</tr>
<tr>
<td>River</td>
<td>Sample Number</td>
<td>Public Land Survey</td>
<td>Remarks</td>
</tr>
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<td>---------------</td>
<td>--------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Yakima</td>
<td>JY-2</td>
<td>Zillah, Wash.</td>
<td>At bridge over Yakima River near Granger. Well bedded, partially cemented silts and sands.</td>
</tr>
<tr>
<td>(con't)</td>
<td></td>
<td>30' quadrangle</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. sec. 21,</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>T. 10 N., R. 21 E.</td>
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</tr>
<tr>
<td></td>
<td>JY-3</td>
<td>Pasco, Wash.</td>
<td>Near Benton City on road along the east side of Yakima River. Sediments chaotically bedded silts and sands with large clastic dikes and with erratics near top of section.</td>
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<tr>
<td></td>
<td></td>
<td>30' quadrangle</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>NW1/4 sec. 20,</td>
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</tr>
<tr>
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<td></td>
<td>T. 9 N., R. 27 E.</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>30' quadrangle</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. sec. 26,</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>T. 7 N., R. 31 E.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>JWW-5</td>
<td>Wallula, Wash.</td>
<td>Half a mile west of Lowden. Chaotically bedded silts and sands with large sandstone dikes and erratics.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30' quadrangle</td>
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<td>SE1/4 sec. 30,</td>
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<td></td>
<td>T. 7 N., R. 34 E.</td>
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</tr>
<tr>
<td></td>
<td>JWW-6</td>
<td>Walla Walla, Wash.</td>
<td>Half a mile south of College Place. Well stratified, partially cemented red silts. No erratics or clastic dikes.</td>
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<tr>
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<td>30' quadrangle</td>
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### TABLE 19: Partial particle size distribution data for samples analyzed for heavy mineral content.

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<td>JMF-16</td>
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<td>JCa-18</td>
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<td>By Difference</td>
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TABLE 20. Particle size distribution statistics for 22 Willamette Silt samples from random sample sites. Asterisk indicates that the values were obtained by a linear extrapolation of the particle size data in order to obtain the phi or quartile values necessary for the computation.

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a = Not computed.
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* = not computed
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<th>K</th>
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<th>$\text{M}_{\phi}$</th>
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<td>2.99</td>
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<td>0.66*</td>
<td>0.67*</td>
<td>0.45*</td>
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TABLE 22. Percentage of sand, silt, and clay in 52 Willamette Silt samples.

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Some as TD6
Same as TSP19
TABLE 22. Continued.

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<td>24</td>
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<td>16</td>
<td>58</td>
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<td>39</td>
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<td><strong>Range</strong></td>
<td>1-31%</td>
<td>42-69%</td>
<td>19-56%</td>
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TABLE 23. Particle size distribution statistics for 22 Willamette River floodplain samples from random sample sites. Asterisk indicates that the values were computed using a linear extrapolation of the particle size data to obtain the phi or quartile values necessary for the computation. Inman's kurtosis measure was not calculated for these samples.

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<td>FMB2</td>
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<td>5.29*</td>
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<td><strong>32</strong></td>
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</tr>
<tr>
<td><strong>Range</strong></td>
<td>1-72%</td>
<td>19-61%</td>
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Appendix C

TABLE 25. Location, nature, and age of samples used in radiocarbon dating. Samples marked with an asterisk were processed by the Exploration Department and the Geochemical Laboratory, Humble Oil and Refining Company, Houston, Texas. The remaining samples were processed by Shell Development Company, Exploration and Production Research Division, Houston, Texas.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Location</th>
<th>Nature</th>
<th>Stratigraphic Position</th>
<th>Depth (ft.)</th>
<th>Altitude (ft.)</th>
<th>Age (B.P.)</th>
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</thead>
<tbody>
<tr>
<td>*0-1899</td>
<td>Sec. 36, T. 3 S., R. 1 W. Canby, 7.5' quad.</td>
<td>Carbonized wood</td>
<td>Near base of Recent alluvium in Pudding River floodplain</td>
<td>8</td>
<td>+87</td>
<td>4,150 ± 125</td>
</tr>
<tr>
<td>RC2-63</td>
<td>Sec. 31, T. 6 S., R. 2 W. Gervais, 7.5' quad.</td>
<td>Peat</td>
<td>Below ash layer in Labish Channel peat</td>
<td>6.6</td>
<td>+128</td>
<td>6,820 ± 200</td>
</tr>
<tr>
<td>RC1-63</td>
<td>Sec. 31, T. 6 S., R. 2 W. Gervais, 7.5' quad.</td>
<td>Peat</td>
<td>Above ash layer in Labish Channel peat</td>
<td>6.4</td>
<td>+128</td>
<td>6,870 ± 190</td>
</tr>
<tr>
<td>RC4-63</td>
<td>Sec. 30, T. 5 S., R. 2 W. Gervais, 7.5' quad.</td>
<td>Organic clay</td>
<td>Below ash in abandoned Willamette River channel</td>
<td>3</td>
<td>+102</td>
<td>7,010 ± 220</td>
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<tr>
<td>Sample Number</td>
<td>Location</td>
<td>Nature</td>
<td>Stratigraphic Position</td>
<td>Depth (ft.)</td>
<td>Altitude (ft.)</td>
<td>Age (B.P.)</td>
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<td>*0-1900</td>
<td>Sec. 31, T. 6 S., R. 2 W. Gervais, 7.5' quad.</td>
<td>Peat</td>
<td>Below ash layer in Labish Channel peat</td>
<td>6.6</td>
<td>+128</td>
<td>7,125 ± 160</td>
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<tr>
<td>*0-1901</td>
<td>Sec. 31, T. 6 S., R. 2 W. Gervais, 7.5' quad.</td>
<td>Peat</td>
<td>Near base of the Labish Channel peat</td>
<td>20.0</td>
<td>+105</td>
<td>11,000 ± 230</td>
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<tr>
<td>RC5-63</td>
<td>Sec. 21, T. 2 S., R. 1 W. Beaverton, 7.5' quad.</td>
<td>Peat</td>
<td>Near middle of peat deposit in Onion Flat</td>
<td>16</td>
<td>+99</td>
<td>12,240 ± 330</td>
</tr>
<tr>
<td>*0-1903</td>
<td>Sec. 35, T. 3 S., R. 4 W. Salem, 15' quad.</td>
<td>Log</td>
<td>Mill Creek-Santiam River gravels</td>
<td>20</td>
<td>+155</td>
<td>34,410 ± 3,450</td>
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<tr>
<td>*0-1898</td>
<td>Sec. 28, T. 3 S., R. 1 E. Canby, 7.5' quad.</td>
<td>Wood</td>
<td>Conglomerate - sandstone-mudstone similar to Unit I at River Bend</td>
<td>155</td>
<td>-16</td>
<td>&gt; 37,000</td>
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