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PLEISTOCENE SEQUENCE IN SOUTHEASTERN PART OF THE PUGET SOUND LOWLAND, WASHINGTON*

D. R. CRANDELL, D. R. MULLINEAUX, and H. H. WALDRON

ABSTRACT. A restudy of Pleistocene deposits in the southeastern part of the Puget Sound lowland has resulted in a refinement and expansion of the sequence originally described by Willis in 1898. Willis' sequence of two glaciations (Admiralty and Vashon) and a single interglacial interval (Puyallup) is replaced by four glaciations separated by nonglacial intervals during which the climate approached or attained conditions like those of the present. The stratigraphic section now recognized consists of the Orting drift (oldest), Alderton formation (nonglacial), Stuck drift, Puyallup formation (nonglacial), Salmon Springs drift and Vashon drift. An erosion interval between the Salmon Springs and Vashon drifts is thought to represent the third nonglacial interval. The name Admiralty is not used in this paper because the stratigraphic position of the drift assigned to this glaciation by Willis appears to be equivocal in the sequence now recognized.

INTRODUCTION

The Pleistocene stratigraphic section established in the Puget Sound lowland by the pioneer work of Willis (1898) and Willis and Smith (1899) has remained essentially unchanged since these men mapped the Tacoma 30-minute quadrangle and described deposits of two Pleistocene glaciations and one interglacial interval. It has been recognized that one or more additional Pleistocene stages are represented in the lowland (Hansen and Mackin, 1949), but the relationship of these to Willis' sequence has been uncertain. The writers are presently engaged in remapping eleven 7½-minute quadrangles that form part of the Tacoma 30-minute quadrangle and thus have had an opportunity to study Pleistocene stratigraphy in an area which includes several sections designated by Willis as typical of certain formations. The restudy of these formations supplemented with pollen analysis of non-glacial sediments has resulted in some new interpretations of genesis and of geologic history (Mullineaux, Crandell, and Waldron, 1957).

Carbon-14 dates on wood and peat samples were provided by Meyer Rubin, geologist-in-charge of the U. S. Geological Survey radiocarbon laboratory. X-ray determinations of clay minerals were made in the laboratories of the Geological Survey under the supervision of A. J. Gude, III.

The term nonglacial is used here to describe climatic environments closely similar to those of today in the southeastern part of the Puget Sound lowland. The term interglacial is not used because of its connotation of an interval comparable in duration to a Pleistocene stage (age). It may well be that most or all of the nonglacial intervals described in this paper are of stage (age) rank, but conclusive proof is not yet available.

PLEISTOCENE SUCCESSION

The Pleistocene deposits of the southeastern part of the Puget Sound lowland record at least four glaciations separated by nonglacial intervals. The sequence of glaciations and nonglacial intervals, named for the formations on which they are based, is as follows:

* Publication authorized by the Director, U. S. Geological Survey.

Vashon glaciation
    Erosion interval (nonglacial interval)
Salmon Springs glaciation
    Puyallup nonglacial interval
Stuck glaciation
    Alderton nonglacial interval
Orting glaciation (oldest)

The physical evidence upon which this sequence is based is contained principally in exposures along the valley walls of the Puyallup River in the vicinity and south of Sumner, Wash. (fig. 1). Some of the most important of these exposures are described in subsequent sections of this paper. In these descriptions, certain sediments are characterized as having a northern, a Cascade, or a Mt. Rainier provenance. Sediments of northern provenance are characterized by igneous and regionally metamorphosed rocks derived chiefly from the Coast Range of British Columbia or the northern part of the Cascade Range of Washington. Sediments of Mt. Rainier provenance are dominated by rocks and minerals derived from the distinctive hypersthene andesite lavas and pyroclastic rocks of Mt. Rainier, and sediments of Cascade provenance are dominated by rocks and minerals derived chiefly from the Keechelus andesitic series of Oligocene and Miocene age, which comprises most of that part of the Cascade Range drained by streams that flow into the Puyallup-Duwamish valley.

Despite the fact that the glaciers originated in the north, Cascade rock types predominate in glacial sediments in the southeastern part of the lowland; both till and outwash of these glaciers commonly have 15 percent or less of northern stones in them. The predominance of Cascade rock types apparently is due to incorporating by the glaciers of large quantities of locally derived stream alluvium.

PALEOCLIMATIC INTERPRETATIONS

Hansen and Mackin (1949, p. 834-835) pointed out that subdivision of pre-Vashon glacial drift sheets in the central part of the Puget Sound basin is generally complicated by the absence of weathering profiles that might have been formed during interglacials, and that there "has been a lack of evidence as . . . to whether a given sedimentary unit was deposited in immediate proximity to glaciers, or during a period of advance or retreat, or during a warm interglacial." These writers went on to demonstrate that pollen analysis of pre-Vashon peats and peaty clays interbedded with drift sheets could be used to construct a sequence of glacial and interglacial climates.

A similar approach has been adopted by the present writers; pollen profiles collected by them and by Estella B. Leopold of the Geological Survey have been studied by Miss Leopold who has suggested the interpretation of nonglacial climates presented here. These paleoclimatic interpretations are based on comparison of tree pollen from the nonglacial deposits with pollen counts from the uppermost deposits in modern bogs at various altitudes on the west slope of the Cascade Range (Hansen, 1947). Thus, for example, a fossil pollen record of a forest assemblage comparable to that existing today

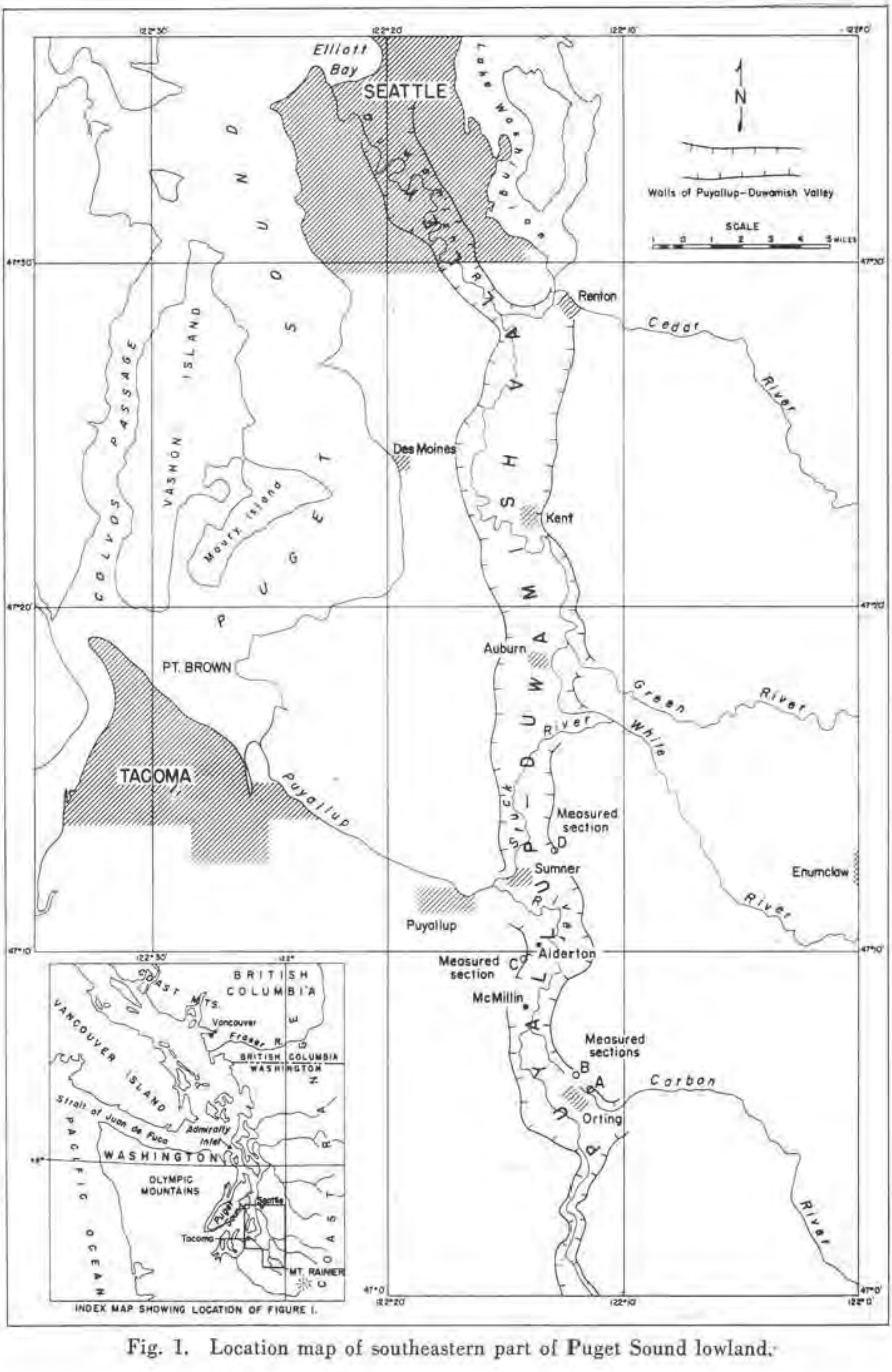

Fig. 1. Location map of southeastern part of Puget Sound lowland.

above an altitude of 5,000 feet in the Cascade Range, where the climate is cool and moist, is used to infer comparably cool and moist conditions in the Puget Sound lowland at the time the pollen-bearing sediments were deposited.

The Puget Sound lowland and the west slope of the Cascades fall into four main vegetational zones, three of which are of concern here: Humid Transition, Canadian, and Hudsonian. The Humid Transition zone lies below 1,500 feet and includes most of the Puget Sound lowland proper. The arboreal pollen fall-out in this zone is dominated by Douglas fir (*Pseudotsuga taxifolia*) and lowland hemlock (*Tsuga heterophylla*). The average annual precipitation at Puyallup at an altitude of about 50 feet is 38.27 inches and the average July temperature 63.6°F. (Anderson, Ness, and Anderson, 1955, p. 6). The average annual precipitation at Buckley at an altitude of 726 feet is 47.01 inches and the average July temperature 63.2°F. (U. S. Department of Agriculture, 1941, p. 1172). The Canadian vegetation zone extends from about 1,500 to 5,000 feet. The distinctive trees of the lower part of this zone are lowland hemlock and mountain hemlock (*Tsuga mertensiana*); the upper part of the zone is characterized by a predominance of Englemann spruce (*Picea englemanni*), alpine fir, and Cascade fir. Average precipitation at Longmire (altitude 2,761 feet) in Mt. Rainier National Park is 76.91 inches, (Anderson, Ness and Anderson, 1955, p. 5) and the average July temperature 60.3°F. (U. S. Department of Agriculture, 1941, p. 1172). The Hudsonian vegetation zone extends from about 5,000 feet to 7,000 feet and is characterized by a predominance of "white-barked" pine. The average annual precipitation at Paradise Inn in Mt. Rainier National Park at an altitude of 5,557 feet is 99.35 inches and the average July temperature 51.7°F. (U. S. Department of Agriculture, 1941, p. 1172).

ORTING DRIFT

The oldest Pleistocene sediments recognized in the southeastern part of the Puget Sound lowland include the Orting gravels of Willis (1898). Willis thought the Orting gravels were deposited during a time characterized by recession of a glacier from the Puget Sound lowland and by a warming climate. The presence of till sheets in the gravels, however, indicates that the Orting gravels of Willis are more probably proglacial outwash. Accordingly, the name Orting drift here replaces the Orting gravels of Willis, which are but one facies of a more diverse assemblage of glacial sediments.

Willis (1898, p. 158) designated as the type section of the Orting gravels an exposure on the "East side of the Puyallup valley at Orting; section observed along the road grade." His description of the Orting at this locality is 140 feet of "Coarse gravels, boulders, gravel, and sand, orange colored, heterogeneously mingled, firmly cemented, granite boulders occasionally decomposed." Overlying the gravel, according to Willis, is 200 feet of sand with a few layers of gravel, which is, in turn, overlain by Vashon drift consisting principally of gravel.

The section designated as typical of the Orting gravels by Willis has been restudied and is redescribed below.

MEASURED SECTION A

Location: SE¼SE¼ sec. 29, T. 19 N., R. 5 E.,; section measured along county road on east valley wall of Carbon River at Orting by D. R. Crandell in August, 1956.

		Feet
Vashon drift		
3. Medium to coarse sand with local lenses and beds of fine pebble gravel	More than	15
2. Till, unoxidized	More than	10
Orting drift		
1. Sand and pebble to cobble gravel with scattered small boulders, local lenses of medium and coarse sand and openwork gravel. Overall color of formation is light yellowish brown; individual stones have coatings of yellowish brown iron oxides. Granitic stones crumble when struck by pick. Prevailing lithology is andesite probably derived from Keechelus andesitic series and Snoqualmie(?) granodiorite, with less than one percent of northern rock types	More than	165
(surface of Carbon River)		

The sand of unit 3 occurs as a veneer that extends upslope several hundred feet to and across kame terrace gravel of Vashon age, and is inferred to represent a near-shore deposit of a glacially dammed lake that occupied the Puyallup valley during the recession of the Vashon glacier.

An additional section several hundred yards to the north of the section along the county road is given below because here the Orting drift includes a till sheet.

MEASURED SECTION B

Location: SE¼NW¼ sec. 29, T. 19 N., R. 5 E.; section measured in ravine by D. R. Crandell in August, 1956.

		Feet
Vashon drift		
4. Unoxidized sand and pebble to boulder gravel enclosing, near base, lenticular sheet of unoxidized till 1 to 15 feet thick	More than	60
Orting drift		
3. Pebble and cobble gravel in yellowish brown sand matrix with scattered small boulders; contains many stones that readily disintegrate under blow of a pick		30-60
2. Till, dark yellowish orange; coating of iron and manganese(?) oxides on stone surfaces and joints; stones weathered as in gravel		2-8
1. Sand and gravel as in 3 above	More than	70
Total thickness of Orting drift	More than	138
(surface of Carbon River)		

The bulk of the Orting drift in the southern part of the Puyallup-Duwamish valley is oxidized sand and pebble to boulder gravel mainly of Cascade provenance, which locally may be as much as 250 feet thick. Till, a few feet to several tens of feet thick, is interbedded in the sand and gravel at several horizons; typically it is brown, very compact, and joint surfaces and pebbles in it commonly are coated with iron and manganese(?) oxides. The presence of till at more than one horizon in the drift suggests oscillation of a glacier margin. The absence of a major erosional break and a lack of sediments indicative of nonglacial environment within the drift, however, suggest that the formation represents only one major glaciation of the lowland. Till in the formation has been recognized as far as 5 miles south of Orting in the Puyallup valley. This indicates that the glacier of Orting age reached what now is the Cascade Mountain front in this sector, but how far up into the mountains the glacier reached, or how much farther south down the Puget Sound lowland the glacier extended has not been determined.

Tills of Orting age contain from 10 to 15 percent or more of northern rock types, and thus represent a glaciation of the Puget Sound lowland by a glacier from the north. Most of the gravel in the Orting, especially in the southern part of the Puyallup-Duwamish valley, however, contains less than one percent northern stones, and therefore is almost wholly of Cascade provenance. This rock-type distribution suggests that much of the gravel was deposited by local streams originating in the Cascades to the southeast and it seems likely that these gravels are outwash from contemporary Cascade glaciers.

The Orting drift overlies sedimentary and volcanic rocks of Tertiary age, which locally are deeply weathered. Nowhere in the lowland has a zone of deep and intense weathering been found in deposits known to be of Orting age, although the gravels of the formation typically are oxidized throughout and many of the component stones readily disintegrate under a gentle blow of a pick. It does not appear that the apparent absence of deep and intense weathering bears on the relative age of the Orting drift, inasmuch as some of the overlying formations locally are weathered. The Orting drift probably was buried by subsequent sedimentation soon after glacial retreat and thus protected from subaerial weathering. It is not known whether the deep oxidation and softening of the stones in the Orting is due to subaerial weathering, or to weathering by ground water circulation, or to both of these processes.

In the sections at Orting (measured sections A and B) the Orting drift is overlain by glacial deposits of Vashon age; the next younger Alderton formation is not known to be present. Along the opposite side of the valley west of Orting, in the SE¼ sec. 25, T. 19 N., R. 4 E., 60 to 70 feet of sand and gravel of Cascade and northern provenance crop out up to an altitude of about 250 feet beneath deposits correlated with the Alderton formation; this sand and gravel is thought to be correlative with the Orting drift on the east side of the valley. Near Alderton, the Alderton formation is underlain by more than 25 feet of sand and gravel of northern origin; this drift proves the existence of a pre-Alderton glaciation and is thought to be the Orting drift.

ALDERTON FORMATION

The Alderton formation is typically exposed in the west wall of the Puyallup-Duwamish valley (measured section C) near the community of Alderton. Here the formation consists of alluvial and lacustrine sediments, peat, volcanic ash, and mudflows from Mt. Rainier. In this section the exposed thickness of the formation is 52 feet and its probable total thickness is more than 130 feet. The alluvial sediments range from sand to pebble and cobble gravel and are composed chiefly of andesite fragments of both Cascade and Mt. Rainier provenance. The lacustrine sediments are mostly silt and fine to medium sand; volcanic ash occurs both as distinct layers and disseminated throughout the formation.

Mudflows consisting predominantly of material derived from Mt. Rainier occur at several horizons in the formation; they range from less than 10 feet to several tens of feet thick and are lenticular in cross section. They are interstratified with alluvium and thus are inferred to have been deposited on the flood plains of valleys that had their headwaters at or very closely adjacent to Mt. Rainier. Some of the mudflows are nearly monolithologic; i. e., 85 percent or more of the stones consist of andesitic material derived from Mt. Rainier.

MEASURED SECTION C

Location: gullies under transmission line of Bonneville Power Administration in center sec. 1, T. 19 N., R. 4 E., about 0.5 mile southwest of Alderton, Wash. Section measured by writers in April, 1956.

	Feet
Vashon drift	
19. Pebble and cobble gravel and sand, unoxidized .... More than	50
Salmon Springs drift	
18. Pebble and cobble gravel in brown sand matrix with scattered boulders up to several feet in diameter and lenticular beds of sand; oxidized throughout	23
Puyallup formation	
17. Mudflow deposit: coarse brownish gray sand and granule-sized deposit, contains scattered pebbles at base, grades upward into medium to very coarse brown sand with scattered granules. Uppermost 10 inches is kaolinized. No visible stratification	8
16. Pebble, cobble, and boulder gravel in brown sand matrix; oxidized	4
15. Mudflow deposit: angular to subrounded pebble, cobble, and boulder-sized fragments in very compact olive brown silty sand matrix; unsorted and unstratified	21
14. Volcanic ash, pale yellow	0.5
13. Fine to medium brownish gray sand and silt	1
12. Interbedded sand and pebble, cobble gravel; cut and fill stratification; oxidized	14
11. Medium to very coarse gray and purplish gray sand, with scattered granules and pebbles of light gray andesite and thin lenses of sand-sized yellow pumice; compact; cross-bedded in part (includes Puyallup sands of Willis)	70
10. Interbedded pinkish gray and gray fine sand, silt, and volcanic ash, grades upward into medium to coarse gray sand. Horizontally laminated, very compact	16
Thickness of Puyallup formation	134.5
Stuck drift	
9. Pebble and cobble gravel in brown sand matrix, oxidized	13
8. Till: subangular to rounded pebbles and cobbles in grayish brown sandy silt matrix; very compact	5
7. Pebble and cobble gravel in brown sand matrix with scattered boulders up to 4 feet in diameter; oxidized	6
Thickness of Stuck drift	24

Alderton formation

6. Gray and purplish gray silty fine sand; contains carbonized fragments of vegetation and a 15-inch layer of pale yellow volcanic ash near top. Horizontally laminated, very compact	4
5. Pebbles and granules of white pumice in pinkish gray ash matrix; unstratified	2
4. Interbedded medium to coarse gray sand with beds of angular granule gravel; very compact	8
3. Mudflow deposit: angular to subrounded pebble to cobble-sized rock fragments in gray sand matrix. Grades upward into pebble and granule-sized fragments in sand matrix; unsorted and unstratified; very compact	11
2. Medium to very coarse brownish gray sand; horizontally bedded	3
1. Mudflow deposit: angular to subrounded pebble to boulder-sized rock fragments in reddish gray to grayish brown silty sand matrix; grades upward into pebble and granule-sized fragments. No sorting or stratification; very compact. Base not exposed ... More than	24
Thickness of Alderton formation ... More than	52

Slopewash, about 75 feet vertically down to level of Puyallup River floodplain at an altitude of about 100 feet.

Climatic conditions that prevailed during deposition of the Alderton formation are inferred from pollen obtained from beds of peat and peaty silt in exposures along the valley wall 0.8 mile south of the measured section. These beds are 1.3 feet thick and are separated from the overlying Stuck drift by 20 feet of alluvial sand of Mt. Rainier provenance. The pollen in the lower half of the peat and peaty silt is dominated by Engelmann spruce (50-60 percent) and fir (15-20 percent) and is indicative of a climate similar to that which characterizes the upper part of the Canadian vegetation zone. The pollen assemblage in the upper half of the beds is dominated by Douglas fir (as much as 40 percent) and alder (as much as 50 percent). According to Miss Leopold, the pollen sample from this horizon is in every observable respect like modern pollen in the southeastern part of the Puget Sound lowland.

The climatic record provided by pollen in the Alderton formation is exceedingly fragmentary and is not necessarily representative of climatic conditions throughout the entire nonglacial interval between the Orting and Stuck glaciations. It is possible only to state that during at least part of this interval, the climate was comparable to that of the present in this part of the lowland.

The Alderton formation is separated from the overlying Stuck drift by a small erosional unconformity; no evidence has been found of deep valley cutting during or after Alderton time and prior to the Stuck glaciation.

STUCK DRIFT

A second glaciation of the Puget Sound lowland is represented by the Stuck drift, which consists chiefly of till and sand and gravel of northern derivation. The formation is typically exposed in the west wall of the Puyallup-Duwamish valley near Alderton (measured section C), and the name Stuck is derived from the river of that name which joins the Puyallup River at Sumner.

Where typically exposed the formation includes an unoxidized or only slightly oxidized till sheet, 5 to 20 feet thick, which is overlain and underlain by oxidized sand and gravel, 10 to 20 feet thick. The sand and gravel is inferred to represent advance and recessional outwash deposited by meltwater from the Stuck glacier. In the pebble-sized fraction the till typically includes 10 to 15 percent of northern rock types and the remainder is of Cascade origin.

The upper part of the Stuck drift contains lacustrine sand and silt in the Puyallup valley near Sumner. Locally the lacustrine sediments include lenticular masses of glacial sand and gravel and scattered glacial boulders, and in places the beds are tilted and faulted. These features suggest that the fine sediments were deposited in an ice-contact glacial lake, which existed during withdrawal of the Stuck glacier when the glacier still blocked northward drainage. The volcanic ash-rich lacustrine sediments at the base of the Puyallup formation in measured section C may have been deposited in this same glacial lake. The absence of a weathering profile at the top of the Stuck drift possibly is explained by deposition of the Puyallup formation immediately upon withdrawal of the Stuck glacier without an intervening weathering or erosion interval.

PUYALLUP FORMATION

The Puyallup formation of this paper contains the Puyallup sands of Willis (1898), which are alluvial sands and granule gravels, as much as 70 feet thick, almost wholly of Mt. Rainier provenance. This thick deposit of sand and gravel forms conspicuous outcrops along the west valley wall of the Puyallup River in the vicinity of Alderton, the area designated by Willis as that in which the Puyallup sands are typically exposed. Lateral tracing to the north and south, however, indicates that the sand is only a local facies of an even thicker and laterally more extensive deposit characterized by coarse and fine alluvium, lacustrine sediments, and mudflows, all of which are predominantly of Mt. Rainier provenance. Because of the apparent genetic unity of these sediments, the Puyallup sands of Willis are here redefined to include the entire assemblage, and the name changed to Puyallup formation.

The Puyallup formation very closely resembles the older Alderton formation in lithology, types of deposits, and general distribution; both formations appear to represent times when floods of fragmental volcanic material were made available to lowland streams which headed on Mt. Rainier. The maximum observed thickness of the Puyallup formation in the vicinity of Alderton is about 135 feet.

Climatic conditions during deposition of the Puyallup formation are inferred from pollen obtained from beds of peat and fine-grained sediments at three localities. The first of these is on the west valley wall of the Puyallup River 0.8 mile south of measured section C where beds of silt and peat immediately overlie the Stuck till. Pollen from these beds is dominated by pine with small amounts of Engelmann spruce, suggestive of the forests of the Hudsonian vegetation zone. Because of the superposition of these silt and peat beds on the Stuck till, the pollen probably records the cool and moist conditions of early postglacial time.

A second pollen locality is about 1.1 mile north of measured section C along the same valley wall where three beds of peat occur at a straigraphic horizon between units 11 and 12 of the measured section. In the lowest of these peat beds pine is predominant, the middle bed shows a rise to prominence of Engelmann spruce and *Abies*, and in the upper peat bed, *Abies* replaces the other conifers. These pollen assemblages record a climatic warming and indicate in the warmest phase an environment similar to that of the upper Canadian vegetation zone.

A third locality at which pollen was obtained is in sea-cliff exposures about 1 mile south of Des Moines. Here a succession, 50 feet thick, of silt, fine sand, and peat, which overlies a mudflow of Mt. Rainier derivation, is thought to occur in the upper part of the Puyallup formation, but inability to trace these beds into the beds of known Puyallup age in the Puyallup-Duwamish valley makes this correlation tentative. The basal beds of this sequence contain as much as 25 percent each of Douglas fir, lowland hemlock, and alder; this composition closely resembles the modern pollen in the lowland except for small additional amounts of fir and pine which according to Miss Leopold, may be coastal fir and beach pine. Above this is an assemblage dominated by fir (*Abies*), with lesser amounts of Douglas fir, lowland and mountain hemlock, and alder. This zone is succeeded by an assemblage dominated by Engelmann spruce and pine, indicative of an upper Canadian or lower Hudsonian vegetation zone forest. The sampled sequence is terminated by a vegetation phase which consists principally of pine and aspen, also suggestive of upper Canadian or Hudsonian zone climatic conditions. The highest beds sampled are about 25 feet below the top of the nonglacial sediments, thus it is not known whether the cooling sequence records the approaching end of the nonglacial interval or whether it is a climatic oscillation within the interval. The Puyallup formation in this exposure is truncated by an unconformity above which is a pre-Vashon till.

In summary, the climate of Puyallup time recorded in the pollen-bearing sediments shows an initial warming trend from the cool and moist conditions of early postglacial time to one similar to that of today. The pollen record concludes with a reversal toward cooler and moister conditions; this may represent a major climatic fluctuation during Puyallup time rather than the beginning of another glacial age.

Near Alderton the top of the Puyallup formation locally is weathered to a depth of about 10 inches. In this zone weathering has altered andesitic rock fragments to halloysite. This clay mineral is absent in the parent material. This alteration suggests that deposition of the Puyallup formation was followed by a period of weathering probably at least several times longer than the period ensuing between Vashon deglaciation and the present.

In the west wall of the Puyallup valley the Puyallup formation thins from about 170 feet at measured section C to only 10 or 15 feet 1.4 mile to the north. This thinning apparently represents erosion that followed deposition of the formation and preceded the next glaciation. The erosion also probably post-dates the creation of the weathered zone at the top of the formation.

SALMON SPRINGS DRIFT

In measured section C and at many other localities in the southern part of the Puyallup-Duwamish valley the Puyallup formation is overlain by pre-Vashon till and pebble to boulder gravel of northern provenance. In most places these sediments appear to represent a single glacial drift unit. In exposures near Sumner, however, the presence of nonglacial sediments between post-Puyallup glacial gravels indicates that two glaciations or two advances of a single major glaciation are represented (measured section D). The Salmon Springs drift is here defined as including both of these post-Puyallup—pre-Vashon glacial deposits. The name Salmon Springs is taken from the springs of that name in the vicinity of the section described below. At this locality the Salmon Springs drift is separated into upper and lower drift sheets by 4 feet of peat and volcanic ash. The peat contains a pollen assemblage dominated by pine and fir (*Abies*); this assemblage represents a climate cooler and moister than that of the present at this locality.

In the valley near Sumner, till is generally thin and discontinuous and the drift consists chiefly of glacial gravel. At one exposure in the vicinity of Salmon Springs a few feet of till is seen between units 9 and 10 of the measured section, and at another exposure, about 5 feet of till occurs at a horizon thought to be in the lower part of the Salmon Springs drift. South of Sumner the Salmon Springs drift generally is thin or absent.

MEASURED SECTION D

Location: east valley wall of Stuck River; in gully 150 feet east and another gully 400 feet north of SE cor. SW¼ sec. 18, T. 20 N., R. 5 E., in vicinity of Salmon Springs, city water supply about 1 mile northeast of Sumner, Wash. (composite section). Section measured by D. R. Crandell in March, 1957.

	Feet
Vashon drift	
11. Sand and pebble to cobble gravel, unoxidized ... More than	30
Upper part of Salmon Springs drift	
10. Sand, very fine, and silt; light olive gray	2.0
9. Sand and pebble to cobble gravel, oxidized; northern provenance in part	37.0
Nonglacial sediments	
8. Silt and clay, pale yellowish brown	.5
7. Peat, very compact, black; and silty peat	.3-1.5
6. Silt, brownish gray, rich in vegetative debris	1.5
5. Volcanic ash	.5-1.0
Lower part of Salmon Springs drift	
4. Sand and pebble to cobble gravel, oxidized; northern provenance	20-27
Puyallup formation	
3. Sand, medium to coarse, and lenses of granule and pebble gravel, poorly defined cut and fill stratification; Mt. Rainier provenance	30.0
Stuck drift	
2. Till, very compact, unoxidized	2-5
1. Sand and pebble to cobble gravel, oxidized, northern provenance ... More than	20

PRE-VASHON EROSION INTERVAL

Probably the most conspicuous features of the southeastern part of the Puget Sound lowland are three large, north-trending valleys; two of these are occupied by Puget Sound (Colvos Passage and the main arm of the Sound), and the third forms the Puyallup-Duwamish valley. The floor of Puget Sound in the two western valleys lies some 400 to 600 feet below sea level, and deep borings indicate that unconsolidated sediments reach at least comparable depth below sea level in the Puyallup-Duwamish valley. The writers share Bretz' (1913, p. 199) opinion that these valleys are primarily the products of interglacial stream erosion, and that the deep erosion that formed them likely was caused by regional uplift. It must be pointed out, however, that deep scouring by the Vashon glacier might be partly responsible for the deepening of these valleys, although just what part of the erosion is attributable to streams and what part to glacial scour is not known (see Bretz, 1913, p. 196-197). Vashon drift commonly extends at least as low as sea level on the sides of these valleys, and probably extends well below sea level as well. The distribution of the Salmon Springs drift, however, seems to bear no such relationship to the Puyallup-Duwamish valley. Thus it appears that this valley was eroded after the Salmon Springs glaciation and before the Vashon glaciation. Because of the lack of definitive evidence that this is the case, however, this conclusion must be regarded as tentative.

VASHON DRIFT

The most recent glacial drift in the southern part of the Puget Sound lowland was deposited by a continental glacier that, just as its predecessors, had its chief source in the Coast Range of British Columbia.

According to Willis (1898), deposits of Vashon age include Vashon drift, Osceola till, Osceola clays, and Douty gravels. The Osceola till of Willis now is known to be a postglacial volcanic mudflow deposit from Mt. Rainier (Crandell and Waldron, 1956). The Osceola clays and Douty gravels of Willis are glacial drift of Vashon age, and the two names are thereby abandoned.

The Vashon drift includes glaciofluvial and glaciolacustrine sediments and till distinguished chiefly by their general lack of oxidation or other signs of weathering. The till is fresh and gray to within a few feet of the surface, and even the gravels are gray or brownish gray and contrast markedly with the typically oxidized and iron-stained gravels of the older glacial formations. Landforms on the drift characteristically are little modified by erosion.

Whereas outcrops of the older Pleistocene formations of the lowland are nearly everywhere restricted to exposures in valley sides and beach cliffs, Vashon drift forms the surface deposit across interfluves in the lowland, and locally extends down valley walls at least to and probably beneath alluvium on valley floors; thus it unconformably overlies all of the older deposits.

RELATION OF ADMIRALTY DEPOSITS OF WILLIS AND BRETZ TO SEQUENCE DESCRIBED HERE

One of the most critical problems in a revision of the Pleistocene sequence involves the position of the Admiralty till and clays of Willis and the

Admiralty till and sediments of Bretz in the stratigraphic sequence described above. Willis used the term Admiralty to describe the deposits of the only glaciation preceding the Vashon that he recognized. This usage has been followed by many subsequent workers concerned with the Pleistocene deposits of the Puget Sound area.

An attempt to determine in the field the relation between typical Admiralty drift at Tacoma, as described by Willis, and formations described in this paper was not successful owing to a lack of adequate exposures in critical areas. At a locality south of Des Moines, deposits described as being of Admiralty age by Willis (1898, p. 152) probably include parts of both the Puyallup formation and the Salmon Springs drift. In the east wall of the Puyallup-Duwamish valley between Kent and Auburn (Willis, 1898, p. 152-153), where Willis described Admiralty till, the till is of Salmon Springs age.

Bretz resolved the problem of correlation by defining the Admiralty as containing all or nearly all of the pre-Vashon sediments of the lowland. Continued use of Admiralty in this sense is not desirable because it implies that the Admiralty represents a single and distinct glacial age (stage) and that the Vashon was preceded by only one glaciation, whereas the Pleistocene record of this part of the Puget Sound lowland now is known to embrace at least three pre-Vashon glaciations separated by nonglacial intervals.

Inasmuch as the Admiralty till and clays of Willis cannot be assigned to a single stratigraphic interval, the name is not used in this paper.

AGE AND CORRELATION

The Pleistocene history of the southeastern part of the Puget Sound lowland consists of at least four episodes of glaciation separated by intervals of erosion, weathering, and nonglacial sedimentation. The youngest of these glaciations, the Vashon, appears to be generally correlative with the (Tazewell) maximum of the Wisconsin stage of the central United States (Waldron, Mullineaux, and Crandell, 1957). Radiocarbon dates (Meyer Rubin, written communication, 1956; Rigg and Gould, 1957) on peat that postdates the Vashon drift in the lowland suggest that the glacier uncovered the lowland south of Seattle at some time prior to 14,000 years ago. A subsequent late Wisconsin glacial advance younger than 11,300±300 radiocarbon years down the Fraser River valley in southwestern British Columbia has been described by Armstrong (1956) and correlated by him with the Mankato subage of the central United States.

The Salmon Springs glaciation is thought to be pre-Wisconsin, but there is little direct substantiating evidence. Wood (W-258) from the top of gravel thought to be correlative with the Salmon Springs drift 3.5 miles southeast of Point Brown was determined to have an age of more than 37,000 radiocarbon years (Rubin and Suess, 1956, p. 444). Nowhere has a zone of deep weathering been seen on the Salmon Springs drift; instead, nearly everywhere an erosional unconformity separates it from the overlying Vashon drift.

An age assignment of pre-Wisconsin for the Puyallup and older formations independent of their stratigraphic relationship to the Salmon Springs drift is based on the inference that the weathered surface and erosional unconformity that separate the Puyallup formation from the overlying Salmon Springs drift required many tens of thousands of years for their development. This inference supplements the pollen evidence that deposition of the Puyallup formation coincided with a nonglacial interval, and suggests that this interval was of interglacial stage rank in duration. In addition, a wood sample (W-259) from the Puyallup(?) formation near Des Moines was found to have an age of more than 37,000 radiocarbon years (Rubin and Suess, 1956, p. 444).

The age of the Orting glaciation is uncertain; the fact that it is the oldest known Pleistocene deposit of the area suggests but does not prove it to be of early Pleistocene age.

On the basis of the sketchy dating evidence at hand, it is suggested that the Orting glaciation may be early Pleistocene, the Stuck glaciation early to middle Pleistocene, and the Salmon Springs glaciation middle to late Pleistocene. The equivalence of these glaciations to the Pleistocene stages of the central United States is not known.

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