STRATIGRAPHY AND CHRONOLOGY OF QUATERNARY DEPOSITS OF THE PUGET LOWLAND AND OLYMPIC MOUNTAINS OF WASHINGTON AND THE CASCADE MOUNTAINS OF WASHINGTON AND OREGON

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INTRODUCTION

The Pleistocene chronology of the Puget Lowland is based on multiple dating methods, including radiocarbon and fission-track dating, as well as amino acid, paleomagnetic, and tephra correlation techniques. Datable material is abundant and age control is generally good. Radiocarbon dates have been obtained from late Wisconsin deposits in the Olympic Mountains, but older deposits are not well dated. Finite ^{14}C dates from the Cascade Mountains are meager and the chronologic framework there is based largely on relative weathering characteristics with limited K–Ar dating and paleomagnetic measurements.

EARLY PLEISTOCENE (> 788 ka)

Puget Lowland

The Pleistocene deposits in the Puget Lowland were first studied by Willis (1898) and Bretz (1913). Type localities for the Orting Drift, Alderton Formation, Stuck Drift, Puyallup Formation, and Salmon Springs Drift were established by Crandell *et al.* (1958) near the southern margin of the Cordilleran ice sheet, but until recently their ages were unknown.

The oldest finite dates of Pleistocene deposits in the Puget Lowland are fission-track ages of 840 ka BP tephra within the Salmon Springs Drift at three localities (Easterbrook and Briggs, 1979; Easterbrook *et al.*, 1981; Naeser *et al.*, 1984), providing an upper limit for at least two glacial drifts and two interglacial deposits which lie stratigraphically lower. Reversed remanent magnetism of the Salmon Springs and older deposits indicates that they were deposited during the Matuyama Reversed Polarity Chron and thus between 0.7 and 2.48 Ma ago (Roland, 1984; Easterbrook *et al.*, 1985, *in press*).

Because many drift units in the region were designated as Salmon Springs on the basis that they were the next-oldest drift beneath Vashon till, the fission-track dates and paleomagnetic measurements of Salmon Springs and older sediments at their type localities invalidated many 'Salmon Springs' correlations. Deposits previously labeled 'Salmon Springs' are likely to be much younger than the type Salmon Springs Drift. Glacial sediments directly underlying Vashon till in the southern Puget Lowland probably are correlative with Salmon Springs Drift, but farther north, drift directly beneath Vashon till is most likely correlative with much younger drifts, such as the Double Bluff or Possession Drifts. Thus, virtually all previously-mapped Salmon Springs Drift needs to be re-examined to determine if it is indeed correlative with Salmon Springs Drift or is younger.

Orting Drift

The oldest glacial unit recognized in the Puget Lowland, the Orting Drift, occurs in restricted outcrops south of Seattle (Crandell *et al.*, 1958; Crandell, 1963). It consists mostly of deeply oxidized sand and gravel derived from the Cascade Range, interbedded with compact and oxidized till in at least three horizons. The tills contain northern rock types and garnet in the sand fraction, suggesting deposition from Cordilleran ice having a British Columbia provenance. The maximum known thickness of Orting Drift is 79 m, consisting mostly of gravel with till lenses less than 8 m thick.

A thick basal gravel, deposited by westward-flowing streams from the Cascade Range prior to the beginning of volcanism at Mt. Rainier, is overlain by till and gravel of northern Cordilleran provenance. Tills occur at more than one horizon but are interpreted to be oscillations of a single major glaciation because the tills are laterally discontinuous and no major unconformities are evident (Crandell *et al.*, 1958; Crandell, 1963).

Because the Orting Drift is reversely magnetized (declination = 164°; inclination = −31°) (Roland, 1984; Easterbrook *et al., in press*) and is stratigraphically beneath Salmon Springs Drift dated at 840 ka BP (Easterbrook *et al.*, 1981), it is considered to have been deposited during the Matuyama Reversed Polarity Chron between 0.78 and 2.48 Ma ago. Considering its deeply weathered character compared with the Alderton Formation, Stuck Drift, Puyallup Formation, and Salmon Springs Drift, the Orting Drift may well be approximately two million years old.

Alderton Formation

Mudflows, alluvium, lahars, and lake sediments, with interbeds of peat and volcanic ash, comprise the interglacial Alderton Formation, known only in the southern Puget Lowland (Crandell *et al.*, 1958; Cran-

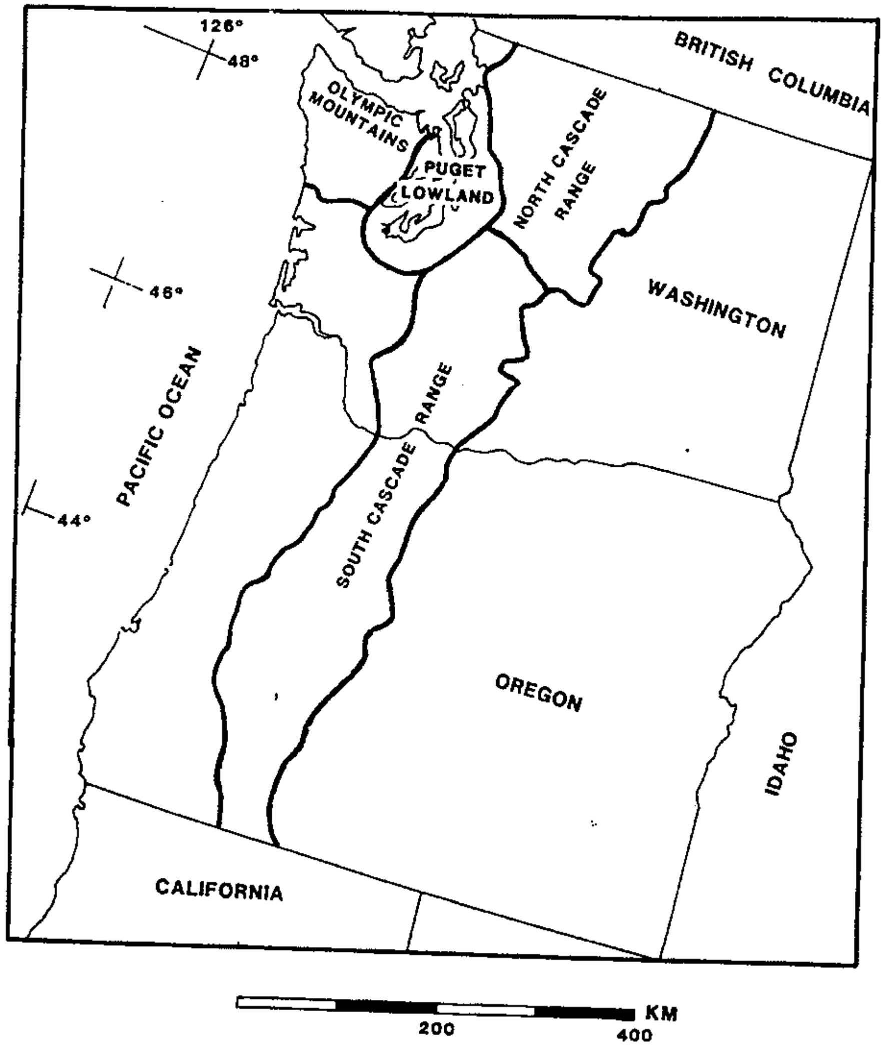

FIG. 1. Index map showing location of Puget Lowland, Olympic Mountains and Cascade Mountains (Northern and Southern Cascade Ranges) in Washington and Oregon.

dell, 1963). Clasts in the sediments are mostly andesite, derived largely from an ancestral Mt. Rainier volcano that predated the modern cone.

Englemann spruce, which dominates pollen from the lower part of a peat bed in the unit, represents a climate somewhat cooler than at present, whereas the upper part of the same peat contains large amounts of Douglas fir and alder pollen, indicative of a climate similar to that of the present (Leopold and Crandell, 1957; Crandell *et al.*, 1958). Pollen from other peat and silt beds suggest climatic conditions ranging from cool and moist to warmer and drier than the present (Heusser, 1977), but poor exposures limit possibilities for reconstruction of vegetation and climate for the Alderton as a whole.

The remanent magnetism of the Alderton at its type locality is reversed (average declination = 176°; average inclination = −50°) (Roland, 1984; Easterbrook *et al., in press*) which places its age within the Matuyama Reversed Polarity Chron. The reversed polarity has been overprinted with a viscous normal remanent magnetism that is removed with high a.f. demagnetization. Normal polarity measured earlier for one silt bed (Easterbrook and Othberg, 1976) is thought to be the result of viscous normal overprinting that could not be removed by a.f. demagnetization equipment then at hand.

Stuck Drift

Stuck Drift, defined from till interbedded with outwash sand and gravel overlying the Alderton Formation (Crandell *et al.*, 1958), is restricted to outcrops in the Puyallup Valley south of Seattle in the southeastern Puget Lowland. Clasts in the drift include rock types transported from the north by the Cordilleran ice sheet.

In the type area, Stuck Drift consists of a single till between layers of outwash sand and gravel, but elsewhere, two tills are separated by 15–50 m of lacustrine and fluvial silt, sand, and gravel (Crandell, 1963; Mullineaux, 1970). Clasts in the alluvium are derived from the Cascade Mountains to the east, indicating sufficient retreat of the ice to permit reestablishment of westward-flowing drainage from the mountains. Poor exposures in the area prevent lateral tracing of deposits to determine whether the Stuck Drift includes two tills separated by a nonglacial interval or whether only one of the tills is part of the Stuck Drift.

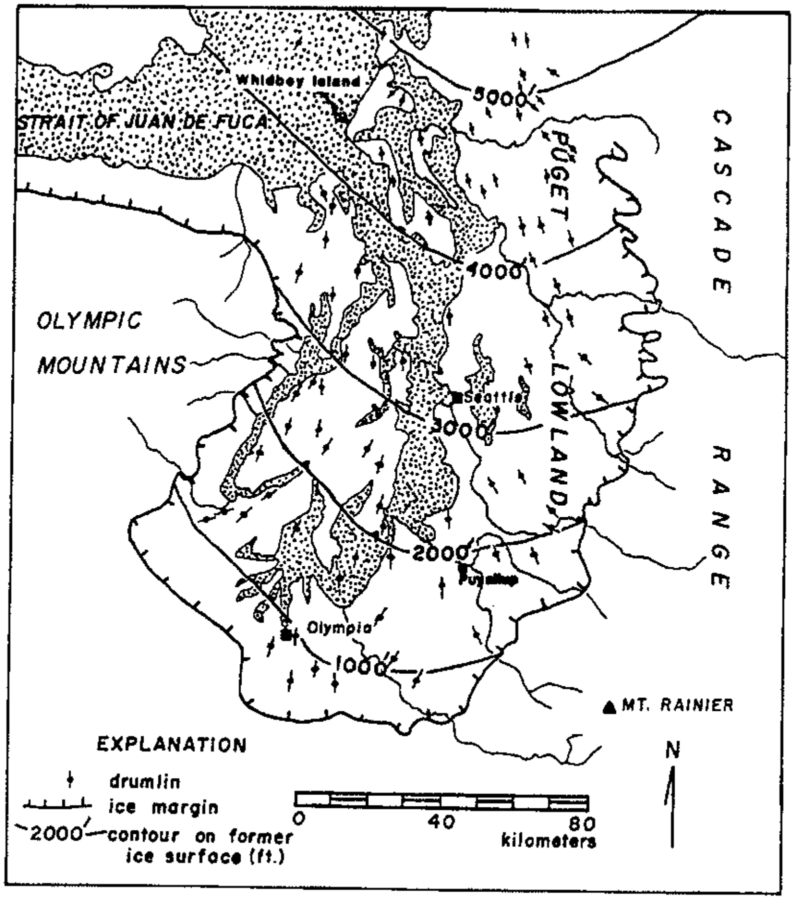

FIG. 2. Map of the Cordilleran ice sheet in the Puget Lowland, Washington.

The Stuck Drift was deposited during the Matuyama Reversed Polarity Chron, based on its pre-Salmon Springs stratigraphic position and reversed remanent magnetism (declination = 183°; inclination = −51°) (Roland, 1984; Easterbrook *et al.*, *in press*).

Puyallup Formation

Nonglacial sediments in the southeastern Puget Lowland, derived mostly from ancestral Mt. Rainier, were named the Puyallup Sand by Willis (1898). Crandell *et al.* (1958) later expanded the unit to include fluvial sand and gravel, lacustrine silt and clay, peat, lahars, and mudflows which they designated the Puyallup Formation. A major erosional unconformity, including a strong weathering profile characterized by kaolin, was recognized by Crandell *et al.* (1958) at the top of the Puyallup Formation and interpreted to represent a long period of erosion and weathering prior to deposition of the overlying Salmon Springs Drift (Waldron, 1961, 1962; Crandell, 1963; Mullineaux, 1970).

Pollen from the basal Puyallup Formation suggest an early postglacial climate followed by gradual warming. Other pollen profiles higher in the section suggest a warm phase followed by a cooling trend, but poor exposures do not allow lateral tracing of sampled units and a considerable portion of the youngest part of the unit, represented by the weathering profile and unconformity, may be missing.

Silt beds in the Puyallup Formation are reversely magnetized (declination = 183°; inclination = −42°) which, together with its stratigraphic position beneath the 840 ka Lake Tapps tephra, places it within the Matuyama Reversed Polarity Chron (Roland, 1984; Easterbrook *et al.*, *in press*).

Previous correlation of the Puyallup Formation with the interglacial Whidbey Formation of the central Puget Lowland (Crandell, 1965; Easterbrook, 1969, 1976a, b), is now known to be impossible because of the 840 ka fission-track age of the Lake Tapps tephra within the overlying Salmon Springs Drift (Easterbrook *et al.*, 1981) and the approximately 100 ka ages estimated from amino acid racemization for the Whidbey Formation (Easterbrook *et al.*, 1982; Blunt *et al.*, *in press*).

Salmon Springs Drift

The Salmon Springs Drift at its type locality in the southeastern Puget Lowland unconformably overlies the Puyallup Formation and is unconformably overlain by late Wisconsin Vashon Drift (Crandell *et al.*, 1958). It was long believed to be of early Wisconsin age on the basis of radiocarbon enrichment dates of 50,100 ± 400 years (GrN-4116c) (Armstrong *et al.*, 1965) and $71{,}500^{+1700}_{-1400}$ years (Stuiver *et al.*, 1978) from peat at the type locality. The Salmon Springs Drift was widely correlated throughout the Pacific Northwest on the basis that it was the next oldest drift beneath Vashon

Drift. However, some of the silt associated with the radiocarbon-dated peat and volcanic ash at the type locality is reversely magnetized and the ash, named the Lake Tapps tephra, has been fission-track dated at 0.84 ± 0.21 Ma (Easterbrook *et al.*, 1981). The ash, which lies directly on lower Salmon Springs outwash gravel, grades upward into the overlying 1-m-thick silt which gradually increases in organic content and becomes peat. Thus, the ash–silt–peat sequence represents continuous deposition uninterrupted by any unconformities. No break in pollen spectra is apparent at the contact between the silt and peat, further supporting the conclusion that no unconformity exists between the peat and ash (Stuiver *et al.*, 1978). In view of the 800 ka gap between the fission-track date from the ash and the radiocarbon dates from the peat, and the lack of any break in the depositional sequence, the radiocarbon dates are considered invalid. If the overlying upper Salmon Springs Drift is, as originally defined, part of the same glaciation, then the unconformity between the Salmon Springs Drift and Vashon Drift spans about 800 ka.

Pollen analysis of the ash–silt–peat section indicates a tundra vegetation changing progressively to a fir forest before burial by upper Salmon Springs gravel (Leopold and Crandell, 1957; Crandell *et al.*, 1958; Crandell, 1963; Heusser, 1977; Stuiver *et al.*, 1978). Thus, the upper and lower Salmon Springs drifts are separated by a short nonglacial interval.

The first paleomagnetic profile from the silt between the ash and peat at the type locality (Easterbrook and Othberg, 1976) included a mixture of normal and reversely polarized samples, as did two later magnetic profiles (Easterbrook *et al.*, 1981). Because many of the samples showed high angular standard deviations for individual spin measurements and low sample stability, evaluation of the validity of the normal polarities is difficult. Strong normal VRM overprinting has been found in several profiles of Salmon Springs and older sediments, suggesting that the normal polarities in the Salmon Springs silt may not represent a normal geomagnetic field during deposition, but rather deposition in a reversed field with normal overprinting much later. A second possibility, that the remanent magnetism of the silt does represent the geomagnetic field at the time of deposition but the field was fluctuating in a transition between reversed and normal polarity, is considered less likely because where sample stability is good, the remanent magnetism is definitely reversed. The normal polarity observed in the silt at the type locality could have been overprinted on reversely magnetized sediments by the Brünhes normal field, but the reversed polarity could not be imparted by the Brünhes normal field. Normal polarity was measured in samples above the reversal zone at Auburn (Othberg, 1973), but those sediments were mapped as early Vashon by Mullineaux (1970).

Definitive geochemical and petrographic characteristics of the Lake Tapps tephra have allowed its positive identification at several other localities (Westgate *et al.*, *in press*). Fission-track dates of 0.87 ± 0.27, 0.84 ± 0.21 (Easterbrook *et al.*, 1981) and 0.89 ± 0.29 Ma (Naeser *et al.*, 1984) confirm the reversed polarities in associated silts as Matuyama. The character of magnetic profiles at two of these localities is exceptionally stable and definitely reversed throughout. Thus, the lower Salmon Springs Drift is now firmly dated as early Pleistocene. However, the status of the upper Salmon Springs Drift above the ash–silt–peat sequence remains uncertain.

The ramifications of the antiquity of the lower Salmon Springs drift are far-reaching. The term Salmon Springs Drift has been widely used in the literature for pre-Vashon drifts, but distinguishing those which are truly correlative with Salmon Springs Drift from younger drifts is very difficult without dating control. 'Salmon Springs Drift' in pre-1981 publications may in fact be Double Bluff or Possession Drift.

Olympic Mountains

Deeply weathered glacial drift, decomposed to a depth of 2–3 m with kaolinized pebbles and oxidized to a depth of more than 9 m, has been recognized in the western Olympic Peninsula (Carson, 1970; Moore, 1965; Crandell 1964, 1965; Heusser, 1974). The intensity of weathering of an unnamed drift in the Hoh Valley (Heusser, 1974), the Wedekind Creek Formation (Carson, 1970), and part of the Donkey Creek Drift (Moore, 1965) suggests great antiquity and probable correlation with the Orting Drift of the Puget Lowland. No paleomagnetic measurements or finite dates have been obtained from these drifts, but Colman and Pierce (1981) suggest an age of >800 ka for the Wedekind Creek Drift on the basis of weathering rinds up to six mm on basalt clasts (Carson, 1970).

Oxidized till at Mt. Octopus and a diamicton which predates the Puyallup Formation (Florer, 1972) near the Hoh Valley in the western Olympic Peninsula are correlated with the Stuck Drift (Heusser, 1974), although the pollen profile designated as Puyallup could belong to the much younger Whidbey Formation. This drift may correlate with part of the Donkey Creek Drift which has also been correlated with Stuck Drift (or Orting Drift) (Moore, 19165; Carson, 1970).

Helm Creek Drift consists of outwash from alpine glaciers in the southeastern Olympic Mountains and till and outwash deposited by the Cordilleran ice sheet in the adjacent Puget Lowland (Carson, 1970). Basalt clasts in the drift have weathering rinds >3 mm (Carson, 1970) and an inferred age of 700–800 ka (Colman and Pierce, 1981). On the basis of its intense weathering, it is correlated with Stuck Drift in the southern Puget Lowland, with unnamed pre-Puyallup drift in the Hoh Valley, and with part of the Donkey Creek Drift in the western Olympic Mountains (Heusser, 1974). Wingate Hill Drift in the Cascade Mountains has similar weathering rind thicknesses (>3 mm) and has been correlated with Helm Creek Drift as one option (Colman and Pierce, 1981).

Clark Creek Drift, deposited by Cordilleran ice in the southwestern Puget Lowland, lies beneath reversely magnetized silt containing Lake Tapps tephra fission-track dated at 890,000 ± 290 years (Naeser *et al.*, 1984). Clark Creek till complexly interfingers with Annas Bay Drift, deposited by Olympic alpine glaciers in the southwestern Puget Lowland where the till is interbedded with reversely magnetized silt (Easterbrook *et al., in press*). Both the Clark Creek and Annas Bay Drifts are correlated with the lower Salmon Springs Drift.

Till at several localities in the western Olympic Peninsula has been correlated with 'Salmon Springs Drift' (Heusser, 1974), but these correlations were made before the early Pleistocene age of the Salmon Springs Drift was discovered (Easterbrook *et al.*, 1981). Some of these tills are clearly too young to be Salmon Springs and are probably correlative with the Double Bluff or Possession Drifts of the Puget Lowland.

Cascade Mountains

In general, drift of the oldest glaciations in the Cascade Mountains was more extensive than that of younger advances so moraines and outwash terraces of successive alpine glacial phases are preserved. Because little isotope or paleomagnetic data is available, most drifts are correlated on the basis of weathering characteristics, topographic expression, and soil development.

Gravel, sand, and till of the Logan Hill Formation in the Cowlitz Valley southwest of Mt. Rainier is deeply weathered to depths of 8–15 m with clasts altered to kaolinite at depths up to 3 m. These sediments were deposited before the modern volcanic cone of Mt. Rainier was developed. No fission-track or K–Ar dates or paleomagnetic measurements have been obtained from the Logan Hill Formation, but its intense weathering suggests possible correlation with the Orting Drift of the Puget Lowland (Crandell, 1963).

The Wingate Hill Drift in the Mt. Rainier area was originally defined by Crandell (1963), then later split into two drifts, the Hayden Creek and Wingate Hill (Crandell and Miller, 1974). Colman and Pierce (1981, 1985) measured weathering rinds averaging 3.01 ± 0.69 mm on fine grained andesite clasts in Wingate Hill Drift and 1.37 ± 0.43 mm in Hayden Creek Drift. Similar weathering rinds on Helm Creek Drift (3.3 ± 2.0 mm) (Carson, 1970) suggest correlation with Wingate Hill Drift, estimated by Colman and Pierce (1981, 1985) to be about 700–800 ka old. An unnamed till at Mt. Rainier lies between lahars and lava flows having normal remanent magnetism. A K–Ar date of 616 ± 60 ka from one of the overlying lava flows indicates that the till is older than 616 ka and the bracketing normal polarities means the till must be younger than 730 ka. However, the stratigraphic relationship of the unnamed till to the Wingate Hill Drift remains to be demonstrated.

Pre-Thorp drift in the Yakima Valley of the eastern north Cascade Range has basalt weathering rinds of 2.78 ± 0.23 mm (Colman and Pierce, 1981), suggesting an early Pleistocene age, but rind thicknesses are considerably less than those of the Logan Hill Formation and the Wedekind Creek Formation and somewhat less than basalt clasts in the Wingate Hill Drift and Helm Creek Drift. Deeply weathered Boundary Butte Drift in the Wenatchee Valley is a possible correlative of the pre-Thorp drift (Page, 1939; Waitt, 1977). Thorp Drift (Porter, 1975, 1976) was later reinterpreted to be largely nonglacial alluvium (Waitt, 1979) and till originally included in the Thorp Drift was defined as Lookout Mt. Ranch Drift (Waitt, 1979; Tabor *et al.*, 1982). Rind thicknesses suggest that the Thorp, pre-Thorp, and Lookout Mountain drifts are more than 500 ka old (Colman and Pierce, 1985).

MIDDLE PLEISTOCENE

Puget Lowland

Pleistocene deposits between 300 ka and 800 ka BP are unknown in the Puget Lowland at present (Easterbrook *et al.*, 1985). Sediments of this interval probably occur below sea level in the Puget Lowland, but are not accessible.

ILLINOIAN (370 ka to 130 ka BP)

The Double Bluff Drift (Easterbrook *et al.*, 1967; Easterbrook, 1968) consists of till, glaciomarine drift, glaciofluvial sediments, and glaciolacustrine deposits, lying stratigraphically beneath the Whidbey Formation of the last major interglaciation in the central and southwestern Puget Lowland. Remanent magnetism of Double Bluff glaciomarine drift is normal (average declination = 1°; average inclination = 49°) (Easterbrook, 1976a).

Amino acid analyses of shells from glaciomarine drift at the type locality in the central Puget Lowland and from glaciomarine drift in the southwestern Puget Lowland, suggest an age in the range of 150–250 ka (Easterbrook and Rutter, 1981; Easterbrook *et al.*, 1982; Blunt, 1982; Blunt *et al., in press*). Confirmation of the amino acid age estimates presently awaits K–Ar dating of pumice from sand directly beneath the Double Bluff Drift.

Double Bluff Drift occurs at or near sea level in sea cliff exposures and underlying sediments are not exposed. Consequently, no deposits spanning the 500 ka gap between the Double Bluff Drift and Salmon Springs Drift are known. In the southwestern Puget Lowland and Olympic Peninsula, the next till below Vashon Drift (Sceva, 1957) or drift beyond the Vashon limit was commonly mapped as Salmon Springs Drift (Molenaar, 1965; Frisken, 1965; Noble and Wallace, 1966; Molenaar and Noble, 1970; Carson, 1970; Heusser, 1974, 1977, 1978; Gayer, 1977; Grimstad and

Carson, 1981). McCleary Drift, proposed by Colman and Pierce (1981) to replace the 'Salmon Springs' Drift of Carson (1970), is probably equivalent to the Double Bluff Drift. Deeter (1979) found that some of these 'Salmon Springs' drifts in the southwestern Puget Lowland were in fact Double Bluff glaciomarine drift containing shells which gave amino acid racemization age estimates of about 250 ka (Easterbrook *et al.*, 1982). Drift extending beyond the limits of the late Wisconsin Fraser glaciation has been tentatively correlated with the Double Bluff Drift on the basis of weathering and soil parameters (Lea, 1984).

Olympic Mountains

Mobray Drift, deposited by alpine glaciers from the southeastern Olympic Mountains, is overlapped by McCleary Drift, but both were deposited during the same glaciation (Carson, 1970), presumably the Double Bluff. The Mobray Drift is correlated with the older part of the Humptulips Drift of the southwestern Olympic Peninsula on the basis of similar weathering characteristics (Carson, 1970). An extensive till in the western Olympic Peninsula, referred to as 'intermediate Wisconsin till' by Crandell (1964), was named the Humptulips Drift by Moore (1965) in the southwestern Olympic Peninsula and called 'early Salmon Springs Drift' in the northwestern peninsula by Heusser (1974, 1977, 1978). Both represent more than one glaciation. Wood from a bog on older Humptulips Drift has a radiocarbon-enrichment age of 63,200 years (Heusser, 1982) and sediments of the last interglaciation occur between older Humptulips Drift and younger Humptulips outwash deposits in one section (Heusser, 1982).

Cascade Mountains

Clasts in Hayden Creek Drift at Mt. Rainier (Crandell and Miller, 1974) have weathering rinds of variable thickness, but average rind thicknesses of 1.37 ± 0.43 mm at undisturbed sites led Colman and Pierce (1981) to an age estimate of about 140 ka and correlation with the McCleary Drift of the southwestern Puget Lowland and the Indian John member of the Kittitas Drift. They suggest a major age difference between the Indian John Member and the older Swauk Prairie Member because the Swauk Prairie Member may locally contain two buried soils, one in till and one in overlying loess, and the Swauk Prairie terrace is more than 25 m above the Indian John terrace. Weathering rinds on basalt clasts in Swauk Prairie Drift average 1.10 ± 0.11 mm compared with 1.05 ± 0.17 mm for Indian John Drift.

The Jack Creek Drift is the oldest in the southern Cascade Mountains of Oregon which still retains morainal topography, including terminal, lateral, and recessional moraines (Scott, 1977). Weathering rinds on clasts attain thicknesses up to 1.2 mm, but average 0.4–0.6 mm. It is correlated with the Moss Creek Drift (Carver, 1972) and the Hayden Creek Drift.

SANGAMON AND 'EOWISCONSIN' (130–70 ka)

Amino acid analyses of wood and shells in glacial and nonglacial deposits of the Whidbey Formation and Possession Drift provide a basis for the chronology of middle Wisconsin to 'Eowisconsin' glacial and interglacial phases in the Puget Lowland (Easterbrook and Rutter, 1981; Easterbrook *et al.*, 1982; Blunt *et al.*, *in press*). The chronology of late Wisconsin sediments is well established by large numbers of radiocarbon dates of Olympia nonglacial deposits and Fraser Drift.

Interglacial floodplain and deltaic sand, silt, clay, and peat of the Whidbey Formation is widespread in much of the Puget Lowland (Easterbrook *et al.*, 1967; Easterbrook, 1968, 1969, 1976a). Measurements of remanent magnetism of Whidbey sediments show normal polarity with declinations ranging from 9–350° and inclinations ranging from 46–64° (Easterbrook, 1976b). Radiocarbon dates from abundant wood and peat in the Whidbey Formation yield only infinite ages (Easterbrook, 1969, 1976a). Six anomalous radiocarbon dates from the Whidbey Formation, ranging in age from 28,910 to 43,250 years (Johnson *et al.*, 1980), were rerun by another lab and found to be >40 ka (Stoffel, 1980). Another half dozen finite radiocarbon dates (Dorn *et al.*, 1962) measured prior to the definition of the Whidbey Formation but probably from Whidbey sediments, were re-analyzed as >40 ka. No confirmed finite radiocarbon dates are known from the Whidbey Formation. Amino acid analyses of wood and shells from the Whidbey Formation suggest an age of about 100 ka ± 20 ka (Blunt, 1982; Blunt *et al.*, *in press*; Easterbrook and Rutter, 1981; Easterbrook *et al.*, 1982). Pollen from peat in the Whidbey Formation suggests that some of the Whidbey sediments were deposited during an interglacial climate with cooler trends at the beginning and ending of the interval (Hansen, 1947; Hansen and Mackin, 1949; Hansen and Easterbrook, 1974; Heusser and Heusser, 1981). Earlier correlation of the Whidbey Formation with the Puyallup Formation (Easterbrook *et al.*, 1967; Easterbrook, 1969) was shown to be impossible because of reevaluation of the age of the Puyallup necessitated by the discovery of the early Pleistocene age of the overlying Salmon Springs Drift (Easterbrook *et al.*, 1981). However, the 1969 correlation was based in part on similarities between the Whidbey Formation and sediments mapped as 'Puyallup Formation' in sea cliff exposures west of the type locality in the southern Puget Lowland (Waldron, 1962) and those 'Puyallup' sediments may in fact be equivalent to the Whidbey Formation. Similarly, sediments in sea cliff sections in the western Olympic Peninsula correlated the Puyallup Formation (Florer, 1972) may also belong to the Whidbey, but independent evidence is lacking. Pollen from peat radiocarbon dated at >61 ka in the western Olympic Peninsula indicates an interglacial climate similar to the present and suggests correlation with the

Whidbey Formation. The Whidbey is considered equivalent to stage 5 in the marine oxygen isotope record.

EARLY AND MIDDLE WISCONSIN (35–70 ka)

Puget Lowland

The Possession Drift (Easterbrook *et al.*, 1967), occurs in discontinuous lenses throughout the central and southwestern Puget Lowland (Easterbrook, 1968, 1969, 1976a; Deeter, 1979). At its type locality, the Possession Drift consists of a single till sheet up to 25 m thick, but elsewhere in the lowland, it includes glaciomarine drift and outwash sand and gravel. Amino acid analyses of marine shells in Possession glaciomarine drift at widely separated localities confirms correlation of the unit and suggests an age of about 80 ka (Easterbrook and Rutter, 1981, 1982; Blunt *et al., in press*). Radiocarbon dates on shells and wood in the glaciomarine drift have been infinite. These sediments were included in the Deception Pass Stade of the Possession Drift by Easterbrook (1976a).

However, at Strawberry Point on Whidbey Island in the central Puget Lowland, two tills are separated by outwash sand and gravel containing two peat beds near the base of the gravel. Wood in the upper peat has been radiocarbon-dated at $34{,}900^{+3000}_{-2000}$ (I-1880), 35,400 ± 200 (QL-148A), and 35,600 ± 300 (QL-148B) years and wood in the lower peat has been dated at $47{,}600^{+3300}_{-1800}$ (GrN-5257), $43{,}900^{+1000}_{-900}$ (QL-149), and $43{,}600^{+1000}_{-900}$ (QL-151) years (Hansen and Easterbrook, 1974; Stuiver *et al.*, 1978). Dates of 27,600 ± 1000 (WW-11), $27{,}200^{+1000}_{-900}$ (I-2285), and 26,850 ± 1700 (I-1111) years from the base of peat lying directly on the upper till provide a limit for the age of the glacial phase (Easterbrook, 1976a). That these deposits are in fact glacial is documented by the following evidence: (1) the upper till is compact, shows deformation structures, and contains clasts from Canada, (2) the gravel also contains Canadian clasts, (3) the gravel and till contain particles far too coarse to have been deposited in the center of the lowland by any process other than meltwater streams, (4) pollen from peat in the outwash gravel indicates a cool, tundra-like climate, and (5) pollen evidence from the Olympic Peninsula indicates a short, cold, climatic phase from about 34 ka to 40 ka (Easterbrook, 1976c; Heusser, 1977). These glacial deposits provide the physical evidence for the ice advance of the Oak Harbor Stade (Easterbrook, 1976a). However, no evidence of glaciation during this time interval has been found to the north in Canada where ice would have to pass in order to reach this part of the Puget Lowland (Fulton *et al.*, 1976), thus posing an enigma. Radiocarbon dates in Canada span all but a few thousand years of the time recorded in the glacial sediments of the Puget Lowland. Easterbrook (1976c) suggested that the Oak Harbor ice advance took place during a brief period not covered by radiocarbon dates in Canada, but a number of dates coincide with those within the outwash gravel. The composition of the sediments preclude a glacier advance from the Cascades to the east, so they must have been deposited by a very limited advance of ice from British Columbia.

Outwash sand and gravel mapped over a wide area in the southwestern Puget Lowland as Salmon Springs Drift by Molenaar (1965) on the basis of its pre-Vashon stratigraphic position and oxidation is probably mostly Possession Drift (Deeter, 1979), oxidized by ground water as a result of its high permeability.

Olympic Mountains

The younger phase of the Humptulips Drift in the western Olympic Mountains (Moore, 1965) consists of outwash which overlies peat probably correlative with the Whidbey Formation (Heusser, 1982) and underlies Chow Chow Drift. Radiocarbon dates of >32 ka and >35.6 ka from peat and silt beneath Chow Chow Drift provide minimum ages for the Humptulips Drift (Heusser, 1982). Peat beneath till at the Bogachiel River in the northwestern Olympic Peninsula was radiocarbon dated at 59,600 ± 700 years (QL-199) using conventional methods and $57{,}000^{+2400}_{-1900}$ years using enrichment techniques (Stuiver *et al.*, 1978; Heusser, 1978). An end moraine of an alpine glacier on the divide between the Hoh and Bogachiel Rivers (Crandell, 1964) lies about 6 km beyond the limit of ice of the Fraser Glaciation. Peat from the base of a bog formed by the moraine was radiocarbon dated at 30,000 ± 800 (Y-2453) years and peat higher in the section was dated at $29{,}650^{+3100}_{-2250}$ (RL-579) years (Heusser, 1978). These dates constrain an alpine glacial advance older than 30 ka and younger than 59.6 ka which may be correlative with the Oak Harbor Stade of the Possession Glaciation in the Puget Lowland. Pollen reflecting a cold climate between about 34 ka and 40 ka in the western Olympic Peninsula was originally referred to a 'late Salmon Springs' glacial advance (Heusser, 1972) and later correlated with the Oak Harbor Stade (Easterbrook, 1974; Heusser, 1977). A radiocarbon date of 34,100 ± 800 (Y-2536) years marks the maximum cold interval (Heusser, 1972). This glacial advance in the Olympic Mountains was more extensive than the alpine advance of the late Wisconsin Fraser glaciation, suggesting that perhaps drift of the Oak Harbor stade in the Puget Lowland was the result of piedmont ice from the Coast Mountains of British Columbia that did not reach the southern Puget Lowland.

Cascade Mountains

Dating of early to middle Wisconsin deposits in the Cascade Mountains is meager, making correlations difficult. 'Late Kittitas Drift' (Porter, 1976) was deposited by a glacial advance older than Lakedale Drift and younger than the Indian John Member of the Kittitas Drift and may be early Wisconsin. The Bullfrog and Ronald Members of the Lakedale Drift were considered late Wisconsin by Porter (1976), but Colman and Pierce (1981) suggested an early Wisconsin age for the Bullfrog Member and a middle Wisconsin age for the Ronald Member on the basis of weathering rind thicknesses. Charcoal from silt older than the Bullfrog Member was originally dated at 37,500 ± 2800 (UW-66) years, but that date is considered invalid because later reruns gave ages of >37,500 (UW-66*) and >37,000 (I-1717) years.

The age of the Hayden Creek Drift was considered to be about 40 to 80 ka by Crandell and Miller (1974) but Colman and Pierce (1981) estimated its age at about 140 ka based on (1) average weathering rind thicknesses of 1.37 mm, (2) argillic B horizons on Hayden Creek deposits, (3) thick weathered loess on some Hayden Creek sediments, and (4) a buried weathering zone beneath loess on some deposits.

LATE WISCONSIN (30–10 ka)

The Olympia nonglacial interval (Armstrong *et al.*, 1965) was defined as 'the climatic episode immediately preceding the last major glaciation, and represented by nonglacial strata lying beneath Vashon Drift'. The sediments consist of floodplain and lacustrine silt, clay, and peat. Radiocarbon dates from the type locality range from 18.1 to 22.4 ka (Mullineaux *et al.*, 1965) and dates in the central Puget Lowland extend to 28 ka (Hansen and Easterbrook, 1974; Easterbrook, 1976a). Dates as young as 15 ka have been obtained from sediments directly beneath Vashon till (Mullineaux *et al.*, 1965; Deeter, 1979). Pollen analyses from peat suggest a climate somewhat cooler than present (Hansen and Easterbrook, 1974; Alley, 1979; Clague, 1978). Paleomagnetic data from silt indicate normal polarity with oscillatory declinations (Easterbrook, 1976a).

Fulton *et al.* (1976) suggested that the Olympia is a true interglacial period, extending from about 20 ka to beyond 59 ka in British Columbia, but till and outwash of the Oak Harbor stade in Washington, radiocarbon-dated between 28 and 35 ka, indicate that the Olympia nonglacial interval was relatively short and pollen suggest that climatic conditions were not quite as mild as at present (Hansen and Easterbrook, 1974).

Near the end of the Olympia interval, piedmont ice advanced into the Fraser Lowland of British Columbia just north of the international boundary and deposited Coquitlam Drift (Hicock, 1976, 1980; Armstrong, 1977; Clague *et al.*, 1980; Hicock and Armstrong, 1981; Clague and Luternauer, 1982, 1983; Armstrong *et al.*, 1985), but the ice apparently did not reach into Washington. Wood from Coquitlam Drift has been radiocarbon dated at 25,800 ± 310 (GSC-2273), 21,700 ± 240 (GSC-2235), 21,700 ± 130 (GSC-2416), 21,600 ± 200 (GSC-2203), 21,500 ± 240 (GSC-2536), and 21,300 ± 250 (GSC-3305) and mammoth tusks from Coquitlam outwash have been dated at 21,400 ± 240 (SFU-65) and 21,600 ± 240 (SFU-66) (Clague, 1980; Armstrong *et al.*, 1985; Hicock *et al.*, 1982). Dates of 18,700 ± 170 (GSC-2344), 18,600 ± 190 (GSC-2194), 18,300 ± 170 (GSC-2322), 18,000 ± 150 (GSC-2371), and 17,800 ± 150 (GSC-2297) were obtained from overlying organic material (Clague, 1980; Armstrong *et al.*, 1985). The Coquitlam Drift is correlated with the Evans Creek Drift of the Cascade Mountains. During this time, deposition of Olympia nonglacial sediments continued in the Puget Lowland (Armstrong and Clague, 1977).

The last major glaciation of the area was the Fraser glaciation (Armstrong *et al.*, 1965), which is subdivided into four stades: (1) the Evans Creek stade, an early alpine phase; (2) the Vashon stade, the maximum advance of the Cordilleran ice sheet; (3) the Everson interstade, an interval of glaciomarine deposition during deglaciation of the lowland; and (4) the Sumas stade, a short readvance of the ice margin before complete deglaciation.

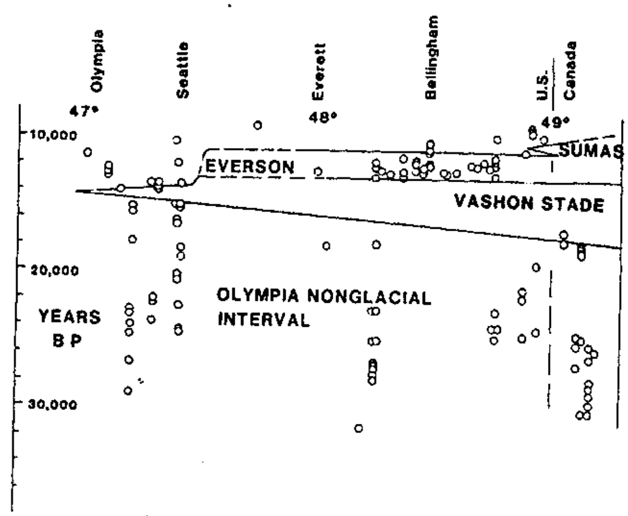

FIG. 3. Radiocarbon dates from the Fraser glaciation and Olympia nonglacial interval in the Puget Lowland, Washington.

Vashon Drift consists of (1) Esperance Sand Member and Quadra Sand deposited by meltwater streams from the advancing ice sheet (Newcomb, 1952; Mullineaux *et al.*, 1965; Clague, 1976, 1977), (2) Vashon till (Willis, 1898; Bretz, 1913) which overlies the Esperance, and (3) recessional outwash sand, gravel, and ice-contact deposits. The Cordilleran ice sheet advanced southward into the Fraser Lowland of British Columbia and deposited till and outwash on glaciolacustrine sediments radiocarbon dated at 18,700 ± 170 (GSC-2344) and 17,800 ± 150 (GSC-2297) years (Clague, 1980; Armstrong *et al.*, 1985; Hicock and Armstrong, 1985). Peat in the Esperance Sand Member at the east end of the Strait of Juan de Fuca gave a radiocarbon date of 18,000 ± 400 (I-2282) years (Easterbrook, 1969) and organic material from floodplain sediments in the south central Puget Lowland gave dates of 16,510 ± 320 (UW-445), 15,450 ± 450 (UW-448) and 15,350 ± 210 (I-10374) years (Deeter, 1979). Organic matter radiocarbon dated at 15,000 ± 400 (W-1227), 15,100 ± 300 (W-1305), and 16,070 ± 600 (W-2125) years beneath Vashon Drift in the Seattle area indicate that Cordilleran ice did not reach there until shortly after 15 ka (Mullineaux *et al.*, 1965; Yount *et al.*, 1980). Waitt and

Thorson (1983) suggested that the westward-flowing Juan de Fuca lobe (Bretz, 1920) may have been out of phase with the southward-flowing Puget lobe and may have reached the western end of the strait by about 17 ka, several thousand years earlier than the Puget lobe. However, ^{14}C dates of 17,000 ± 240 GSC-2829) years from southeastern Vancouver Island (Keddie, 1979); $17{,}250^{+1000}_{-900}$ from the central Strait of Juan de Fuca (Anderson, 1968); $17{,}350^{+1260}_{-1085}$ (B-1062), 18,265 ± 345 (B-1063), and 18,000 ± 400 years (I-2282) from the southeastern Strait of Juan de Fuca (Easterbrook, 1969; G. Thorsen, *written commun.*) indicate that the lobe had not yet entered the eastern strait by 17 ka BP and may well have advanced synchronously with the Puget lobe.

The terminal zone of the Puget Lobe is marked by rather small segments of end moraines, extensive outwash deposits, and kame–kettle complexes (Bretz, 1913; Mackin, 1941; Crandell, 1963; Noble and Wallace, 1966; Carson, 1970; Porter and Carson, 1971; Lea, 1983, 1984). As the Puget lobe underwent large-scale recession and down-wasting between 13 ka and 14.5 ka, it retreated from its terminus by backwasting and recessional outwash was deposited along with proglacial lacustrine sediments in lakes impounded by the receding ice front (Bretz, 1913; Curran, 1965; Deeter, 1979; Waitt and Thorson, 1983). The ice sheet had retreated from the Seattle area before 14,000 ± 900 (L-330), 13,650 ± 550 (L-346A) and 13,430 ± 200 years (Rigg and Gould, 1957; Leopold *et al.*, 1982). A radiocarbon date of 13,570 ± 130 (UW-35) years from wood in ice-dammed lake sediments east of Seattle suggests that the ice sheet may still have occupied the Puget Lowland at that time. Timing of the retreat of the Juan de Fuca lobe from its terminal position is indicated by radiocarbon dates of 14,460 ± 200 (Y-2452) years from a bog on Vashon Drift near the western margin of the Strait of Juan de Fuca and dates of 13,380 ± 250 (RL-140), 13,100 ± 180 (Y-2449), 13,080 ± 260 (Y-2450), 13,010 ± 240 (RL-139), and 12,020 ± 210 (RL-138) years from wood in till at five localities in the terminal zone of the Juan de Fuca lobe (Heusser, 1973a, 1973b). Bottom sediments in the Strait of Juan de Fuca dated at 14,400 ± 400 and 13,150 ± 400 years (Anderson, 1968) were deposited during recession of the lobe and basal peat from a mastodon site along the western portion of the strait has been dated at 12,100 ± 310 (WSU-1866) years (Petersen *et al.*, 1983). The Okanogan lobe of the Cordilleran ice sheet was physically connected to the Puget lobe across the northern part of the north Cascade Mountains and it advanced and retreated approximately synchronously with the Puget lobe (Easterbrook, 1976a, 1979).

Rapid thinning of Vashon ice after the terminus had receded north of Seattle allowed marine water to flood the lowland, floating the remaining ice and depositing Everson glaciomarine drift over much of the central and northern Puget Lowland and San Juan Islands (Easterbrook, 1963, 1966a, 1968, 1969, 1970, 1971, 1976a, 1979). The glaciomarine sediments consist largely of poorly sorted diamictons deposited when melting of floating ice released rock debris which accumulated on the sea floor. Unbroken, articulated marine shells in growth positions indicate that the glaciomarine drift is essentially *in-situ* (Easterbrook, 1963, 1982). More than 80 radiocarbon dates from marine shells in the glaciomarine drift in Washington and British Columbia yield ages of 11 to 13.5 ka, making it a valuable stratigraphic marker. An alternative view, that the Everson glaciomarine drift is time-transgressive as a result of deposition by calving of ice from a backwasting terminus (Pessl *et al.*, 1981; Domack, 1983), is considered untenable in view of the distribution of radiocarbon dates from the galciomarine drift. Domack (1983) proposed an adjacent, progressively retreating, ice terminus during deposition of the Everson glaciomarine drift, based on detailed sedimentological studies on Whidbey Island. Such an origin would entail transgressive deposition of the glaciomarine drift over a distance of more than 170 km and would imply that the northern glaciomarine drift should be younger than the southernmost. However, the distribution of radiocarbon dates demonstrates similar ages for all of the glaciomarine sediments regardless of their geographic location. The southernmost date from Everson glaciomarine drift is 12,670 ± 90 years (USGS-64), and other dates on shells from Everson glaciomarine drift on Whidbey Island include 11,850 ± 240 (I-1448), 12,300 ± 180 (I-2154), 12,400 ± 190 (I-2286), 12,535 ± 300 (I-1079), and 13,010 ± 170 (UW-32) years (Easterbrook, 1966a, 1968, 1969, 1976a). In the San Juan Islands, about midway in the distribution of the glaciomarine drift, dates of 11,900 ± 170 (I-2156), 12,000 ± 450 (I-1471), 12,160 ± 290 (I-1470), 12,350 ± 330 (I-1469), 12,350 ± I-969), and 12,600 ± 190 (I-1881) years have been obtained (Easterbrook, 1969, 1976a). At the northernmost occurrences in Washington, Everson glaciomarine drift has been dated at 12,970 ± 280 (I-1447) and 12,090 ± 350 (W-984) years (Easterbrook, 1963, 1969, 1976a) and in British Columbia, more than 20 dates range from 12,900 ± 170 (GSC-2193) to 12,000 ± 100 (GSC-2177) (Armstrong *et al.*, 1985; Clague, 1980). The overlapping of so many widely-distributed dates precludes a transgressive period of deposition over the 2 ka period and invalidates the calving ice front model. Deposition from shelf ice is also considered unlikely in light of paleoecological constraints imposed by diatoms and foraminifera in the glaciomarine drift (Crandall, 1979). Deposition largely from abundant berg ice is considered most likely (Armstrong and Brown, 1954; Armstrong, 1981; Easterbrook, 1963, 1969, 1971).

A brief readvance of ice from British Columbia into northern Washington following the end of glaciomarine deposition occurred during the Sumas stade (Easterbrook, 1963, 1966a, b, 1969, 1971, 1976d; Armstrong, 1977, 1981; Armstrong *et al.*, 1965). Sumas till and ice contact deposits lie directly on outwash, indicating that a period of outwash deposition preceded a subaerial readvance of ice and that the Sumas is not just due to grounding of floating ice (Easterbrook, 1963). Wood from Sumas till in British Columbia has been radiocarbon dated at 11,600 ± 280 (GSC-1675), 11,500 ± 1100 (L-221D), and 11,400 ± 170 (GSC-1695) (Armstrong *et al.*, 1965; Armstrong, 1981). Numerous erratics on Sumas Drift are derived from the Fraser Canyon in British Columbia where radiocarbon dates of 11,430 ± 150 (I-6057), 11,140 ± 260 (I-6058), and 11,000 ± 170 (I-5346) years from bogs indicate the canyon was ice-free by then (Mathews *et al.*, 1972; Mathews and Heusser, 1981; Mathews and Rouse, 1975). The dates from the Fraser Canyon have led to speculation that perhaps the source of Sumas ice was the Coast Mountains rather than the Fraser Canyon. However, Clague (1981) points out that the dates allow the possibility of up to 250 m of ice in the canyon at 11,430 ± 150 and 150 m of ice at 11,140 ± 260 years, and valleys from alternative source areas were known to be ice free during the climax of the Sumas stade. Sumas ice also filled the Columbia Valley of Washington and the contiguous lower Chilliwack Valley of British Columbia in the Cascade Mountains with up to 250 m of outwash and ice-contact deposits containing wood radiocarbon dated at 11,300 ± 100 (GSC-2523) (Easterbrook, 1971; Armstrong, 1981; Clague, 1980). Radiocarbon dates of 9,920 ± 760 (I-2280), 9,750 ± 150 (WW-6), 9,500 ± 200 (WW-8), and 9,300 ± 250 (I-2281) from the bases of peat bogs in abandoned outwash channels indicate that meltwater from Sumas ice had ended by that time (Easterbrook, 1969, 1971).

Cascade Mountains

Climatic deterioration beginning about 25–28 ka BP led to the expansion of alpine glaciers in the Cascade Mountains, culminating about 22 ka BP. The Evans Creek stade is the 'Climatic episode early in the Fraser Glaciation during which large alpine glaciers formed and reached their maximum extents and deposited drift in the mountains . . .' (Armstrong *et al.*, 1965). The alpine drift in the western foothills is overlain by glaciolacustrine sediments deposited in ice-marginal lakes formed by damming of westward-flowing streams from the mountains (Cary and Carlston, 1937; Mackin, 1941) by the Cordilleran ice sheet in the Puget Lowland.

The advance of Evans Creek alpine glaciers in the Cascades appears to have been contemporaneous with the early growth of Cordilleran ice in western British Columbia where a pre-Vashon advance of ice deposited Coquitlam Drift about 22 ka BP (Armstrong and Hicock, 1976; Armstrong, 1977; Hicock, 1976, 1980; Clague, 1980). Alpine glaciers in the northern part of Cascade Mountains were eventually overwhelmed by the Cordilleran ice sheet, whereas the alpine glaciers to the south had retreated prior to the appearance of the Cordilleran ice in the adjacent Puget Lowland (Cary and Carlston, 1937; Mackin, 1941; Crandell, 1963; Crandell and Miller, 1974). Pollen from Davis Lake just beyond drift of the Evans Creek stade near Mt. Rainier suggest a tundre-parkland environment from 26,100 ± 1200 (QL-1308) to about 16,000 years (Barnosky, 1981).

Lakedale Drift in the Yakima Valley was considered to be late Wisconsin by Porter (1976), but Colman and Pierce (1981) suggested that the two older members of the Lakedale Drift are pre-Wisconsin. That question remains unresolved in the absence of any datable material. Lakedale Drift is considered broadly correlative with the Leavenworth Drift of the Wenatchee Valley, the Cabot Creek Formation of the Metolius River area, the Waban Drift of the Mountain Lakes area. Basal peat on Hyak Drift has been radiocarbon dated at 11,050 ± 50 years (UW-321) and correlated with McNeeley Drift of Mt. Rainier and Sumas Drift of the Puget Lowland (Porter, 1976).

Retreat of the Okanogan lobe from its terminal moraine along the eastern flanks of the north Cascade Mountains took place synchronously with recession of the Puget lobe to the west (Easterbrook, 1976a, 1979). Numerous eskers, kames, kame terraces, ice-marginal fans and related ice-contact sediments were deposited during the Everson interstade when glaciomarine drift was being deposited in the Puget Lowland. Volcanic ash more than 50 km north of the terminal moraine indicates that the Okanogan lobe had retreated at least that far north by 12.7 ka BP (Mullineaux *et al.*, 1978; Porter, 1978; Waitt and Thorson, 1983). A kame-moraine complex in the Sinlahekin Valley still farther north may represent a Sumas equivalent stand of Okanogan ice, but it is undated (Pine, 1985).

Olympic Mountains

Extension of glaciers from the Olympic Mountains to the shores of the Pacific Ocean was recognized by Arnold (1906), Reagan (1909), Lupton (1914), and Baldwin (1939). Radiocarbon dates of 18,800 ± 800 (RL-228), 15,600 ± 240 (Y-2457), 15,050 ± 550 (I-379) 14,480 ± 600 (Y-2454) from three basal bogs on Evans Creek Drift in the Hoh Valley (the 'younger Wisconsin till' of Crandell, 1964) limit the age of the Evans Creek maximum in the Olympic Mountains. These dates suggest that the Evans Creek Drift in the Olympic Mountains is contemporaneous with the Evans Creek Drift of the Cascade Mountains and that both are perhaps equivalent to the Coquitlam Drift of British Columbia.

HOLOCENE

Fluctuations of alpine glaciers in the Cascade and Olympic Mountains during the Holocene resulted in the deposition of multiple end moraines (Crandell, 1969; Crandell and Miller, 1964, 1974; Barnosky, 1984; Beget, 1979, 1980a, b, 1981, 1984; Burbank, 1981; Burke, 1972; Easterbrook and Rahm, 1970; Easterbrook and Burke, 1971, 1972; Easterbrook *et al.*, *in press*; Fuller, 1980; Hodge, 1925; Hopkins, 1976; Mahaney, 1981; Porter and Denton, 1967; Waitt *et al.*, 1982). A three-fold pattern of glacial expansion can be recognized: (1) an early Holocene phase older than Mazama ash (~7 ka), (2) an early Neoglacial advance at about 2–3 ka, and (3) multiple, smaller late Neoglacial advances during the last 700 years.

The Whitechuck moraines near Glacier Peak represent an early Holocene glacial advance older than Mazama ash and younger than Glacier Peak tephras G,N,F,C,M,T, and B which were erupted between about 12.5 and 11.25 ka (Beget, 1981, 1984). Fragments of disseminated charcoal in the till were radiocarbon dated at 8,380 ± 90 (W-4277) and 8,350 ± 50 (W-1070) years (Beget, 1981). Waitt *et al.* (1982) report many moraines high in cirques east and southeast of Glacier Peak that overlie the entire Glacier Peak tephra sequence and are blanketed by Mazama ash. The Brisingamen moraine in the Enchantment Lakes region is overlain by Mazama ash and is inferred to be younger than the youngest Rat Creek moraine (Waitt *et al.*, 1982). Small cirques near Mt. Rainier contain McNeeley moraines capped with Mazama ash (Crandell and Miller, 1964). One of the outermost McNeeley moraines is overlain by the >8750 year old 'R' ash from Mt. Rainier, but all of the other McNeeley moraines examined have yielded only Mazama ash and therefore may be younger than the late Pleistocene Sumas stade (Waitt *et al.*, 1982) and perhaps correlative with the Brisingamen moraine.

The Park Butte moraine in a small cirque adjacent to Mt. Baker is mantled with Mazama ash which is bracketed by radiocarbon dates of 6,630 ± 130 (I-2917) and 5,965 ± 120 (I-2916) years (Easterbrook, 1975). The moraine is younger than the latest part of the Vashon stade (about 13 ka) (Easterbrook and Burke, 1971, 1972; Easterbrook, 1970, 1975; Easterbrook, Burke and Fuller, *in press*). However, without a more restrictive lower age limit on the moraine, it could be either early Holocene or equivalent to the Sumas stade. Another early Holocene or Sumas glacial advance is

AREA	REFERENCE	ILL. E	ILL. L	WISCONSIN E	WISCONSIN M	WISCONSIN L	HOLO. E	HOLO. NEO
Mt. Lassen	Kane, P. S., 1982 ____, 1974 Crandell, D.R., 1972	X		X XX	X	X XX		
N. Ca. Coast Ra.-Snow Mtn, Black Butte, Hull Mtn, Anthony Peak	Davis, S.N., 1958			X				
Trinity Alps/ Klamaths	Sharp, R.P., 1960 Hershey, O.H., 1903	XX		X X	X X	X		
Mt. Shasta	Hill, M., 1977 Aune, Q. A., 1970 Williams, H., 1949				X		X	
Mt. Thielson	Nafziger, R.H., 1974	more extensive than present						
Mt. Mazama	Williams, H., 1942 Atwood, W.W.Jr., 1935	multiple during growth of volcano						
Three Sisters	Dethier, D.P., 1980						X	
Central Oregon	Taylor, E.M., 1979 ______, 1968					X X		
Bachelor Butte	Rollins, A., 1976					XX		
Albany/Lebanon area	Allison, I. S., 1953	XX		XX				
Blue River	Swanson, F.J. and James, M.E., 1975			X		X		
N. Santiam River	Thayer, T.P., 1939	X		X				
Mt Jefferson	Walker, G.W. and Greene, R.C., 1966 Hodge, E.T., 1925			X		X X	X X	
Mt Hood	Wise, W.S., 1969 Crane, H.R. and Griffin, J.B., 1960				X		X	
Mt Adams	Mahaney, W.C., Fahey, B.D., and Lloyd, D.T., 1981 Hopkins, K.D., 1976	X				X X	XXX X	
Mt St Helens	Hyde, J.A., 1975 Crandell, D.R. and Mullineaux, D.R., 1973	XXX				X		

FIG. 4. Glaciations recorded in the Southern Cascade Range and other mountains in Oregon and northern California.

represented by a post-Fraser till on Mt. Baker that is overlain by Mazama ash which is in turn overlain by a mudflow containing wood radiocarbon dated at 5,980 ± 250 (W-2944) years (Fuller, 1980; Easterbrook *et al.*, *in press*).

A pre-Mazama moraine in the Three Sisters region of the Oregon Cascades may also be early Holocene in age, but it is not well dated (Dethier, 1980).

Radiocarbon dates of 4,960 ± 90 (UW-99) and 4,700 ± 300 (W-1030) years were obtained from trees overridden by the South Cascade glacier in the Dome Peak area (Miller, 1969).

Burroughs Mountain moraines in the Mt. Rainier area are bracketed by the Mt. St. Helens Y ash (3.3–4 ka) and the Mt. Rainier C tephra 2.04–2.3 ka) (Crandell and Miller, 1964). Moraines containing trees overridden by the Deming Glacier on Mt. Baker yielded radiocarbon dates of 1,860 ± 80 and 1,840 ± 80 years (Easterbrook, Burke and Fuller, *in press*).

Multiple late Neoglacial moraines were constructed at many localities in the Cascade and Olympic Mountains during the past 700–800 years (e.g. Burbank, 1981; Burke, 1972; Crandell and Miller, 1964; Easterbrook, 1970; Easterbrook *et al.*, *in press*; Fuller, 1980; Heikkinen, 1984; Heusser, 1957; Miller, 1969; Sigafoos and Hendricks, 1972). The number of moraines is so large and they are so closely spaced in time that no attempt is made here to correlate them. A general pattern seems to exist, beginning about the 13th century and continuing through the 20th century.

REFERENCES

Alley, N.F. (1979). Middle Wisconsin stratigraphy and climatic reconstruction, southern Vancouver Island, British Columbia. *Quaternary Research*, **11**, 213–237.

Allison, I.S. (1953). Geology of the Albany quadrangle, Oregon. *Oregon Department of Geology and Mineral Industries Bulletin*, **37**, 18 pp.

Anderson, F.E. (1968). Seaward terminus of the Vashon continental glacier in the Strait of Juan de Fuca. *Marine Geology*, **6**, 419–438.

Armstrong, J.E. (1977). Quaternary stratigraphy of the Fraser Lowland. *Geological Society of America Annual Meeting*, Guidebook for Field Trip No. 6, pp. 204–226.

Armstrong, J.E. (1981). Post-Vashon Wisconsin glaciation, Fraser Lowland, British Columbia. *Geological Survey of Canada Bulletin* **322**, 34 pp.

Armstrong, J.E. and Brown, W.L. (1954). Late Wisconsin marine drift and associated sediments of the lower Fraser Valley, British Columbia, Canada. *Geological Society of America Bulletin*, **65**, 349–364.

Armstrong, J.E. and Clague, J.J. (1977). Two major Wisconsin lithostratigraphic units in southwest British Columbia. *Canadian Journal of Earth Sciences*, **14**, 1471–1480.

Armstrong, J.E., Clague, J.J. and Hebda, R.J. (1985). Late Quaternary geology of the Fraser Lowland, southwestern British Columbia. Guidebook for Field Trip 15, *Geological Society of America Cordilleran Section Meeting*, Vancouver, British Columbia, 25 pp.

Armstrong, J.E. and Hicock, S.R. (1976). Quaternary multiple valley development of lower Coquitlam Valley, Coquitlam, British Columbia. *Geological Survey of Canada Paper*, **76-1B**, 197–200.

Armstrong, J.E., Crandell, D.R., Easterbrook, D.J. and Noble, J.B. (1965). Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington. *Geological Society of America Bulletin*, **76**, 321–330.

Arnold, R. (1906). Geological reconnaissance of the coast of the Olympic Peninsula, Washington. *Geological Society of America Bulletin*, **17**, 321–330.

Atwood, W.W. (1935). The glacial history of an extinct volcano, Crater Lake National Park. *Journal of Geology*, **43**, 142–168.

Aune, Q.A. (1970). Glaciation in Mt. Shasta–Castle Crags, California. *California Division of Mines and Geology Mineral Information Service*, **23**, 145–148.

Baldwin, E.M. (1939). Late Cenozoic diastrophism along the Olympic coast. MSc Thesis, Washington State College, 47 pp.

Barnosky, C.W. (1981). A record of Quaternary vegetation from Davis Lake, southern Puget Lowland, Washington. *Quaternary Research*, **16**, 221–239.

Barnosky, C.W. (1984). Late Pleistocene and early Holocene environmental history of southwestern Washington State, USA. *Canadian Journal of Earth Sciences*, **21**, 619–629.

Beget, J.E. (1979). Late Pleistocene and Holocene pyroclastic flows and lahars at Glacier Peak, Washington. *Geological Society of America Abstracts with Programs*, **11**, 68.

Beget, J.E. (1980a). Tephrochronology of deglaciation and latest Pleistocene or early Holocene moraines at Glacier Peak, Washington. *Geological Society of America Abstracts with Programs*, **12**, 96.

Beget, J.E. (1980b). Tephrochronology of late glacial and Holocene moraines in the central Cascade Range, Washington State. *Geological Society of America Abstracts with Programs*, **12**, 384.

Beget, J.E. (1981). Early Holocene glacier advance in the North Cascade Range, Washington. *Geology*, **9**, 409–413.

Beget, J.E. (1984). Tephrochronology of late Wisconsin deglaciation and Holocene glacier fluctuations near Glacier Peak, North Cascade Range, Washington. *Quaternary Research*, **21**, 304–316.

Blunt, D.J. (1982). Geochemistry of amino acids in mollusks and wood Pacific Northwest, United States. MSc Thesis, California State University at Haywood, 183 pp.

Blunt, D.J., Easterbrook, D.J. and Rutter, N.A. (in press). *Amino Acid Chronology and Correlation of pre-Wisconsin Sediments in the Puget Lowland, Washington*. Washington Division of Natural Resources.

Bretz, J.H. (1913). Glaciation of the Puget Sound region. *Washington Division of Mines and Geology Bulletin*, **8**, 244 pp.

Bretz, J.H. (1920). The Juan de Fuca lobe of the Cordilleran ice sheet. *Journal of Geology*, **28**, 333–339.

Burbank, D.W. (1981). A chronology of late Holocene glacier fluctuations on Mt. Rainier, Washington. *Arctic and Alpine Research*, **13**, 369–386.

Burke, R.M. (1972). Neoglaciation of Boulder Valley, Mt. Baker, Washington. MSc Thesis, Western Washington University, 47 pp.

Carson, R.J. (1970). Quaternary geology of the south–central Olympic Peninsula, Washington. PhD Thesis, University of Washington, Seattle, Washington, 67 pp.

Carver, G.A. (1972). Glacial geology of the Mountain Lakes Wilderness and adjacent parts of the Cascade Range, Oregon. PhD Thesis, University of Washington, Seattle, Washington, 75 pp.

Cary, A.S. and Carlston, C.W. (1937). Notes on Vashon stage glaciation of the South Fork of the Skykomish River valley, Washington. *Northwest Science*, **11**, 61–62.

Clague, J.J. (1976). Quadra Sand and its relation to the late Wisconsin glaciation of southwest British Columbia. *Canadian Journal of Earth Sciences*, **13**, 803–815.

Clague, J.J. (1977). Quadra Sand: A study of the late Pleistocene geology and geomorphic history of coastal southwest British Columbia. *Geological Survey of Canada Paper*, **77-17**, 24 pp.

Clague, J.J. (1978). Mid-Wisconsinan climates of the Pacific Northwest. *Geological Survey of Canada Paper*, **78-1B**, 95–100.

Clague, J.J. (1980). Late Quaternary geology and geochronology of British Columbia, Part 1: Radiocarbon dates. *Geological Survey of Canada Paper*, 80-13, 28 pp.

Clague, J.J. (1981). Late Quaternary geology and geochronology of British Columbia, Part 2: Summary and discussion of radiocarbon-dated Quaternary history. *Geological Survey of Canada Paper* **80-35**, 41 pp.

Clague, J.J., Armstrong, J.E. and Mathews, W.H. (1980). Advance of the late Wisconsin Cordilleran ice sheet in southern British Columbia since 22,000 yr b.p. *Quaternary Research*, **13**, 322–326.

Clague, J.J. and Luternauer, J.L. (1982). Late Quaternary sedimentary environments, southwestern British Columbia. *International Association of Sedimentology, 11th International Congress, Field Excursion Guide Book 30A*, 167 pp.

Clague, J.J. and Luternauer, J.L. (1983). Late Quaternary geology of southwestern British Columbia. *Geological Association of Canada Annual Meeting, Field Trip no. 6, Field Trip Guidebook*, **1**, 112 pp.

Colman, S.M. and Pierce, K.L. (1981). Weathering rinds on andesitic and basaltic stones as a Quaternary age indicator, western United States. *U.S. Geological Survey Professional Paper*, **1210**, 56 pp.

Colman, S.M. and Pierce, K.L. (1985). Correlation of Quaternary glacial sequences in the western United States based on weathering rinds and related studies. *In*: Mahaney, W.C. (ed.) *Correlation of Quaternary Chronologies*, pp. 437–453. Geobooks, Norwich, England.

Crandall, R. (1979). Diatoms and magnetic anisotropy as means of distinguishing glacial till from glaciomarine drift. MSc Thesis, Western Washington University, Bellingham, Washington, 62 pp.

Crandell, D.R. (1963). Surficial geology and geomorphology of the Lake Tapps Quadrangle, Washington *U.S. Geological Survey Professional Paper*, **388-A**, 84 pp.

Crandell, D.R. (1964). Pleistocene glaciations of the southwestern Olympic Peninsula, Washington. *U.S. Geological Survey Professional Paper*, **501-B**, B135–B139.

Crandell, D.R. (1965). The glacial history of western Washington and Oregon. *In*: Wright, H.E., Jr. and Frey, D.G. (eds) *The Quaternary of the U.S.*, pp. 341–353. Princeton University Press.

Crandell, D.R. (1969). Surficial geology of the Mount Rainier National Park, Washington. *U.S. Geological Survey Bulletin*, **1288**, 41 pp.

Crandell, D.R. (1972). Glaciation near Lassen Peak, northern California. *U.S. Geological Survey Professional Paper*, **800-C**, C179–C188.

Crandell, D.R. and Miller, R.D. (1964). Post-Hypsithermal glacier advances at Mount Rainier, Washington. *U.S. Geological Survey Professional Paper*, **501-D**, D110–D114.

Crandell, D.R. and Miller, R.D. (1974). Quaternary stratigraphy and extent of glaciation in the Mount Rainier region, Washington. *U.S. Geological Survey Professional Paper*, **847**, 59 pp.

Crandell, D.R., Mullineaux, D.R. and Waldron, H.H. (1958). Pleistocene sequence in the southeastern part of the Puget Sound Lowland, Washington. *American Journal of Science*, **256**, 384–398.

Crane, H.R. and Griffin, J.B. (1960). University of Michigan radiocarbon dates V. *American Journal of Science, Radiocarbon Supplement*, **2**, 31–48.

Curran, T.A. (1965). Surficial geology of the Issaquah area, Washington. MSc Thesis, University of Washington, Seattle, Washington.

Davis, S.N. (1958). Glaciated peaks in the northern Coast Ranges, California. *American Journal of Science*, **256**, 620–629.

Deeter, J.D. (1979). Quaternary geology and stratigraphy of Kitsap County, Washington. MSc Thesis, Western Washington University, Bellingham, Washington, 175 pp.

Dethier, D.P. (1980). Reconnaissance study of Holocene glacier fluctuations in the Broken Top area, Oregon. *Geological Society of America Abstracts with Program*, **12**, 104.

Domack, E.W. (1983). Facies of late Pleistocene glacial-marine sediments on Whidbey Island, Washington. *In*: *Glacial–Marine Sedimentation*, pp. 535–570. Plenum Press, New York.

Dorn, T.F., Fairhall, A.W., Schell, W.R. and Takashima, Y. (1962). Radiocarbon dating at the University of Washington I. *Radiocarbon*, **4**, 1–12.

Easterbrook, D.J. (1963). Late Pleistocene glacial events and relative sea-level changes in the northern Puget Lowland, Washington. *Geological Society of America Bulletin*, **74**, 1465–1483.

Easterbrook, D.J. (1966a). Radiocarbon chronology of late Pleistocene deposits in northwest Washington. *Science*, **152**, 764–767.

Easterbrook, D.J. (1966b). Glaciomarine environments and the Fraser Glaciation in northwest Washington. Guidebook for First Pacific Coast Friends of the Pleistocene Field Conference, 52 pp.

Easterbrook, D.J. (1968). Pleistocene stratigraphy of Island County, Washington. Washington Division of Water Resources Bulletin 25, pp. 1–34.

Easterbrook, D.J. (1969). Pleistocene chronology of the Puget Lowland and San Juan Islands, Washington. *Geological Society of America Bulletin*, **80**, 2273–2286.

Easterbrook, D.J. (1970). Glacial events in the Puget Lowland between 14,000 and 10,000 years ago. *American Quaternary Association Abstracts*, First Meeting, p. 39.

Easterbrook, D.J. (1971). *Geology and Geomorphology of Western Whatcom County, Washington*. Western Washington University Press, Bellingham, Washington, 68 pp.

Easterbrook, D.J. (1974). Comparison of late Pleistocene glacial fluctuations. *In*: *Quaternary Glaciations in the Northern Hemisphere*, International Geological Correlation Project 73-1/24 Report no. 1, Sibrava, V. (ed.), pp. 96–109, Prague.

Easterbrook, D.J. (1975). Mt. Baker eruptions. *Geology*, **3**, 679–682.

Easterbrook, D.J. (1976a). Quaternary geology of the Pacific Northwest. *In*: Mahaney, W.C. (ed.) *Quaternary Stratigraphy of North America*, pp. 441–462. Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania.

Easterbrook, D.J. (1976b). Middle and early Wisconsin chronology in the Pacific Northwest. *In*: *Quaternary Glaciations in the Northern Hemisphere*, International Geological Correlation Program, Project 73/1/24, Report no. 3, Easterbrook, D.J. and Sibrava, V. (eds), pp. 90–98, Prague.

Easterbrook, D.J. (1976c). Stratigraphy and palynology of late Quaternary sediments in the Puget Lowland, Washington: Reply. *Geological Society of America Bulletin*, **87**, 155–156.

Easterbrook, D.J. (1976d). Geologic map of western Whatcom County, Washington. *U.S. Geological Survey Miscellaneous Investigations*, Map I-854B.

Easterbrook, D.J. (1979). The last glaciation of northwest Washington. *In*: Armentrout, J.M., Cole, M.R. and Terbest, H. (eds) *Cenozoic Paleogeography of the Western United States*. Pacific Coast Paleogeography Symposium 3, pp. 177–189. Los Angeles, Pacific Coast Section, Society of Economic Paleontologists and Mineralogists.

Easterbrook, D.J. (1982). Characteristic features of glacial sediments. *In*: *American Association of Petroleum Geologists Memoir*, **31**, 1–10.

Easterbrook, D.J., Blunt, D.J. and Rutter, N.A. (1982). Pleistocene glacial and interglacial chronology in western Washington. *Geological Society of America Abstracts with Program*, **14**, pp. 161.

Easterbrook, D.J. and Briggs, N.A. (1979). Age of the Auburn reversal and the Salmon Springs and Vashon Glaciations in Washington. *Geological Society of America Abstracts with Program*, **11**, 76–77.

Easterbrook, D.J., Briggs, N.D., Westergate, J.A. and Gorton, M.P. (1981). Age of the Salmon Springs Glaciation in Washington. *Geology*, **9**, 87–93.

Easterbrook, D.J. and Burke, R.M. (1971). Neoglaciation on the flanks of Mt. Baker, Washington. *Northwest Science Abstracts*, **45**, 4.

Easterbrook, D.J. and Burke, R.M. (1972). Glaciation of the northern Cascades, Washington. *Geological Society of America Abstracts with Program*, **4**, 152.

Easterbrook, D.J., Burke, R.M. and Fuller, S.R. (in press). Late Quaternary glaciation of Mt. Baker, Washington.

Easterbrook, D.J., Crandell, D.R. and Leopold, E.B. (1967). Pre-Olympia stratigraphy and chronology in the central Puget Lowland, Washington. *Geological Society of America Bulletin*, **78**, 13–20.

Easterbrook, D.J. and Othberg, K. (1976). Paleomagnetism of Pleistocene sediments in the Puget Lowland, Washington. *In*: *Quaternary Glaciations of the Northern Hemisphere*, International Geological Correlation Program, Project 73/1/24, Report no. 3 Easterbrook, D.J. and Sibrava, V. (eds) pp. 189–207, Prague.

Easterbrook, D.J. and Rahm, D.A. (1970). *Landforms of Washington*. Union Printing Company, Bellingham, Washington, 156 pp.

Easterbrook, D.J. and Rutter, N.A. (1981). Amino acid ages of Pleistocene glacial and interglacial sediments in western Washington. *Geological Society of America Abstracts with Program*, **13**, 444.

Easterbrook, D.J. and Rutter, N.A. (1982). Amino acid analysis of wood and shells in development of chronology and correlation of Pleistocene sediments in the Puget Lowland, Washington. *Geological Society of America Abstracts with Program*, **14**, 480.

Easterbrook, D.J., Westgate, J.A. and Naeser, N. (1985). Pre-Wisconsin fission-track, paleomagnetic, amino acid, and tephra chronology in the Puget Lowland and Columbia Plateau, Washington. *Geological Society of America Abstracts with Programs*, **17**, 353.

Easterbrook, D.J., Westgate, J.A. and Roland, J. (in press). Paleomagnetism and tephrochronology of early Pleistocene sediments in the southern Puget Lowland, Washington.

Florer, L.E. (1972). Quaternary paleoecology and stratigraphy of the

sea cliffs, western Olympic Peninsula, Washington. *Quaternary Research*, **2**, 202–216.
Frisken, J.G. (1965). Pleistocene glaciation of the Brinnon area, east-central Olympic Peninsula, Washington. MSc Thesis, University Washington, Seattle, Washington, 75 pp.
Fuller, S.R. (1980). Neoglaciation of Avalanche Gorge and the Middle Fork Nooksack River Valley, Mt. Baker, Washington. MSc Thesis, Western Washington University, Bellingham, Washington, 68 pp.
Fuller, S.R., Easterbrook, D.J. and Burke, R.M. (1983). Holocene glacial activity in five valleys on the flanks of Mt. Baker, Washington. *Geological Society of America Abstracts with Program*, **15**, 430.
Fulton, R.J., Armstrong, J.E. And Fyles, J.G. (1976). Stratigraphy and palynology of late Quaternary sediments in the Puget Lowland, Washington: discussion. *Geological Society of America Bulletin*, **87**, 153–155.
Gayer, M.J. (1977). Quaternary and environmental geology of northeastern Jefferson County, Washington. MSC Thesis, North Carolina State University, 140 pp.
Grimstad, P. and Carson, R.J. (1981). Geology and ground-water resources of eastern Jefferson County, Washington. *Washington Department of Natural Resources Water Supply Bulletin*, **54**, 125 pp.
Hansen, B.S. and Easterbrook, D.J. (1974). Stratigraphy and palynology of late Quaternary sediments in the Puget Lowland, Washington. *Geological Society of America Bulletin*, **85**, 587–602.
Hansen, H.P. (1947). Postglacial forest succession, climate, and chronology in the Pacific Northwest. *American Philosophical Society Transactions*, **37**, 130 pp.
Hansen, H.P. and Mackin, J.H. (1949). A pre-Wisconsin forest succession in the Puget Lowland, Washington. *American Journal of Science*, **247**, 833–855.
Heikkinen, O. (1984). Dendrochronological existence of variations of Coleman Glacier, Mt. Baker, Washington, U.S.A. *Arctic and Alpine Research*, **16**, 53–64.
Hershey, O.H. (1903). Some evidence of two glacial stages in the Klamath Mountains in California. *American Geologist*, **31**, 139–156.
Heusser, C.J. (1957). Variations of Blue, Hoh, and White Glaciers during recent centuries. *Arctic*, **10**, 139–150.
Heusser, C.J. (1972). Palynology and phytogeographical significance of a late-Pleistocene refugium near Kalaloch, Washington. *Quaternary Research*, **2**, 189–201.
Heusser, C.J. (1973a). Environmental sequence following the Fraser advance of the Juan de Fuca lobe, Washington. *Quaternary Research*, **3**, 284–306.
Heusser, C.J. (1973b). Age and environment of allochthonous peat clasts from the Bogachiel River Valley, Washington. *Geological Society of America Bulletin*, **84**, 797–804.
Heusser, C.J. (1974). Quaternary vegetation, climate, and glaciation of the Hoh Valley, Washington. *Geological Society of America Bulletin*, **85**, 1547–1560.
Heusser, C.J. (1977). Quaternary palynology of the Pacific slope of Washington. *Quaternary Research*, **8**, 282–306.
Heusser, C.J. (1978). Palynology of Quaternary deposits of the lower Bogachiel River area, Olympic Peninsula, Washington. *Canadian Journal of Earth Science*, **15**, 1568–1578.
Heusser, C.J. (1982). Quaternary vegetation and environmental record of the western Olympic Peninsula. *American Quaternary Association, 7th Biennial Conference*, Seattle, Washington, Guide for Day 2 of Field Trip G, 23 pp.
Heusser, C.J. and Heusser, L.E. (1981). Palynology and paleotemperature analysis of the Whidbey Formation, Puget Lowland, Washington. *Canadian Journal of Earth Sciences*, **18**, 136–149.
Hicock, S.R. (1976). Quaternary geology: Coquitlam-Port Moody area, British Columbia. MSc Thesis, University British Columbia, Vancouver, British Columbia, 114 pp.
Hicock, S.R. (1980). Pre-Fraser Pleistocene stratigraphy, geochronology, and paleoecology of the Georgia Depression, British Columbia. PhD Thesis, University of Western Ontario, London, Ontario, 230 pp.
Hicock, S.R. and Armstrong, J.E. (1981). Coquitlam Drift: a pre-Vashon Fraser glacial formation in the Fraser Lowland, British Columbia. *Canadian Journal of Earth Sciences*, **18**, 1443–1451.
Hicock, S.R. and Armstrong, J.E. (1985). Vashon Drift: definition of the formation in the Georgia Depression, southwest British Columbia *Canadian Journal of Earth Sciences*, **22**, 748–757.
Hicock, S.R., Hebda, R.J. and Armstrong, J.E. (1982). Lag of Fraser glacial maximum in the Pacific Northwest: pollen and macrofossil evidence from western Fraser Lowland, British Columbia. *Canadian Journal of Earth Sciences*, **19**, 2288–2296.
Hicock, S.R., Hobson, K. and Armstrong, J.E. (1982). Late Pleistocene proboscideans and early Fraser glacial sedimentation in eastern Fraser Lowland, British Columbia. *Canadian Journal of Earth Sciences*, **19**, 899–906.
Hill, M. (1977). Glaciers of Mt. Shasta, California. *Geology*, **30**, 75–80.
Hodge, E.T. (1925). Geology of Mt. Jefferson, Oregon. *Mazama*, 7(2), 25–58.
Hopkins, K.D. (1966). Glaciation of Ingalls Creek valley, east central Cascade Range, Washington. MSc Thesis, University of Washington, Seattle, Washington, 79 pp.
Hopkins, D.K. (1976). Geology of the south and east slope of Mt. Adams volcano, Cascade Range, Washington. PhD Thesis, University of Washington, Seattle, Washington, 143 pp.
Hyde, J.A. (1975). Upper Pleistocene pyroclastic flow deposits and lahars south of Mt. St. Helens volcano, Washington. *U.S. Geological Survey Bulletin*, **1383-B**, 20 pp.
Johnson, R., Introne, D.S., Mattes, J. and Stipp, J.J. (1980). University of Miami radiocarbon dates XVII. *Radiocarbon*, **22**, 99–107.
Kane, P.S. (1974). Pleistocene glaciation and volcanism in Lassen Volcanic National Park, California. *Geological Society of America Abstracts with Program*, **6**, 200.
Kane, P.S. (1982). Pleistocene glaciation in Lassen Volcanic National Park. *California Geology*, **35**, 95–105.
Keddie, G.R. (1979). The late Ice Age of southern Vancouver Island. *Midden*, **11**, 16–22.
Lea, P.D. (1983). Glacial history of the southern margin of the Puget Lowland, Washington. *Geological Society of America Abstracts with Programs*, **15**, 430.
Lea, P.D. (1984). Pleistocene glaciation at the southern margin of the Puget Lobe, western Washington. PhD Thesis, University of Washington, Seattle, Washington, 96 pp.
Leopold, D.R. and Crandell, D.R. (1957). Pre-Wisconsin interglacial pollen spectra from Washington State, USA. *Geobotanisches Institut Rubel in Zurich Veroffentlichung*, **34**, 76–79.
Leopold, L.B., Nickmann, R., Hedges, J.I. and Ertel, J.R. (1982). Pollen and lignin records of late Quaternary vegetation, Lake Washington. *Science*, **218**, 1305–1307.
Lupton, C.T. (1914). Oil and gas in the western part of the Olympic Peninsula, Washington. *U.S. Geological Survey Bulletin*, **581**, 23–81.
Mackin, J.H. (1941). Glacial geology of the Snoqualmie-Cedar area, Washington. *Journal of Geology*, **49**, 449–481.
Mahaney, W.G., Fahey, B.D. and Lloyd, D.T. (1981). Late Quaternary glacial deposits, soils, and chronology, Hell Roaring Valley, Mt. Adams, Cascade Range, Washington. *Arctic and Alpine Research*, **13**, 339–356.
Mathews, R.W., Borden, C.E. and Rouse, G.E. (1972). New radiocarbon dates from the Yale area of the lower Fraser River canyon, British Columbia. *Canadian Journal of Earth Sciences*, **9**, 1055–1057.
Mathews, R.W. and Heusser, L.E. (1981). A 12,000 year palynological record of temperature and precipitation trends in southwestern British Columbia. *Canadian Journal of Botany*, **59**, 707–710.
Mathews, R.W. and Rouse, G.E. (1975). Palynology and paleoecology of postglacial sediments from the lower Fraser canyon of British Columbia. *Canadian Journal of Earth Sciences*, **12**, 745–756.
Miller, C.D. (1969). Chronology of Neoglacial moraines in the Dome Peak area, North Cascade Range, Washington. *Arctic and Alpine Research*, **1**, 49–66.
Molenaar, D. (1965). Geology and ground-water resources. *In*: *Water resources and geology of the Kitsap Peninsula and certain adjacent islands*, Washington Division of Water Resources, Water-Supply Bulletin 18, pp. 24–50.
Molenaar, D. and Noble, J.B. (1970). Geology and related ground water occurrences, southeastern Mason, County, Washington. Washington *Division of Water Resources Water-Supply Bulletin*, **29**, 38 pp.
Moore, J.L. (1965). Surficial geology of the southwestern Olympic Peninsula. MSc Thesis, University of Washington, Seattle, Washington, 63 pp.
Mullineaux, D.R. (1970). Geology of the Renton, Auburn, and Black Diamond Quadrangles, King County, Washington. *U.S. Geological Survey Professional Paper*, **672**, 92 pp.
Mullineaux, D.R., Waldron, H.H. and Rubin, M. (1965). Strati-

graphy and chronology of late interglacial and early Vashon time in the Seattle area, Washington. *U.S. Geological Survey Bulletin*, **1194-0**, 1–10.

Naeser, N., Westgate, J.A., Easterbrook, D.J. and Carson, R. (1984). Pre-0.89 m.y. glaciation in the west central Puget Lowland, Washington. *Geological Society of America Abstracts with Program*, **16**, 324.

Nafziger, R.H. (1974). The geology of Mt. Thielson: from Pliocene to present. *The Geological Newsletter*, 73–75.

Newcomb, R.C. (1952). Ground-water resources of Snohomish County, Washington. *U.S. Geological Survey Water Supply Paper*, **1135**, 1–133.

Noble, J.B. and Wallace, E.F. (1966). Geology and ground-water resources of Thurston County, Washington. *Washington State Division of Water REsources, Water Supply Bulletin*, **10**, 1–61.

Othberg, K.L. (1973). Paleomagnetism of late Pleistocene sediments, Puget Lowland, Washington. MSc Thesis, Western Washington University, Bellingham, Washington. 54 pp.

Page, B.P. (1939). Multiple glaciation in the Leavenworth area, Washington. *Journal of Geology*, **47**, 785–815.

Pessl, F., *et al.* (1981). Sedimentary facies and depositional environments of late Wisconsin glacial-marine deposits in the central Puget Lowland, Washington. *American Association of Petroleum Geologists Abstracts*, San Francisco.

Petersen, K.L., Mehringer, P.J. and Gustafson, C.E. (1983). Late glacial vegetation and climate at the Manis Mastodon site, Olympic Peninsula, Washington. *Quaternary Research*, **20**, 215–231.

Pine, K. (1985). Glacial geology of the Tonasket-Spectacle Lake area, Okanogan County, Washington. MSc Thesis, Western Washington University, Bellingham, Washington, 131 pp.

Porter, S.C. (1975). Weathering rinds as a relative-age criterion: Application to subdivision of glacial deposits in the Cascade Range. *Geology*, **3**, 101–104.

Porter, S.C. (1976). Pleistocene glaciations in southern part of the North Cascade Range, Washington. *Geological Society of America Bulletin*, **87**, 61–75.

Porter, S.C. (1978). Glacier Peak tephra in the North Cascade Range, Washington: stratigraphy, distribution, and relationships to late-glacial events. *Quaternary Research*, **10**, 30–41.

Porter, S.C. and Carson, R.J. (1971). Problems of interpreting radiocarbon dates from dead-ice terrain with an example from the Puget Lowland of Washington. *Quaternary Research*, **1**, 410–414.

Porter, S.C. and Dentoin, G.H. (1967). Chronology of Neoglaciation in the North American Cordillera. *American Journal of Science*, **265**, 177–210.

Reagan, A.B. (1909). Some notes on the Olympic Peninsula, Washington. *Kansas Academy of Science Transactions*, **22**, 131–238.

Rigg, G.B. and Gould, H.R. (1957). Age of Glacier Peak eruption and chronology of postglacial peat deposits in Washington and surrounding areas. *America Journal of Science*, **255**, 341–363.

Roland, J. (1984). A paleomagnetic age determination of pre-Salmon Springs drift Pleistocene deposits in the southern Puget Lowland, Washington. *Geological Society of America Abstracts with Programs*, **16**, 330.

Rollins, A. (1976). Geology of the Bachelor Mountain area, Linn and Marion Counties, Oregon. MSc Thesis, Oregon State University, Corvallis, Oregon, 83 pp.

Sceva, J.E. (1957). Geology and groundwater resources of Kitsap County, Washington. *U.S. Geological Survey Water Supply Paper*, **1413**.

Scott, W.E. (1977). Quaternary glaciation and volcanism, Metolius River area, Oregon. *Geological Society of America Bulletin*, **88**, 113–124.

Sharp, R.P. (1960). Pleistocene glaciation in the Trinity Alps of northern California. *American Journal of Science*, **258**, 305–340.

Sigafoos, R.S. and Hendricks, E.L. (1972). Recent activity of glaciers of Mount Rainier, Washington. *U.S. Geological Survey Professional Paper*, **387-B**, pp. B1–B24.

Stoffel, K.L. (1980). Stratigraphy of pre-Vashon Quaternary sediments applied to the evaluation of a proposed major tectonic structure in Island County, Washington. *U.S. Geological Survey Open File Report*, **81-292**, 161 pp.

Stuiver, M., Heusser, C.T. and Yang, I.C. (1978). North American glacial history back to 75,000 years B.P. *Science*, **200**, 16–21.

Swanson, F.J. and James, M.E. (1975). Geomorphic history of the lower Blue River–Lookout Creek area, western Cascades. *Northwest Science*, **49**, 1–11.

Tabor, R.W., *et al.* (1982). Geologic map of the Wenatchee 1:100,000 quadrangle, central, Washington. *U.S. Geological Survey Miscellaneous Investigation Series*, Map I-1311, 26 pp.

Taylor, E.M. (1968). Roadside geology, Santiam and McKenzie Pass Highways, Oregon. *Oregon Department of Geology and Mineral Industries Bulletin*, **62**, 3–33.

Taylor, E.M. (1979). Central High Cascade roadside geology, Bend, Sisters, McKenzie Pass, and Santiam Pass, Oregon. *Field Trip Guide, American Geophysical Union*, Bend, Oregon.

Thayer, T.P. (1939). Geology of the Salem Hills and the north Santiam River Basin, Oregon. *Oregon Department of Geology and Mineral Industries Bulletin*, **15**, 40 pp.

Waitt, R.B. (1977). Guidebook to Quaternary geology of the Columbia, Wenatchee, Pechastin, and upper Yakima Valleys, west-central Washington. *U.S. Geological Survey Open File Report*, **77-753**, 25 pp.

Waitt, R.B. (1979). Late Cenozoic deposits, landforms, stratigraphy, and tectonism in Kittitas Valley, Washington. *U.S. Geological Survey Professional Paper*, **1127**, 18 pp.

Waitt, R.B. and Thorson, R.M. (1983). The Cordilleran ice sheet in Washington, Idaho, and Montana. *In*: Porter, S.C. (ed.) *Late Quaternary Environments of the U.S.*, Vol. 1, *The Late Pleistocene*, pp. 53–70. University of Minnesota Press, Minneapolis, Minnesota.

Waitt, R.B., Yount, J.C. and Davis, P.T. (1982). Regional significance of an early Holocene moraine in Enchantment Lakes Basin, North Cascade Range, Washington. *Quaternary Research*, **17**, 191–210.

Waldron, H.H. (1961). Geology of the Poverty Bay quadrangle, Washington. *U.S. Geological Survey*, Geologic Quadrangle Map, GQ-158.

Waldron, H.H. (1962). Geology of the Des Moines quadrangle, Washington. *U.S. Geological Survey*, Geologic Quadrangle Map, GQ-159.

Walker, G.W. and Greene, R.C. (1966). Mineral resources of the Mt. Jefferson Primitive Area, Oregon. *U.S. Geological Survey Bulletin*, **1230-D**.

Westgate, J.A., Easterbrook, D.J., Naeser, N. and Carson, R.J. (in press). Lake Tapps tephra: an early Pleistocene stratigraphic marker in the Puget Lowland, Washington.

Williams, H. (1942). The geology of Crater Lake National Park, Oregon, with a reconnaissance of the Cascade Range southward to Mt. Shasta. *Carnegie Institute Publication*, **540**, 162 pp.

Williams, H. (1949). Geology of the MacDoel Quadrangle, California. *California Division of Mines Bulletin*, **151**, 7–60.

Willis, B. (1898). Drift phenomena of Puget Sound. *Geological Society of America Bulletin*, **9**, 111–162.

Wise, W.S. (1969). Geology and petrology of the Mt. Hood area: a study of high Cascade volcanism. *Geological Society of America Bulletin*, **80**, 969–1006.

Yount, J.C., Marcus, K.L. and Mozley, P.S. (1980). Radiocarbon-dated localities from the Puget Lowland, Washington. *U.S. Geological Survey Open File Report*, **80-780**, 51 pp.