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R. J. Fulton

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R. J. Fulton

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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## ABSTRACT

The radiocarbon-dated Quaternary history of southern British Columbia extends over the past 52,000 years. This interval has been subdivided into 3 major geologic-climate units: Olympia Interglaciation, Fraser Glaciation, and Postglacial.

In southern British Columbia the Olympia Interglaciation began more than 52,000 years ago and ended about 19,000 years B.P. Meagre information available from the west coast suggests that the climate during this period was cool and damp but probably not too different from present. Bison and Equus bones collected from deposits of this age in the interior of British Columbia indicate that the climate was such that it could support large herbivorous animals. The Olympia Interglaciation sedimentary framework, the processes active and the deposits formed, were similar to those of the same area at present. Three major depositional cycles have been recognized: (1) an early period of deposition at base levels higher than present, (2) a period of low base levels, and (3) a late episode of deposition at base levels above those of present day.

Fraser Glaciation ice did not occupy the lowlands of southern British Columbia until later than 19,000 years ago, but probably began to build-up in the mountainous areas before that time. Parts of the west coast were ice free about 13,000 years ago and all of southern British Columbia was probably as free of ice as at present by 10,000 years B.P.

From the time of deglaciation to about 8,000 years ago, isostatic movements tended to control local sea level and to mask eustatic changes. The apparent sea levels were high, due to isostatic depression at the time of Fraser deglaciation. Isostatic adjustments caused local sea levels to fall during deglaciation, rise again about 11,000 years ago and fall below the present level about 8,000 years B.P. At that time, it appears that approximate isostatic equilibrium was achieved and the later sea level history is largely one of changes in response to worldwide eustatic fluctuations.

The Postglacial record of southern British Columbia includes four dated ash falls: (1) Mazama, about 6,600 years B.P., (2) St. Helens Y, about 3,300 years B.P., (3) Bridge River, about 2,400 years B.P., and (4) St. Helens W (?), later than 1,200 years B.P. The climate was cold 12,000 years ago, but it warmed sufficiently to be similar to the present when most of southern British Columbia was deglaciated. A thermal maximum about 6,000 years ago was followed by a cooler period which persisted until present. Glacial advances took place 3,000 to 2,500 years ago and in the past few centuries. During this most recent advance, the alpine glaciers of southern British Columbia were more extensive than at any time since the end of Fraser Glaciation about 10,000 years ago.

## RÉSUMÉ

La chronologie du Quaternaire en Colombie-Britannique méridionale, telle qu'établie au radiocarbone, remonte à 52, 000 ans. Ce temps a été divisé en trois périodes géologiques et climatiques: l'interglaciaire d'Olympia, la glaciation de Fraser et la période postglaciaire.

Dans le sud de la Colombie-Britannique, l'interglaciaire d'Olympia a commencé il y a 52, 000 ans et s'est terminé il y a environ 19, 000 ans (B. P.).

Le peu de renseignements obtenus par l'étude de la côte ouest laisse supposer que le climat au cours de cette période était frais et humide mais probablement sans être bien différent du climat actuel. La mise à jour dans l'intérieur de la Colombie-Britannique d'ossements de bisons et d'équidés datant de cette époque révèle que le climat permettait aux grands herbivores d'y vivre. La structure sédimentaire, les transformations et les dépôts au cours de l'interglaciaire d'Olympia étaient semblables à ceux de la région actuelle. On distingue trois principaux cycles de dépôts: 1) une période ancienne de dépôts à des niveaux de base supérieurs au palier actuel, 2) une période de dépôts à des niveaux inférieurs er 3) une période plus récente de dépôts à des niveaux de base plus élevés que ceux d'aujourd'hui.

Les glaces de la glaciation de Fraser n'ont envahi les basses-terres du sud de la province qu'il y a 19,000 ans, mais elles s'étaient probablement accumulées dans les montagnes antérieurement à cette époque. Certains secteurs de la côte ouest étaient libres de glaces il y a 13,000 ans et vers 10,000 and (B.P.) la Colombie-Britannique méridionale était probablement entièrement libérée et telle qu'elle apparaît à notre époque.

Du retrait des glaces jusqu'aux environs de 8,000 ans, les mouvements isostatiques ont eu tendence à contrôler le niveau de la mer à l'échelle locale et à masquer l'évolution eustatique. Le niveau apparent de la mer était assez élevé en raison d'une dépression isostatique lors du recul de la glaciation de Fraser. Le rétablissement isostatique a occasionné une baisse locale du niveau de la mer au cours du recul glaciaire, puis une hausse il y a 11,000 ans et une baisse au niveau actuel vers 8,000 ans (B.P.). A cette époque, il semble qu'un certain équilibre isostatique se soit manifesté; depuis lors, les fluctuations du niveau de la mer dépendent de celles du niveau eustatique mondial.

La chronologie postglaciaire de la Colombie-Britannique méridionale comprend quatre chutes de cendres de dates connues: 1) la chute de Mazama, il y a environ 6,600 ans (B.P.), 2) de St-Helens Y, il y a environ 3,300 ans (B.P.), 3) de Bridge River, vers 2,400 ans (B.P.) et 4) de St-Helens W (?), postérieure à 1,200 ans (B.P.). Le climat était froid il y a 12,000 ans, mais il s'est réchauffé suffisamment après le retrait des glaces du sud de la Colombie-Britannique pour ressembler au climat actuel. Une température maximum vers 6,000 ans a été suivie d'une période plus fraîche qui se poursuit actuellement. Des avancées glaciaires ont eu lieu entre 3,000 et 2,500 ans (B.P.) et depuis quelques siècles. Au cours de l'avancée la plus récente. les glaciers alpins de la Colombie-Britannique méridionale étaient plus vastes qu'à aucun temps depuis la fin de la glaciation de Fraser il y a environ 10,000 ans.

# RADIOCARBON GEOCHRONOLOGY OF SOUTHERN BRITISH COLUMBIA

## INTRODUCTION

This paper consists of a chronology of the last 52,000 years of the Quaternary of southern British Columbia and a compilation of most published radiocarbon dates of geologic significance. Much of this chronology is based on work published by a number of people over the past twenty years and the reader is referred to the original papers listed as references for specific details.

The radiocarbon-dated history of southern British Columbia covers the last 52,000 years. This period has been subdivided into three major geologic-climate units, Olympia Interglaciation, Fraser Glaciation and Postglacial (Fig. 1). The radiocarbon dates have been tabulated as related groups associated with each of these major units. Where possible, a bibliographic source is given for each date (generally in Radiocarbon) and credit is given to the original collector. All ages mentioned in this paper are in radiocarbon years based on the original ("Libby") half life of 5,568 ± 30 years or 5,570 years.

## DATES BEYOND RADIOCARBON RANGE

The distribution of radiocarbon dates which are beyond dating range is shown on Figure 2 and the dates are tabulated in Table I. In interpreting these dates, one must be careful not to use the number other than as a minimum date. The time-stratigraphic significance of an infinite date is very heavily dependent on the stratigraphic interpretation made of the sample collection site.

It appears that the majority of infinite dates listed come from deposits of the last nonglacial period, as the dated horizon generally is overlain by no more than one till. This in itself is not proof that the samples formed during the last nonglacial as ice sheets do not leave a till cover on all older deposits. In the Interior System*, however, surface till is the only till present in all but a few exposures and, where older glacial materials are found, they are generally separated from deposits of the last Glaciation by a thick sequence of nonglacial strata. If the glacial deposits found at the surface of an individual exposure were laid down during a glaciation other than the last, one would expect to find some supporting evidence in the generally excellent exposures.

The majority of listed dates that are beyond radiocarbon dating range come from the vicinity of the Strait of Georgia. Several of these are from below two tills, but most were collected from below only one till. Many of the dates from below one till can probably be assigned to the Olympia

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*Physiographic names in this report are those used by Holland (1964, Fig. 1).

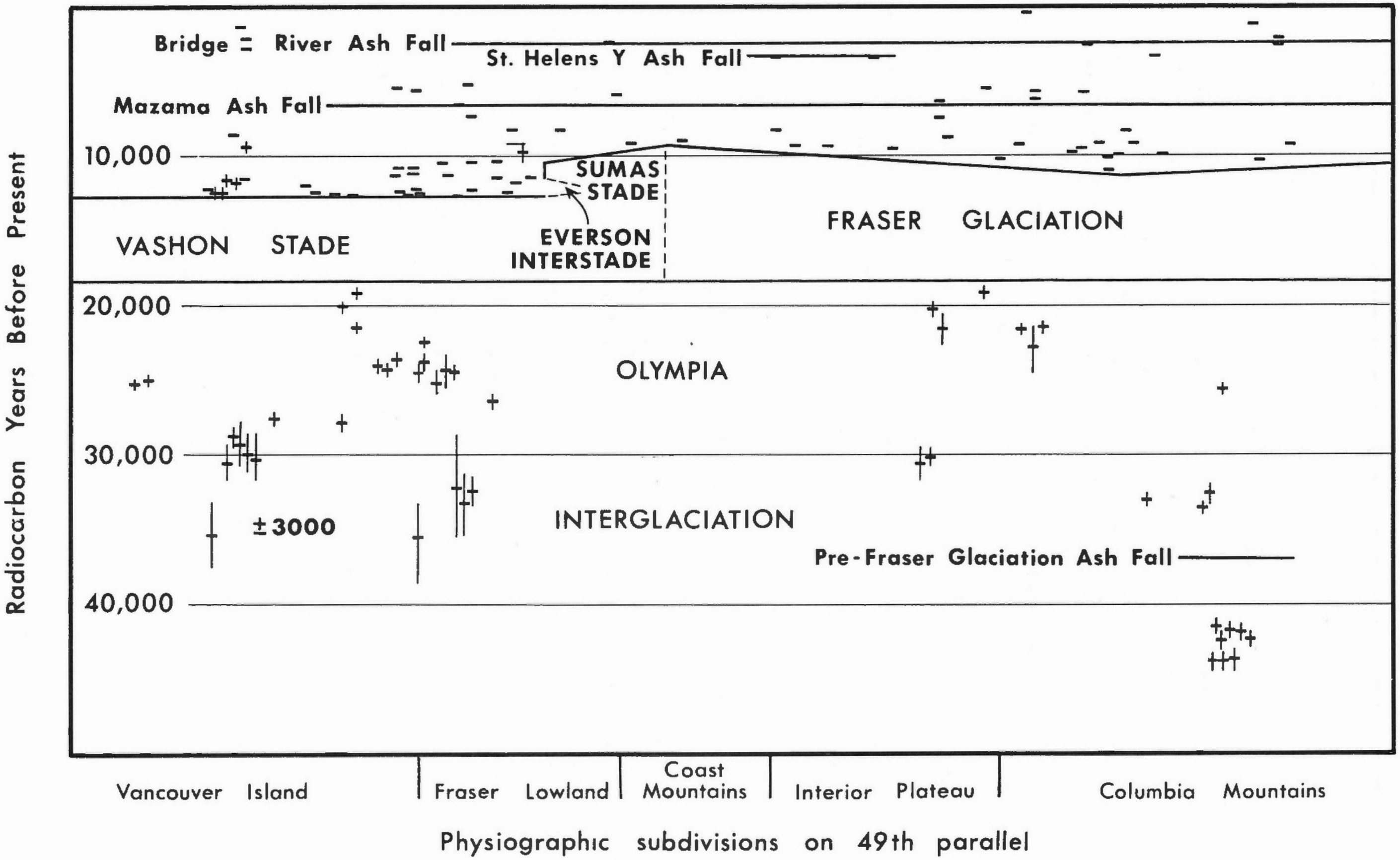

Figure 1. Time-stratigraphic framework of southern British Columbia with finite radiocarbon dates plotted against position as projected to the 49th parallel - date with error less than ± 200 years (vertical line shows the range of the date and error).

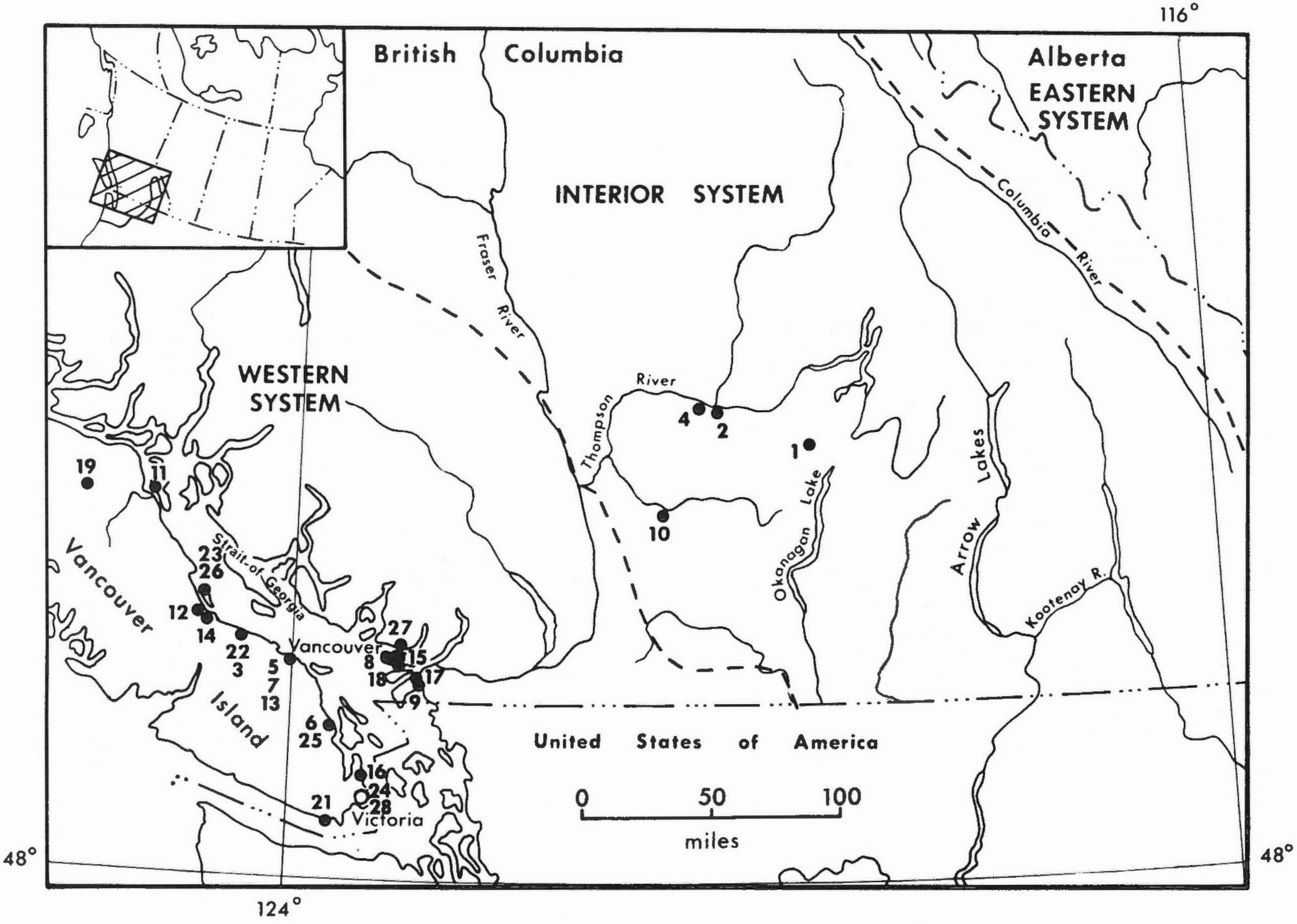

Figure 2. Distribution of localities containing organic material beyond the range of radiocarbon dating. Numbers refer to dates listed in Table I.

## TABLE I

Dates on organic materials beyond radiocarbon dating range

| Site No. Fig. 2 | Laboratory Dating No. | Date | Location | | Published | | Collector | Comments | Material |
|---|---|---|---|---|---|---|---|---|---|
| | | | Lat. N. | Long. W. | Radiocarbon Volume No. | Page | | | |
| 1 | GSC-479 | >22,200 | 50°26'15" | 119°27'30" | 9 | 172 | R.J. Fulton | in soil under Fraser till | charcoal |
| 2 | GSC-275 | >32,700 | 50°39'45" | 120°19'40" | 8 | 109 | R.J. Fulton | sediment under Fraser till | wood |
| 3 | L-475B | >35,000 | 49°22' | 124°31' | 3 | 148 | J.G. Fyles | stony clay; base of Quadra | marine shells |
| 4 | GSC-413 | >35,500 | 50°41'20" | 120°26'30" | 8 | 109 | R.J. Fulton | presumed Interglacial sed. | freshwater shells |
| 5 | GSC-98 | >36,200 | 49°14'30" | 124°00'30" | 6 | 171 | J.G. Fyles | overlain by one till | peat |
| 6 | GSC-153 | >36,500 | 48°52'30" | 123°38'40" | 6 | 172 | E.C. Halstead | overlain by Vashon till | wood |
| 7 | GSC-196 | >36,550 | 49°14'30" | 124°00'30" | 7 | 37 | E.C. Halstead | upper intertill series | peat |
| 8 | GSC-81 | >36,800 | 49°15' | 123°11' | 5 | 48 | J.E. Armstrong | base of Quadra Sediments | peat |
| 9 | GSC-60 | >37,000 | 49°07' | 122°54' | 5 | 47 | J.E. Armstrong | overlain by one till | wood |
| 10 | GSC-258 | >37,200 | 50°04'55" | 120°48'15" | 7 | 34 | R.J. Fulton | overlain by one till | freshwater shells |
| 11 | GSC-52 | >37,200 | 50°07'40" | 125°18'30" | 4 | 19 | J.G. Fyles | overlain by one till | wood |
| 12 | GSC-78 | >37,600 | 49°28'25" | 124°50'00" | 5 | 50 | J.G. Fyles | overlain by one till | peat |
| 13 | GSC-155 | >37,600 | 49°14'30" | 124°00'30" | 6 | 171 | E.C. Halstead | overlain by two tills | peat |
| 14 | GSC-99 | >37,900 | 49°27' | 124°45' | 5 | 50 | J.G. Fyles | from Quadra Sediments | wood |
| 15 | GSC-36 | >38,100 | 49°15' | 123°06' | 5 | 48 | J.E. Armstrong | overlain by Vashon till | wood |
| 16 | GSC-94 | >38,400 | 48°34' | 123°22' | 5 | 51 | J.G. Fyles | overlain by one till | wood |
| 17 | GSC-62 | >39,000 | 49°10' | 122°55' | 5 | 47 | J.E. Armstrong | under one till, possibly predate Quadra | wood |
| 18 | GSC-396 | >40,000 | 49°12'15" | 123°05'30" | 8 | 111 | W.L. Brown | overlain by Vashon till | wood |
| 19 | GSC-30 | >40,000 | 50°15' | 125°48' | 4 | 19 | J.G. Fyles | overlain by one till | wood |
| 20 | GSC-851 | >40,000 | 53°00' | 122°31' | 10 | 228 | J.E. Armstrong | from till overlying Tertiary | wood |
| 21 | GSC-358 | >40,300 | 48°21'28" | 123°44'48" | 8 | 112 | E.C. Halstead | overlain by one till | peat |
| 22 | GSC-207 | >40,500 | 49°22' | 124°31' | 7 | 37 | J.G. Fyles | stony clay overlain by Quadra sediment | marine shells |
| 23 | L-475A | >41,500 | 49°36' | 124'29' | 3 | 147 | J.G. Fyles | stony clay; base of Quadra | marine shells |
| 24 | L-514C | >42,000 | 48°34' | 123°22' | 3 | 148 | J.G. Fyles | stony clay; base of Quadra | wood |
| 25 | GSC-163-2 | >47,400 | 48°52'30" | 123°38'40" | 8 | 111 | E.C. Halstead | overlain by Vashon till | peat |
| 26 | GSC-277 | >49,000 | 49°35'36" | 124°49'18" | 8 | 112 | J.G. Fyles | stony clay; base of Quadra | marine shells |
| 28 | GSC-94-2 | >51,000 | 48°34' | 123°22' | unpublished | | J.G. Fyles | overlain by one till | wood |
| 27 | GSC-555 | >52,300 | 49°18' | 123°03' | 9 | 173 | J.E. Armstrong | overlain by two tills | wood |

GSC - Geological Survey of Canada
L - Lamont Geological Observatory
I - Isotopes - A Teledyne Company
S - Saskatchewan, Department of Chemistry, Saskatoon

Interglacial geologic-climate unit as the dated sediments lie with apparent conformity or without intervening glacial deposits below deposits which contain organic material of finite Olympia Interglaciation radiocarbon age (Fyles, 1963, p. 38; Dyck et al., 1965, p. 37).

## OLYMPIA INTERGLACIATION

The Olympia Interglaciation is defined as the "climatic episode immediately preceeding the last major glaciation" (Armstrong et al., 1965, p. 324). Extensive deposits of this interval lie on either side of the Strait of Georgia and scattered dated occurrences of Olympia deposits have been reported from major valleys of the Interior System. Figure 3 shows the distribution of localities from which the finite Olympia Interglaciation dates listed in Table II were collected.

### Interior System

Finite radiocarbon dates from nonglacial deposits older than Fraser Glaciation in the Interior System range from 43,800 ± 800 to 19,100 ± 240 years B.P. (GSC-740 and GSC-913, Table II, Fulton, 1968 and Smith, 1969). About all that can be said about the climate of this interval is that, for at least part of the time, it was warm and humid enough for the area to be forested (Fulton, 1965a, p. 99) and to support large vertebrates such as: Bison sp. and Equus cf. conversidens (C.R. Harrington and C.C. Churcher, personal communication). The geomorphic framework during this period was roughly similar to that at present, with large valleys filled in part by sediments and in part by lakes, set between hilly upland or mountain blocks. The sedimentation pattern was complex, as it is at present, with streams and rivers pushing fans and deltas into the main valleys and lake basins. The main valleys acted as channels for the advancing Fraser Glaciation ice so that much of the older sediment was removed. During deglaciation, major glacial lakes formed in many valleys so that the older deposits which remained were buried under thick covers of silt (Fulton, 1965b). The irregular erosion combined with later burial has rendered scarce exposures of sediments predating Fraser Glaciation in the Interior System and hence details of sedimentation and drainage are not well known.

With one exception, single exposures proven to span long intervals have not been found. The exception is in the Purcell Trench where a nonglacial radiocarbon-dated sequence extends from 25,840 ± 320 to 43,800 ± 800 years B. P. (Fulton, 1968, GSC-715 and GSC-740, Table II). Elsewhere, single dates from exposures are either infinite (Fig. 2 and Table I) or fall in the 19,000 to 23,000 years B. P. interval. This time distribution of dated deposits suggests that the Olympia Interglaciation contained two main periods during which base level was as high or higher than present base level. The first of these was more than 37,200 years ago (GSC-258, Table I); the second occurred from about 22, 900 ± 1,500 radiocarbon years ago (I-773, Table II) until advance of Fraser Glaciation ice. During the time between these two intervals, streams probably dissected their earlier deposits and continued sediment deposition in lake basins. However, as these deposits formed below present base level, drilling or excavation are the only ways we can locate these sediments today. Evidence of this succession can be seen

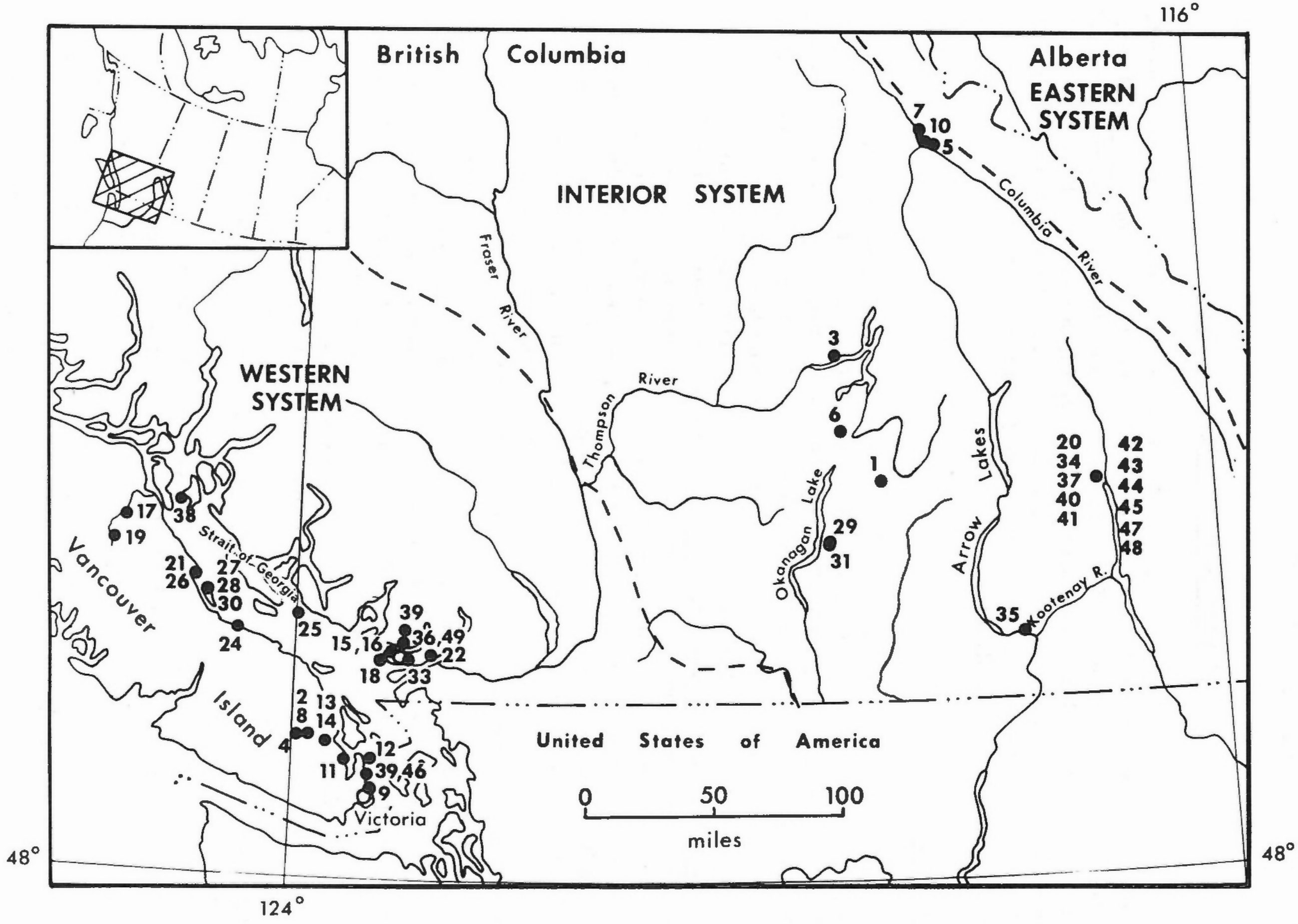

Figure 3. Distribution of radiocarbon dates of Olympia Interglacial age. Numbers refer to dates listed in Table II.

## TABLE II

Radiocarbon dates pertaining to Olympia Interglaciation

| Site No. Fig. 3 | Laboratory Dating No. | Date | Location | | Published | | Collector | Material |
|---|---|---|---|---|---|---|---|---|
| | | | Lat. N. | Long. W. | Radiocarbon Volume No. | Page | | |
| 1 | GSC-913 | 19,100±240 | 50°18' | 118°51' | 12 | 72 | G.W. Smith | plant detritus |
| 2 | GSC-210 | 19,150±250 | 48°46'36" | 123°53'36" | 7 | 36 | E.C. Halstead | organic silt |
| 3 | GSC-194 | 20,230±270 | 50°56'10" | 119°24'15" | 7 | 33 | R.J. Fulton | wood |
| 4 | GSC-195 | 21,070±290 | 48°46'30" | 123°56'50" | 7 | 36 | E.C. Halstead | wood |
| 5 | GSC-173 | 21,500±300 | 52°06' | 118°23' | 7 | 32 | H.W. Nasmith | wood |
| 6 | GSC-477 | 21,630±870 | 50°37'30" | 119°11'50" | 9 | 172 | R.J. Fulton | wood |
| 7 | GSC-1258 | 21,700±240 | 52°11'40" | 118°27'23" | 13 | - | R.A. Achard | wood |
| 8 | GSC-317 | 21,730±230 | 48°46'43" | 123°53'36" | 8 | 111 | E.C. Halstead | wood |
| 9 | GSC-84 | 22,600±300 | 48°29'40" | 123°19'10" | 5 | 50 | J.G. Fyles | plant fibers |
| 10 | 1-773 | 22,900±1500 | 52°07' | 118°24' | 8 | 175 | F. Mylrea | wood |
| 11 | GSC-518 | 23,840±300 | 48°37' | 123°31' | 9 | 173 | E.C. Halstead | wood |
| 12 | GSC-59 | 23,920±420 | 48°38'40" | 123°19'40" | 5 | 51 | J.G. Fyles | wood |
| 13 | GSC-318 | 24,060±300 | 48°45'22" | 123°40'15" | 8 | 111 | E.C. Halstead | peat |
| 14 | GSC-385 | 24,380±350 | 48°45'22" | 123°40'15" | 8 | 111 | E.C. Halstead | peat |
| 15 | L-502 | 24,400±900 | 49°17' | 123°13' | 3 | 148 | J.E. Armstrong | wood |
| 16 | GSC-108 | 24,500±500 | 49°17' | 123°13' | 5 | 47 | J.E. Armstrong | wood |
| 46 | I-1225 | 24,560±800 | 48°34' | 123°22' | unpublished | | E.C. Halstead | wood |
| 17 | GSC-58 | 25,000±400 | 49°56'50" | 125°35'50" | 5 | 48 | J.G. Fyles | wood |
| 18 | GSC-109 | 25,100±600 | 49°16' | 123°15' | 5 | 48 | J.E. Armstrong | peat |
| 19 | GSC-96 | 25,190±470 | 49°51'05" | 125°37'20" | 5 | 49 | J.G. Fyles | wood |
| 20 | GSC-715 | 25,840±320 | 50°15' | 116°59' | 10 | 225 | R.J. Fulton | wood |
| 21 | GSC-53 | 26,100±400 | 49°40'10" | 124°53'50" | 5 | 49 | J.G. Fyles | wood |
| 22 | GSC-124 | 26,450±520 | 49°14' | 122°47' | 6 | 171 | J.E. Armstrong | peaty silt |
| 23 | GSC-536 | 27,180±460 | 49°14' | 122°47' | 9 | 173 | J.E. Armstrong | wood |
| 24 | GSC-263 | 27,670±410 | 49°22' | 124°31' | 7 | 37 | J.G. Fyles | peat |
| 25 | GSC-232 | 27,960±420 | 49°22'40" | 123°59'30" | 7 | 37 | R.J. Mott | wood |
| 26 | GSC-95 | 28,800±740 | 49°40'10" | 124°53'50" | 5 | 49 | J.G. Fyles | wood |
| 27 | L-424C | 29,300±1400 | 49°36' | 124°49' | 1 | 10 | J.G. Fyles | wood |
| 28 | L-424E | 30,000±1200 | 49°36' | 124°49' | 1 | 11 | J.G. Fyles | wood |
| 29 | GSC-563 | 30,180±530 | 49°54'45" | 119°20'30" | 12 | 73 | E. Livingston | wood |
| 30 | L-424B | 30,200±1300 | 49°36' | 124°49' | 1 | 10 | J.G. Fyles | peat |
| 31 | GSC-1005 | 30,700±1090 | 49°53'30" | 119°24'30" | 12 | 73 | E. Livingston | wood |
| 32 | I(GSC)-214 | 32,200±3300 | 49°19' | 123°03' | 4 | 35 | J.E. Armstrong | peat |
| 33 | GSC-221 | 32,580±720 | 49°14'30" | 123°01'15" | 7 | 35 | J.E. Armstrong | wood |
| 34 | GSC-493 | 32,710±800 | 50°15' | 116°59' | 10 | 224 | R.J. Fulton | wood |
| 35 | GSC-1008 | 33,000±280 | 49°21'00" | 117°44'50" | 12 | 70 | R.J. Fulton | charcoal |
| 36 | GSC-93* | 33,200±2300<br>±1800 | 49°21' | 123°02' | 5 | 48 | J.E. Armstrong | wood |
| 37 | GSC-542 | 33,700±300 | 50°15' | 116°59' | 10 | 224 | R.J. Fulton | wood |
| 38 | L-455B | 35,400±2200 | 50°05' | 125°02' | 3 | 147 | J.G. Fyles | wood |
| 39 | GSC-200 | 35,600±3000 | 48°34' | 123°22' | 7 | 36 | J.G. Fyles | soil |
| 49 | GSC-93* | 36,200±2200<br>± 500 | 49°21' | 123°02' | 7 | 26 | J.E. Armstrong | wood |
| 40 | GSC-1017 | 41,500±520 | 50°15' | 116°59' | 12 | 70 | R.J. Fulton | peat |
| 41 | GSC-716 | 41,800±600 | 50°15' | 116°59' | 10 | 224 | R.J. Fulton | wood |
| 42 | GSC-733 | 41,900±600 | 50°15' | 116°59' | 10 | 224 | R.J. Fulton | wood |
| 43 | GSC-1015 | 42,300±650 | 50°15' | 116°59' | 12 | 70 | R.J. Fulton | plant fragments |
| 44 | GSC-720 | 42,300±700 | 50°15' | 116°15' | 10 | 224 | R.J. Fulton | peat |
| 47 | GSC-740-2 | 43,000±600 | 51°15' | 116°59' | 13 | - | R.J. Fulton | wood |
| 48 | GSC-1017-2 | 43,600±700 | 51°15' | 116°59' | 13 | - | R.J. Fulton | peat |
| 45 | GSC-740 | 43,800±800 | 50°15' | 116°59' | 10 | 224 | R.J. Fulton | wood |

*GSC-93 was dated twice. The older date was obtained in the 5L counter and is the more reliable.

in the sedimentary record at two places in the Interior System (Fulton, 1965a, pp. 89-93 and pp. 98-100) where oxidized nonglacial sediments containing organic material beyond radiocarbon dating range are unconformably overlain by unoxidized sediments presumed to have been deposited shortly before Fraser ice advance.

Three sample dates from the Interior System fall between the two periods of high base level. Two of the samples, from a former lake basin fill, were obtained by drilling below present base level (30,180 ± 530 and 30,700 ± 1,090 years B.P., GSC-563 and GSC-1005, Table II). The third sample (33,000 ± 280 years B.P., GSC-1008, Table II) came from a paleosol and therefore deposition did not necessarily bear a definite relationship to the base level of that time.

The youngest pre-Fraser Glaciation date from the Interior System (19,100 ± 240, GSC-913, Table II) is from the contact between a succession of flood plain sediments and an overlying, sterile, regularly laminated grey silt on Bessette Creek south of Mabel Lake (Smith, 1969, p. 54). Smith does not provide an explanation for the sudden change from flood plain deposition to stable lake sedimentation ("Information necessary to deduce the cause of the change from fluvial to lacustrine conditions is not provided by the available exposure", Smith, 1969, p. 57). Mullineaux et al. (1965) describe an almost identical succession from an exposure in the Puget Lowland. Their lower unit is interpreted as being "deposited in a nonglacial environment of flood plains and shallow lakes". They interpret the thinly laminated clay and silt unit as "having been deposited rapidly in a relatively stable lacustrine environment" and say that the lake probably formed when Fraser Glaciation ice advance blocked regional drainage (Mullineaux et al., 1965, pp.
If this explanation is adopted for the rapid change from flood plain to lacustrine environment deposits in the Bessette Creek section, 19,100 ± 240 is a moderately accurate date for the end of Olympia Interglaciation in the Interior Plateau.

## Strait of Georgia Region

In originally defining Olympia Interglaciation in the coastal area, finite radiocarbon dates were cited to indicate that the nonglacial period lasted from before 36,200 until after 19,150 years ago (Armstrong et al., 1965). It seems reasonable, however, to extend Olympia Interglaciation time to at least 51,000 years B.P. (GSC-94-2, Table I) by including the basal "Quadra sediments" unit of Fyles (1963) in the Olympia Interglaciation. Fyles says that "Quadra sediments" were deposited during the last nonglacial period (defined as Olympia Interglaciation, Armstrong et al., 1965). Fyles (1963, pp. 20, 28 and 33) divides "Quadra sediments" into three units: a lower basal clay unit which "appears to record the transition from glacial to marine conditions"; a middle plant-bearing silt-gravel unit which could have accumulated "either in the channels, flood plains, and back-swamps of a river plain, or in dunes, lagoons and marshes along a shelving shoreline"; and an upper sand unit which "is a fluvial plain deposit". This succession appears to be an ideal interglacial sequence which begins with a deposit formed as ice retreated from an isostatically depressed basin, progressed into a swampy coastal plain situation and ended with an influx of coarser fluvial sediments burying the older deposits. Fyles (1963, p. 38 and in Dyck et al., 1965, p. 37) and Armstrong et al. (1965, p. 326) question the inclusion of the lowest

"Quadra sediments" unit of Vancouver Island in the Olympia Interglaciation because radiocarbon dates from this unit, so far, have all been infinite (see Table I), whereas those from the overlying unit have all been finite. However, as Fyles (1963, p. 22) states that the contact between upper "Quadra sediments" units and the lower is, in places, gradational and as glacial deposits have nowhere been described as occurring between the lower and upper units of the "Quadra sediments", it is assumed that all three "Quadra sediments" units were deposited during the same nonglacial period.

Little published information is available on climatic interpretation of the Olympia Interglaciation in the coastal area. Fyles (1963, p. 37) says that at least part of the region was forested and that the climate during part of the interval was probably cool or temperate. Easterbrook (1969, p. 2279), writing about Whitby Island to the south, says that pollen analysis of peat beds deposited between 27,200 and 22,700 years ago indicates a cool moist climate.

The youngest pre-Fraser Glaciation date from the Strait of Georgia region (19,150 ± 250, GSC-210, Table II) comes from the Cowichan River valley near the south end of Vancouver Island. Halstead (in Dyck et al., 1965, p. 36 and 1966, p. 111) correlates the enclosing deposits with "Quadra sediments".

## FRASER GLACIATION

Fraser is the name given to the last major glaciation in British Columbia (Armstrong et al., 1965). In the Puget Lowland and Strait of Georgia region, it has been subdivided into Evans Creek Stade, Vashon Stade, Everson Interstade, and Sumas Stade (Fig. 1). At the present time none of these subdivisions have been recognized in the Interior System.

### Strait of Georgia Region

Evans Creek Stade: Evans Creek Stade is defined as the "Climatic episode early in Fraser Glaciation during which large alpine glaciers formed ..." (Armstrong et al., 1965, p. 326). The episode was recognized in the western Cascade Mountains adjacent to the Puget Lowland where glacial deposits, referred to as Evans Creek, underlie glaciolacustrine sand deposited at Vashon Stade maximum (Crandell, 1963, pp. 32-36). The only place in southern British Columbia where a distinction has been made between alpine advance stage deposits and later, Vashon Stade ice sheet, deposits is the Cowichan River valley of southern Vancouver Island (Halstead, 1968). A maximum age of 19,150 ± 250 years B.P. (Halstead, 1968, GSC-210, Table III) has been indicated for these Evans Creek Stade deposits by organic material dated from underlying nonglacial sediments in the Cowichan River valley. Evans Creek Stade is not differentiated from Vashon Stade or Fraser Glaciation on the stratigraphic chart (Fig. 1) as, at the present time, very little is known of the extent, age and significance of deposits of this stade in southern British Columbia.

Vashon Stade: The Vashon Stade has been defined as the "last major climatic episode during which drift was deposited by continental ice originating in the mountains of the mainland of British Columbia and occupying the lowlands of

## TABLE III

Radiocarbon dates pertaining to Fraser Glaciation

| Site No. Fig. 4 | Laboratory Dating No. | Date | Location | | Published | | Collector | Significance | Material |
|---|---|---|---|---|---|---|---|---|---|
| | | | Lat. N. | Long. W. | Radiocarbon Volume No. | Page | | | |
| 1 | GSC-193 | 8,900±150 | 50°23'10" | 119°16'40" | 7 | 33 | R.J. Fulton | Fraser Min. | organic silt |
| 2 | S-113 | 9,000±150 | 49°33' | 121°24' | 4 | 77 | C.E. Borden | Sumas Min. | charcoal |
| 3 | GSC-1119 | 9,100±140 | 50°05'34" | 117°49'14" | 13 | - | R.J. Fulton | Fraser Min. | peat |
| 45 | GSC-1390 | 9,120±540 | 49°03'36" | 120°08'28" | 13 | - | A.L. van Ryswyk | Fraser Min. | charcoal |
| 4 | GSC-1065 | 9,160±150 | 50°38'10" | 117°55'35" | unpublished | | R.J. Fulton | Fraser Min. | wood |
| 5 | GSC-511 | 9,210±150 | 51°15' | 121°59' | 10 | 227 | W.H. Mathews | Fraser Min. | peat |
| 6 | GSC-923 | 9,280±160 | 50°36'30" | 118°43'30" | 12 | 72 | G.W. Smith | Fraser Min. | peat |
| 7 | GSC-256 | 9,320±160 | 49°53'00" | 120°37'30" | 7 | 33 | R.J. Fulton | Fraser Min. | peat |
| 8 | GSC-332 | 9,330±170 | 51°58' | 116°43' | 8 | 108 | J. Westgate | Fraser Min. | charcoal |
| 44 | GSC-1306 | 9,490±160 | 51°00' | 118°12' | 13 | - | H.W. Nasmith | Fraser Min. | wood |
| 9 | GSC-939 | 9,510±160 | 51°21'00" | 124°56'30" | 13 | - | R.J. Fulton | Fraser Min. | peat |
| 10 | GSC-526 | 9,750±170 | 50°32'30" | 119°45'10" | 9 | 172 | R.J. Fulton | Fraser Min. | plant fibers |
| 11 | GSC-522 | 9,880±160 | 54°03' | 128°37' | 9 | 174 | J.E. Armstrong | Fraser Min. | marine shells |
| 12 | GSC-1059 | 9,990±150 | 51°01'15" | 118°13'20" | unpublished | | R.J. Fulton | Fraser Min. | wood |
| 43 | GSC-1457 | 10,000±140 | 51°28'55" | 17°13'25" | unpublished | | R.J. Fulton | Fraser Min. | peat |
| 13 | GSC-855 | 10,000±150 | 49°14'40" | 117°58'50" | 12 | 71 | R.J. Fulton | Fraser Min. | peat |
| 14 | GSC-1012 | 10,000±150 | 49°52' | 118°05' | unpublished | | R.J. Fulton | Fraser Min. | wood |
| 15 | GSC-905 | 10,200±190 | 50°15' | 118°47' | 12 | 72 | G.W. Smith | Fraser Min. | plant fibers |
| 16 | GSC-719 | 10,270±190 | 49°57' | 116°51'15" | 10 | 223 | R.J. Fulton | Fraser Min. | peat |
| 17 | GSC-535 | 10,420±160 | 54°21' | 128°31' | 9 | 174 | J.E. Armstrong | Fraser Min. | marine shells |
| 18 | GSC-185 | 10,690±180 | 49°35' | 123°13' | 7 | 34 | J.E. Armstrong | Fraser Min. | wood |
| 19 | GSC-523 | 10,790±180 | 54°25' | 128°31' | 9 | 174 | J.E. Armstrong | Sumas (?) Max. | marine shells |
| 20 | GSC-909 | 11,000±180 | 49°30'30" | 118°05'20" | 12 | 71 | R.J. Fulton | Fraser Min. | freshwater marl |
| 21 | GSC-227 | 11,300±190 | 49°35' | 123°13' | 7 | 34 | J.E. Armstrong | Fraser Min. | marine shells |
| 22 | GSC-226 | 11,590±280 | 49°02'30" | 122°47' | 7 | 34 | J.E. Armstrong | Sumas Max.* | wood |

*Date is also a Vashon Minimum

TABLE III (CONT.)

| Site No. Fig. 4 | Laboratory Dating No. | Date | Location | | Published | | Collector | Significance | Material |
|---|---|---|---|---|---|---|---|---|---|
| | | | Lat. N. | Long. W. | Radiocarbon Volume No. | Page | | | |
| 23 | GSC-186 | 11,680±180 | $49^{\circ}06'$ | $122^{\circ}30'$ | 7 | 35 | J.E. Armstrong | Sumas Max.* | marine shells |
| 24 | GSC-168 | 11,930±190 | $49^{\circ}10'$ | $122^{\circ}35'$ | 6 | 170 | J.E. Armstrong | Sumas Max.* | marine shells |
| 25 | GSC-398 | 12,440±230 | $48^{\circ}35'30''$ | $123^{\circ}23'30''$ | 8 | 113 | E.C. Halstead | Fraser Min. | marine shells |
| 26 | GSC-64 | 12,460±170 | $49^{\circ}08'$ | $122^{\circ}55'$ | 5 | 46 | J.E. Armstrong | Vashon retreat | marine shells |
| 27 | I(GSC)-9 | 12,500±450 | $49^{\circ}38'40''$ | $125^{\circ}00'10''$ | 3 | 48 | J.G. Fyles | Fraser Min. | marine shells |
| 28 | I(GSC)-6 | 12,625±450 | $49^{\circ}01'$ | $122^{\circ}50'$ | 3 | 49 | J.E. Armstrong | Vashon Min. | marine shells |
| 29 | GSC-246 | 12,660±160 | $48^{\circ}28'30''$ | $123^{\circ}21'$ | 7 | 36 | C.H. Clapp | Fraser Min. | marine shells |
| 30 | GSC-389 | 12,740±170 | $49^{\circ}12'18''$ | $124^{\circ}00'$ | 8 | 113 | E.C. Halstead | Fraser Min. | worm tubes |
| 31 | GSC-418 | 12,750±170 | $48^{\circ}39'30''$ | $123^{\circ}26'$ | 8 | 113 | E. Livingston | Fraser Min. | marine shells |
| 32 | I(GSC)-248 | 12,800±175 | $49^{\circ}01'$ | $123^{\circ}04'$ | 4 | 36 | J.E. Armstrong | Vashon retreat | marine shells |
| 33 | GSC-913 | 19,100±240 | $50^{\circ}18'$ | $118^{\circ}51'$ | 12 | 72 | G.W. Smith | Fraser Max. | plant detritus |
| 34 | GSC-210 | 19,150±250 | $48^{\circ}46'43''$ | $123^{\circ}53'36''$ | 7 | 36 | E.C. Halstead | Fraser Max. | organic silt |
| 35 | GSC-194 | 20,230±270 | $50^{\circ}56'10''$ | $119^{\circ}24'15''$ | 7 | 33 | R.J. Fulton | Fraser Max. | wood |
| 36 | GSC-195 | 21,070±290 | $48^{\circ}46'30''$ | $123^{\circ}56'50''$ | 7 | 36 | E.C. Halstead | Fraser Max. | wood |
| 37 | GSC-173 | 21,500±300 | $52^{\circ}06'$ | $118^{\circ}23'$ | 7 | 32 | H.W. Nasmith | Fraser Max. | wood |
| 38 | GSC-477 | 21,630±870 | $50^{\circ}37'30''$ | $119^{\circ}11'50''$ | 9 | 172 | R.J. Fulton | Fraser Max. | wood |
| 39 | GSC-1258 | 21,700±2409 | $52^{\circ}11'40''$ | $118^{\circ}27'33''$ | 13 | - | R.A. Achard | Fraser Max. | wood |
| 40 | GSC-84 | 22,600±300 | $48^{\circ}29'40''$ | $123^{\circ}19'10''$ | 5 | 50 | J.G. Fyles | Vashon Max. | plant fibers |
| 41 | I-773 | 22,900±1500 | $52^{\circ}07'$ | $118^{\circ}24'$ | 8 | 175 | F. Mylrea | Fraser Max. | wood |
| 42 | I-2280 | 9,920±760 | $48^{\circ}59'$ | $122^{\circ}06'$ | Easterbrook | 1969 | D.J. Easterbrook | Sumas Min. | peat |

*Date is also a Vashon Minimum

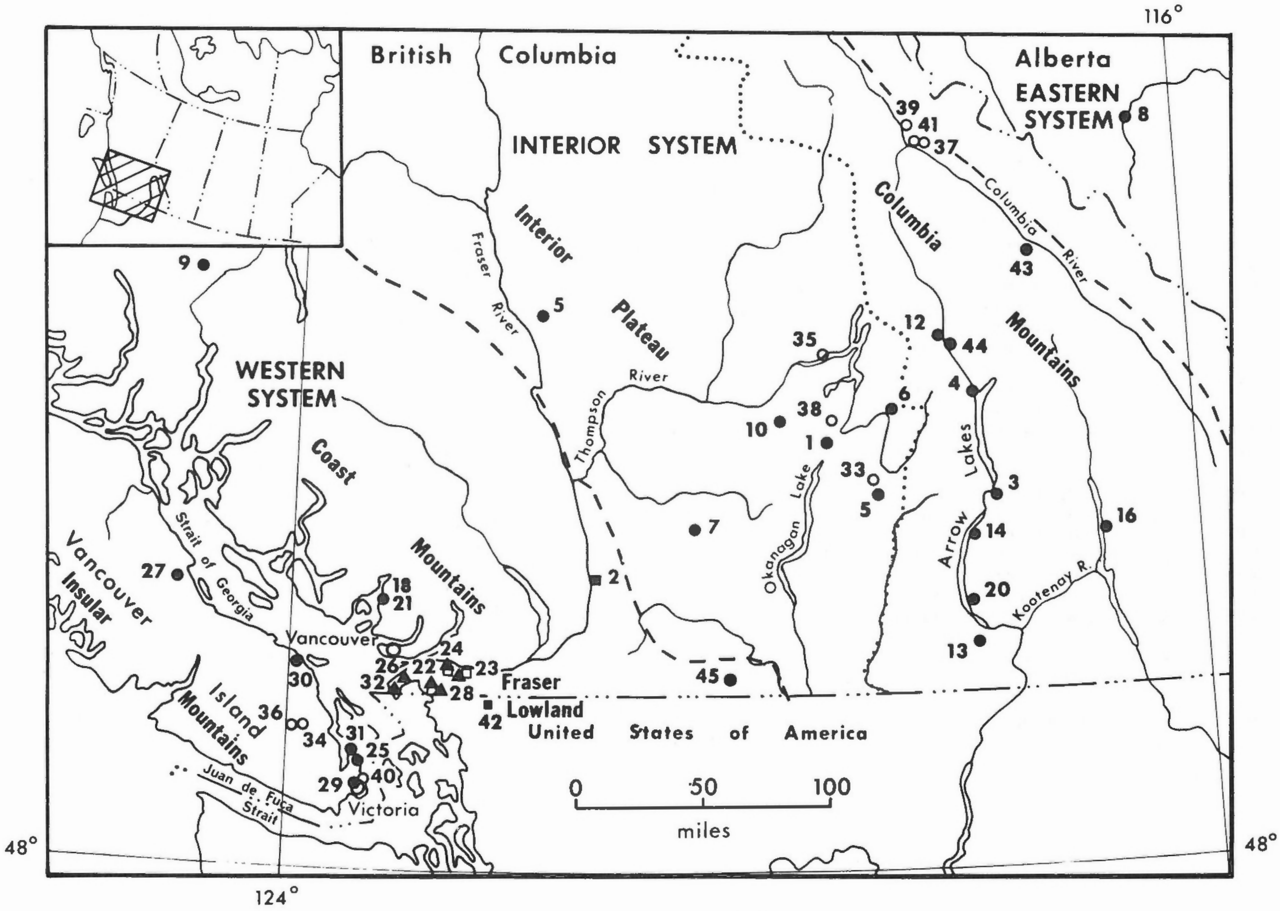

Figure 4. Distribution of Fraser Glaciation radiocarbon dates - minimum age ●. maximum age ○.
Date pertaining to Vashon Stade - minimum ▲. maximum △.
Date pertaining to Sumas Stade - minimum ■. maximum □.
Numbers refer to dates listed in Table III.

southwestern British Columbia and northwestern Washington" (Armstrong et al., 1965, p. 327). During the Vashon Stade, ice moving out of the Coast and Insular Mountains filled the valleys, covered the lowlands and pushed south across the Fraser Lowland and down the Strait of Georgia as an ice sheet. Fyles (1963, p. 40) says Vashon ice was thick enough to flow across the Vancouver Island Mountains. Mathews et al. (1970, p. 691) are more specific and suggest that the ice extended upward to about 4,000 or 5,000 feet in the mountains of Vancouver Island and declined southward to about 3,500 feet near Victoria and 1,500 feet near the west end of Juan de Fuca Strait. To the south, the Vashon ice terminated in the southern Puget Lowland about 50 miles south of Seattle (Mullineaux et al., 1965, p. 08). Most workers refer to the ice as terminating on the continental shelf at the west end of Juan de Fuca Strait (Wilson, 1958) but no one has actually defined a limit. Anderson (1968) disputes the generally accepted view and states that "there is no sedimentary evidence (submarine) that the Vashon 'Juan de Fuca' ice lobe penetrated to the Pacific Ocean as previously postulated". Instead, he suggests that the terminus lay near the eastern end of Juan de Fuca Strait in the vicinity of Victoria. The youngest limiting maximum date for Vashon advance is 19,150 ± 250 years B.P. (GSC-210, Halstead, 1968, Table III). Other dates of 21,070 ± 290 and 22,600 ± 300 years B.P. (GSC-195 and GSC-84, Table III) from underlying nonglacial deposits in the Strait of Georgia region suggest that the Vashon ice sheet did not override the area until after 20,000 years B.P. Retreat of Vashon Stade ice, as dated by marine deposits laid down during post-Vashon submergence, suggest that the Strait of Georgia and Fraser Lowland were undergoing deglaciation about 13,000 years ago (12,750 ± 170, GSC-418; 12,740 ± 170, GSC-389; 12,500 ± 450, I(GSC)-9; Table III, Fyles, 1963, p. 74; Mathews et al., 1970, p. 695).

Everson Interstade: The Everson Interstade is defined as the episode of Vashon ice retreat during which glaciomarine, marine, and related deposits accumulated in the coastal lowlands (Armstrong et al., 1965, p. 327). It is said to have begun when marine water invaded the area and ended during advance of Sumas ice or with the withdrawal of the sea and disappearance of floating ice. Using this definition, it follows that the Everson Interstade began about 13,000 years B.P. (see retreat of Vashon Stade ice above) and had ended 11,500 ± 200 years ago (L-441B, Fyles, 1963, p. 92; Mathews et al., 1970, p. 696, Table IV) on the Vancouver Island side of the Strait of Georgia and ended about 10,690 ± 180 years ago (GSC-185, Table IV) in Howe Sound on the mainland side. This period agrees well with the Everson Interstade in the San Juan Islands as reported by Easterbrook (1969, p. 2284).

Sumas Stade: The Sumas Stade was a period when, it appears, Cordilleran ice readvanced in the Fraser Valley to deposit Sumas drift on top of Everson Interstade deposits (Armstrong et al., 1965). Stratigraphic evidence for the Sumas advance has been found only in the Fraser Lowland (Armstrong, 1960, pp. 12-13). Mathews et al. (1970), however, refer to a submarine moraine said to mark the limit of Sumas ice in Howe Sound and Halstead (1968, p. 1413) refers to a still stand in the Cowichan Valley of Vancouver Island, which he ascribes to the climatic change responsible for the Sumas readvance. The average dates of pre- and proglacial Sumas samples as reported by Mathews et al. (1970, p. 696) is 11,400 years B.P., indicating that the Sumas maximum probably occurred soon after that time. Easterbrook (1969, p. 2285)

## TABLE IV

Radiocarbon dates connected with postglacial sea levels different from the present level

| Site No. Fig. 5 | Laboratory Dating No. | Date | Location | | Published | | Collector | Significance | Material |
|---|---|---|---|---|---|---|---|---|---|
| | | | Lat. N. | Long. W. | Radiocarbon Volume No. | Page | | | |
| 1 | GSC-325 | 5,790±140 | 48°28'30" | 123°21'30" | 8 | 112 | E.C. Halstead | 90 ft. above * | peat |
| 2 | GSC-395 | 6,790±150 | 49°02'30" | 123°04'00" | 8 | 110 | W.L. Brown | 50 ft. below * | shells |
| 3 | GSC-229 | 8,290±140 | 49°13' | 122°42' | 7 | 35 | A. McLean | 34 ft. below * | peaty silt |
| 4 | GSC-225 | 8,360±170 | 49°02' | 122°16' | 7 | 35 | E.C. Halstead | 35 ft. below * | plant detritus |
| 5 | GSC-265 | 8,680±140 | 49°40'20" | 124°53' | 8 | 113 | J.G. Fyles | 10 ft. above * | soil |
| 6 | GSC-228 | 9,420±180 | 49°15' | 122°56' | 7 | 35 | W.H. Mathews | 41 ft. above * | limnic peat |
| 7 | GSC-522 | 9,880±160 | 54°03' | 128°37' | 9 | 174 | J.E. Armstrong | 125 ft. above * | shells |
| 8 | GSC-535 | 10,420±160 | 54°21' | 128°31' | 9 | 174 | J.E. Armstrong | 300 ft. above * | shells |
| 9 | GSC-519 | 10,430±150 | 49°05' | 122°47'45" | 9 | 173 | E.C. Halstead | 105 ft. below * | shells |
| 10 | GSC-185 | 10,690±180 | 49°35' | 123°13' | 7 | 34 | J.E. Armstrong | 190 ft. above ** | wood |
| 11 | GSC-523 | 10,790±180 | 54°25' | 128°31' | 9 | 174 | J.E. Armstrong | 300 ft. above * | shells |
| 33 | GSC-1130 | 11,200±170 | 48°24'45" | 123°21'15" | 13 | - | H.W. Nasmith | 5 ft. above * | freshwater shells |
| 32 | GSC-1142 | 11,200±190 | 48°24'45" | 123°21'15" | 13 | - | H.W. Nasmith | 5 ft. above * | muck |
| 12 | GSC-227 | 11,300±190 | 49°35' | 123°13' | 7 | 34 | J.E. Armstrong | 190 ft. above ** | shells |
| 13 | GSC-945 | 11,400±190 | 48°27' | 123°29' | 12 | 74 | H.W. Nasmith | 50 ft. above * | gyttja |
| 34 | GSC-1131 | 11,500±160 | 48°24'45" | 123°21'15" | 13 | - | H.W. Nasmith | 5 ft. above * | peat |
| 14 | L-441B | 11,500±200 | 49°35' | 124°49' | 1 | 16 | J.G. Fyles | 120 ft. above ** | shells |
| 15 | GSC-186 | 11,680±180 | 49°06' | 122°30' | 7 | 35 | J.E. Armstrong | 310 ft. above * | shells |
| 16 | I(GSC)-10 | 11,780±450 | 49°38'30" | 125°00'10" | 3 | 48 | J.G. Fyles | 500 ft. above ** | peat |
| 17 | L-391F | 11,850±300 | 49°29' | 124°49' | 1 | 15 | J.G. Fyles | 70 ft. above ** | wood |
| 18 | GSC-168 | 11,930±190 | 49°10' | 122°35' | 6 | 170 | J.E. Armstrong | 40 ft. above * | shells |
| 19 | I(GSC)-1 | 12,000±450 | 49°17' | 124°12' | 3 | 48 | J.G. Fyles | 170 ft. above ** | wood |
| 35 | GSC-1114 | 12,100±160 | 48°24'45" | 123°21'15" | 13 | - | H.W. Nasmith | 5 ft. above * | shells |
| 20 | GSC-24 | 12,200±160 | 49°41' | 125°02' | 4 | 19 | J.G. Fyles | 175 ft. above ** | wood |
| 21 | GSC-74 | 12,230±200 | 49°15' | 122°56' | 5 | 45 | W.H. Mathews | 39 ft. above * | shells |
| 22 | L-391E | 12,350±250 | 49°17' | 124°12' | 1 | 15 | J.G. Fyles | 170 ft. above ** | shells |
| 23 | GSC-38 | 12,360±140 | 49°41' | 125°02' | 4 | 19 | J.G. Fyles | 175 ft. above ** | shells |
| 24 | GSC-80 | 12,420±150 | 49°09'00" | 123°58'10" | 5 | 46 | E.C. Halstead | 354 ft. above * | shells |
| 25 | GSC-398 | 12,440±230 | 48°35'30" | 123°23'30" | 8 | 113 | E.C. Halstead | 25 ft. above * | shells |
| 26 | I(GSC)-9 | 12,500±450 | 49°38'40" | 125°00'30" | 3 | 48 | J.G. Fyles | 500 ft. above ** | shells |
| 27 | I(GSC)-6 | 12,625±450 | 49°01' | 122°50' | 3 | 49 | J.E. Armstrong | 260 ft. above * | shells |
| 28 | GSC-246 | 12,660±160 | 48°28'30" | 123°21' | 7 | 36 | C.H. Clapp | 90 ft. above * | shells |
| 29 | GSC-763 | 12,720±160 | 48°27'39" | 123°26'36" | 12 | 73 | H.W. Nasmith | 85 ft. above * | shells |
| 30 | GSC-389 | 12,740±170 | 49°12'20" | 124°00' | 8 | 113 | J.G. Fyles | 230 ft. above * | worm tubes |
| 31 | GSC-418 | 12,750±170 | 48°39'30" | 123°26' | 8 | 113 | E. Livingston | 80 ft. above ** | shells |

*Elevation is that of the dated sediment and is not necessarily related to sea level at that time.

**Elevation refers to sea level at the time of deposition of the organic-bearing sediments.

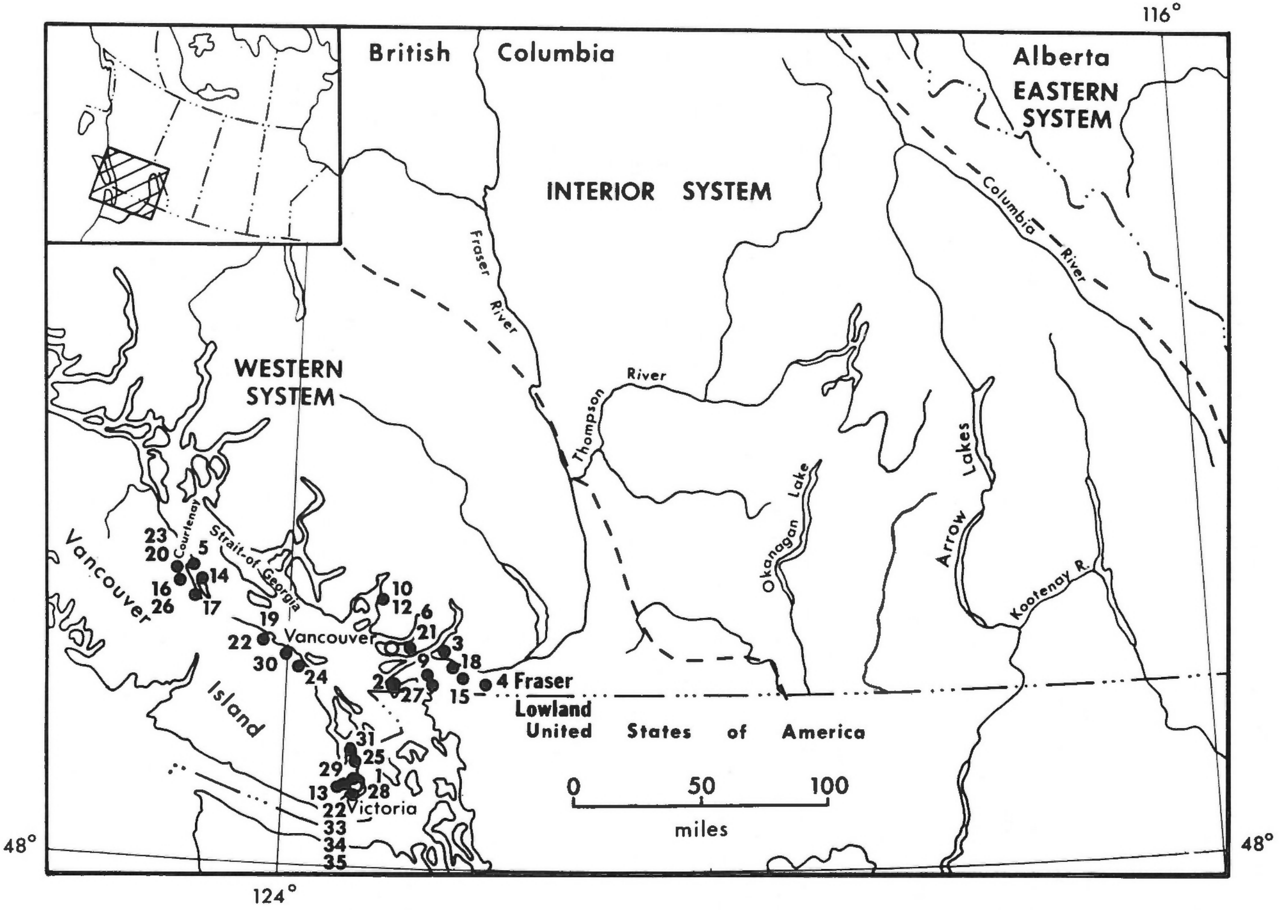

Figure 5. Distribution of radiocarbon dates connected with postglacial sea levels different from present sea level (dates mainly on marine limit). Numbers refer to dates listed in Table IV.

reports a date of 9,920 ± 760 years B.P. (I-2280, Table III) for bog bottom peat overlying Sumas Stade outwash. This means that Sumas ice had withdrawn from its maximum position before that time. Borden (1965, p. 165) reports Indian occupation at the south end of the Fraser Canyon in an area that, during Sumas time, would either have been covered by ice or flooded by a glacial lake 9,000 ± 150 years B.P. (S-113, Table III). The Sumas Stade, therefore, must have ended more than 9,000 years ago.

## Interior System

Fraser Advance: At the onset of Fraser Glaciation, ice build-up in the Interior System is believed to have begun in the Coast and Columbia Mountains with ice tongues from these areas coalescing as an ice sheet in the Interior Plateau. At the southern end of the Plateau this ice sheet moved south over the International Boundary to a terminus on the Columbia Plateau in northern Washington. At Fraser Glaciation maximum, according to the "Glacial Map of Canada" (Wilson, 1958), ice in the Interior Plateau probably formed a domed mass, the surface of which stood higher than the rimming mountains.

Fraser Retreat: The major domed ice sheet which occupied the Interior Plateau at Fraser Glaciation maximum would have acted as the main accumulation area for the Interior System (Flint, 1957, p. 306). Because this ice sheet was held in place by surrounding mountain ranges, it would have been necessary to raise the regional snowline as high as the domed top of the ice mass before retreat away from the inside edges of the mountains could begin. Once the snowline was near the top of the dome, the hemmed-in sheet would recede largely by downwasting. Downwasting would lower the dome and would have the same effect on the size of the accumulation area as raising the snowline. Hence, even though there was no climatic change, the height of the climatic snowline above the top of the ice dome would increase. This means that, once recession of the Interior ice mass started, to all intents the sheet became climatically dead, and a significant lowering of the snowline would have been required to produce a readvance.

Insufficient work has been done on the Interior System to permit construction of a detailed regional deglaciation picture. However, enough work has been done in limited areas (Nasmith, 1962; Fulton, 1967 and 1969) to permit general comments on the patterns of retreat. Ice sheet recession was accomplished by downwasting with a frontal retreat beginning in the southern Columbia Mountains and proceeding northwest towards the topographically low part of the Interior Plateau, in the vicinity of the 52nd parallel. On a local scale, individual mountains and uplands appeared through the ice cover while ice remained in the adjacent valleys. This pattern of retreat caused a complicated history of glacial lake formation (Fulton, 1969). On a regional scale, ice receded from the mountainous areas and hilly uplands while stagnant, climatically dead ice remained in the major valleys and topographic basins. Hence, the southern Columbia Mountains became free of ice before the Okanagan Highlands to the west; the Okanagan Highlands became ice free while an ice tongue remained in Okanagan Valley and the hilly Thompson Plateau was ice free while ice remained on the lower Fraser Plateau to the north.

Interior System during Sumas Stade: A Sumas ice advance in the Interior System has not been documented. The oldest postglacial date, 11,000 ± 180

(GSC-909, Table III) falls within the Sumas Stade as defined on the coast. This suggests that deglaciation of at least part of the Interior occurred before or during the part of Fraser Glaciation referred to as Sumas Stade. Dates of 10,100 ± 150 and 9,990 ± 150 (GSC-1012 and GSC-1059, Table III) from shoreline deposits of a lake that occupied the Columbia River valley after most differential isostatic recovery had taken place, reinforce the suggestion that the glaciers were not advancing in the Interior System during the Sumas Stade.

Bog bottom dates become progressively younger as one moves from the Columbia Mountains towards the Coast Range (Fig. 1). This might be explained as an effect of the climatic deterioration responsible for the Sumas Stade. The ice retreat, which began in the Interior System prior to the Sumas Stade (see above), possibly caused the interior ice dome to downwaste to a level below the subsequent elevation of the Sumas snowline. The following Sumas climatic episode, then, was not severe enough to cause a significant ice advance in the southern Interior System area. The Coast Mountains to the west, however, acted as a Sumas accumulation area. This ice build-up at the western edge of the Interior System may have steepened the west to east gradient of the surface of the interior ice mass, and slowed and changed the direction of recession of the ice front.

Fraser Glaciation ice had probably retreated from southern British Columbia at least 9,510 ± 160 years ago (GSC-939, Table III). This date from basal sediments of a bog immediately outside the terminus of present-day Tiedemann Glacier indicates that the Coast Mountains were as free of ice as they are at present, at least that long ago, and the Interior System was probably ice free as early as were the valleys in the Coast Mountains.

## POSTGLACIAL SEA LEVELS

A few of the many dates on postglacial sea levels different from present sea level are given in Table IV and located on Figure 5. Most dates listed are related to marine limit and early high sea levels. Postglacial sea levels and the events that caused fluctuations of sea level are discussed in detail by Mathews *et al*. (1970). Some of their general conclusions are: sea level was high at the time of Vashon ice retreat because of isostatic depression; the marine limit varied from 250 feet at Victoria to 500 feet near Courtenay, to possibly as much as 1,000 feet near Vancouver; emergence was rapid and, despite a eustatic rise, local sea level fell to, or below, its present level in less than 2,000 years; a second later period of submergence, which took place in the Fraser Lowland and parts of the Strait of Georgia, could have been due to a combination of isostatic depression due to build-up of Sumas ice and rapid eustatic sea level rise; the second emergence of the affected areas was rapid and was probably completed in less than 2,000 years; at the end of the second emergence, local sea level was as much as 35 feet lower than present; isostatic uplift appears to have been completed by 8,000 years ago and, since then, eustatic changes in sea level have brought it to its present level.

## VOLCANIC ASH FALLS

Ash falls are deposits of airborne, volcanic dust consisting of glass shards and both light and heavy phenocryst mineral grains. Ash fall deposits are exceedingly useful as a time synchronous marker bed. Once the date of an ash fall has been established, one knows that ash represents the same time interval at every other place at which that primary deposit can be identified. The big difficulty is in positively identifying and correlating ash falls. Most ashes have similar mineralogy and similar gross appearance so that positive identification cannot be made by casual observation. Difficult and time consuming techniques have been developed to identify and correlate ash fall deposits. The two main techniques used are precise measuring of the refractive indices of volcanic glass and mineral grains (Wilcox, 1965) and chemical analysis by means of the electron probe (Smith and Westgate, 1969).

Four postglacial deposits and one of Olympia Interglacial age have been dated in southern British Columbia. Table V lists radiocarbon dates pertaining to these deposits. The main published information on southern British Columbia ash falls is Nasmith et al. (1967) and Westgate et al. (1970).

### Olympia Interglacial Volcanic Ash Falls

Ash falls have been reported from several Quaternary successions in British Columbia pre-dating Fraser Glaciation (Fulton, 1965a, 1968, and Smith, 1969). At only one place has it been possible to bracket one of these ash falls with finite radiocarbon dates and so show that the ash fall is definitely of Olympia Interglaciation age (Fulton, 1968, Table V). Smith (1969) used this ash, approximately 37,000 years old, to correlate sections one hundred miles apart. The correlating potential of these older ash falls has not been tapped as yet.

### Postglacial Ash Falls

Mazama Ash Fall: The Mazama ash fall, the most widespread deposit of its type in southern British Columbia, is found from Victoria to Saskatchewan (Westgate et al., 1970) and possibly extends as far as one hundred miles north of Prince George (Hansen, 1955, p. 653). The irruptive source of the ash is at Crater Lake in southwestern Oregon (Powers and Wilcox, 1964). A 6,640 ± 250 years B.P. date on charcoal buried in pumice at Crater Lake has been used to date this ash fall (W-858, Rubin and Alexander, 1960, p. 161). A 6,560 ± 115 B.P. (I-3809, Table V) age for charcoal collected from Mazama ash in the Columbia River valley (date obtained by CASECO Engineering, Vancouver) agrees closely with this date from the source area. The other dates (Table V) from British Columbia bracket this accepted age.

St. Helens Y Ash Fall: St. Helens Y ash has been recognized as a narrow northeast-trending fall extending across southern British Columbia from the source volcanic peak, Mount St. Helens, in southwestern Washington (Westgate et al., 1970). Crandell et al. (1962) assigned a date of about 3,200 to the St. Helens Y ash fall. Two dates, 3,410 ± 130 and 3,390 ± 130 (GSC-345 and GSC-298, Table V) on peat from below this ash in southern

British Columbia do not contradict this age assignment but a date on wood (3,430 ± 140, GSC-1461, Table V) from above an ash bed assigned to this fall suggests the ash may be older than 3,200 years B.P.

Bridge River Ash Fall: Bridge River ash is the only indigenous southwest British Columbia ash that has been studied in detail (Stevenson, 1947, Wilcox, 1965, Nasmith et al., 1967, Westgate and Driemanis, 1967, Westgate et al., 1970). The source vent has not been precisely located but the fall occurs as a relatively narrow strip extending east from the headwaters of the Bridge and Lillooet Rivers. Bridge River ash fall has been dated as having occurred between 2,290 ± 130 (GSC-1520, Table V) and 2,440 ± 140 years B.P. (GSC-529, Nasmith et al., 1967, Table V).

Other Postglacial Ash Fall: A thin widely dispersed ash fall occurs across southcentral British Columbia. A detailed study has not been made of this ash but it appears similar petrographically to St. Helens W ash, is about the same age and lies immediately north of a locality where Wilcox reports a St. Helens W-like ash (Wilcox, pers. comm., 1967). In southcentral British Columbia, a piece of wood from below this ash has been dated at 1,220 ± 130 years B.P. (GSC-832, Table V).

Glacier Peak Ash Fall: The Glacier Peak ash, which fell about 12,000 years B.P. (Powers and Wilcox, 1964) has not been identified in British Columbia but probably will be found in the southeastern corner of the province. Glacier Peak ash has been identified in southern Alberta (Westgate et al., 1970) and known occurrences lie as near as twenty miles south of the British Columbia-Washington border (Powers and Wilcox, 1964).

## POSTGLACIAL CLIMATE

A radiocarbon dated postglacial climate chronology is not available for southern British Columbia. The most comprehensive climate report to date is that of Hansen (1955). His main general conclusions for southcentral British Columbia are: (1) the arboreal pollen record begins in the lowest organic sediments and even in underlying silt; (2) a thermal maximum was reached about 6,000 years ago. The first conclusion suggests that the area quickly went from glacial to nonglacial climate without an intervening stage of tundra vegetation. This conclusion may hold true for southcentral British Columbia but there is evidence for a much colder climate on Vancouver Island about 12,000 years ago (Terasmae and Fyles, 1959). In Alaska severe climate is said to have ended 11,000 years B.P. (McCulloch and Hopkins, 1966). As this is the time when southcentral British Columbia was undergoing deglaciation, it is possible much of this area was deglaciated late enough so that it lay in a zone of temperate climate when it was uncovered by ice. The inclusion of a *Bison* cf. *occidentalis* skull in a glacial lake delta near Vernon also suggests that the climate was moderately warm at the time of deglaciation of the Interior System.

Hansen (1955) based the 6,000 year age of the thermal maximum on its coincidence with volcanic ash which he mistakenly thought came from Glacier Peak. More recent work (Powers and Wilcox, 1964, p. 1335) has

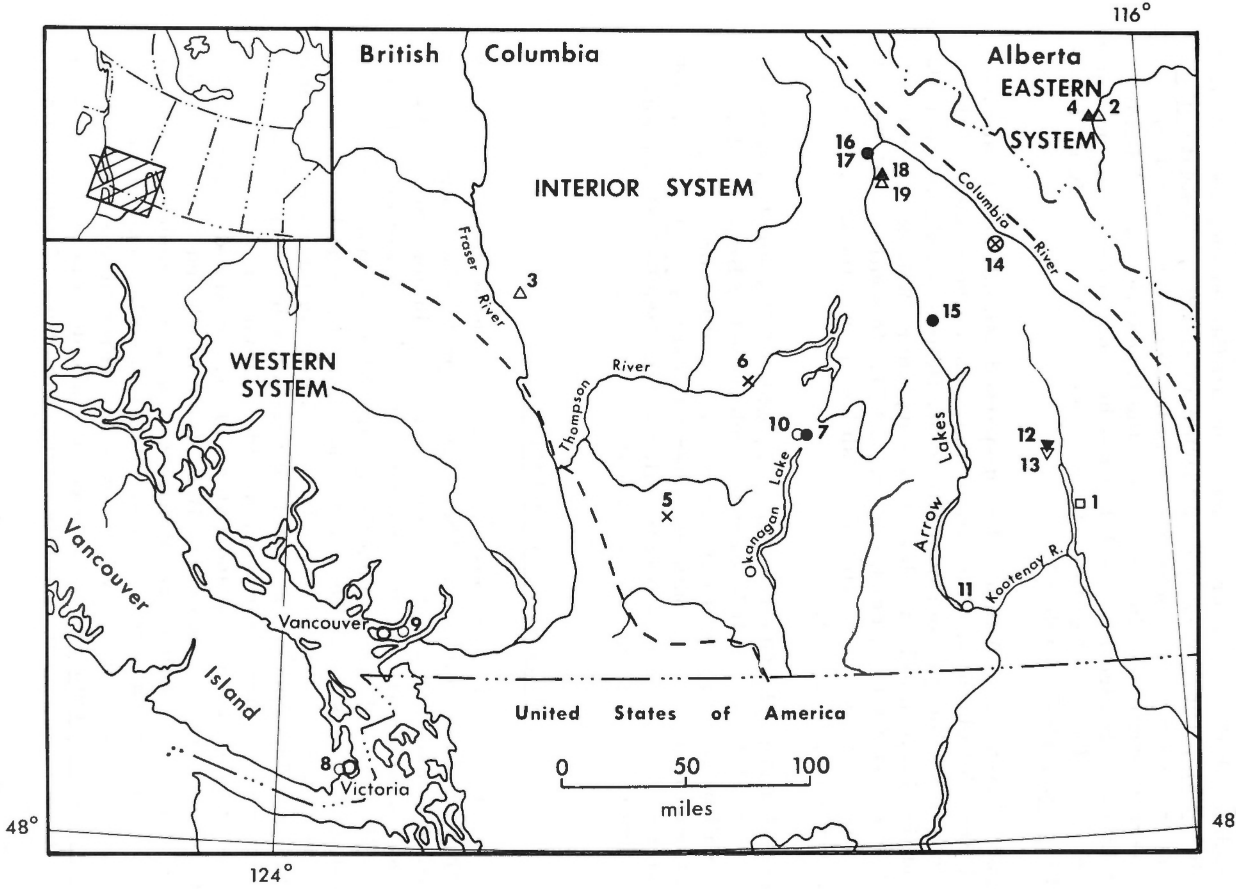

Figure 6. Distribution of radiocarbon dates pertaining to volcanic ash falls: Mazama, Minimum date ● Maximum date ○ ; St. Helens Y, Maximum date × Minimum date ⊕ ; Bridge River, Minimum date ▲ ; Maximum date △ ; St. Helens W(?), Maximum date □ ; Pre-Fraser Ash, Minimum ▼ ; Maximum ▽ . Numbers refer to dates listed in Table V.

TABLE V

Radiocarbon dates pertaining to ash falls

| Site No. Fig. 6 | Laboratory Dating No. | Date | Location |  | Published |  | Collector | Significance |  | Material |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Lat. N. | Long. W. | Radiocarbon Volume No. | Page |  | Min. | Max. |  |
|  |  |  | St. Helens W |  |  |  |  |  |  |  |
| 1 | GSC-832 | 1,220±130 | 49°57'00" | 116°51'15" | 12 | 70 | R.J. Fulton |  | Max. | wood |
|  |  |  | Bridge River |  |  |  |  |  |  |  |
| 2 | GSC-577 | 2,120±150 | 51°58' | 116°43' | 10 | 223 | A. Dreimanis | Min. |  | charcoal |
| 18 | GSC-1520 | 2,290±130 | 52°01' | 118°34' | unpublished |  | R.J. Fulton | Min. |  | peat |
| 3 | GSC-529 | 2,440±140 | 51°15' | 121°59' | 10 | 227 | W.H. Mathews |  | Max. | peat |
| 19 | GSC-1532 | 2,480±130 | 52°01' | 118°34' | unpublished |  | R.J. Fulton |  | Max. | peat |
| 4 | GSC-531 | 2,670±140 | 51°58' | 116°43' | 10 | 223 | A. Dreimanis |  | Max. | charcoal |
|  |  |  | St. Helens Y |  |  |  |  |  |  |  |
| 14 | GSC-1461 | 3,430±140 | 51°28'55" | 117°13'25" | unpublished |  | R.J. Fulton | Min. |  | wood |
| 5 | GSC-298 | 3,390±130 | 49°53'00" | 120°37'30" | 8 | 110 | R.J. Fulton |  | Max. | peat |
| 6 | GSC-345 | 3,410±130 | 50°41'25" | 119°50'50" | 8 | 110 | R.J. Fulton |  | Max. | charcoal |
|  |  |  | Mazama "0" |  |  |  |  |  |  |  |
| 15 | GSC-1183 | 5,500±140 | 51°04'25" | 118°04'15" | 13 | - | R.D. Muir | Min. |  | peat |
| 17 | I-3807 | 5,550±120 | 52°06' | 118°33' | unpublished |  | K. Ricker | Min. |  | wood |
| 7 | GSC-214 | 6,270±140 | 50°23'10" | 119°16'40" | 7 | 33 | R.J. Fulton | Min. |  | organic muck |
| 8 | GSC-963 | 6,390±160 | 48°27' | 123°29' | 12 | 74 | H.W. Nasmith |  | Max. | gyttja |
| 16 | I-3809 | 6,560±115 | 52°06' | 118°33' | unpublished |  | K. Ricker | within ash |  | charcoal |
| 9 | GSC-321 | 7,340±360 | 49°14'45" | 122°57'15" | 8 | 110 | W.H. Mathews | - | - | peat |
| 10 | GSC-206 | 7,510±150 | 50°23'10" | 119°16'40" | 7 | 33 | R.J. Fulton |  | Max. | organic muck |
| 11 | GSC-213 | 8,380±150 | 49°20' | 117°52' | 7 | 32 | H.W. Nasmith |  | Max. | plant detritus |
|  |  |  | Pre-Fraser Glaciation ash fall |  |  |  |  |  |  |  |
| 12 | GSC-542 | 33,700±300 | 50°15' | 116°59' | 10 | 224 | R.J. Fulton | Min. |  | wood |
| 13 | GSC-716 | 41,800±700 | 50°15' | 116°59' | 10 | 224 | R.J. Fulton |  | Max. | wood |

## TABLE VI

Radiocarbon dates on evidence of postglacial climate significantly different from present climate

| Site No. Fig. 7 | Laboratory Dating No. | Date | Location | | Published | | Collector | Significance | | Material |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Lat. N. | Long. W. | Radiocarbon Volume No. | Page | | Warm | Cold | |
| 1 | GSC-571 | 450±130 | 51°17' | 118°29' | 9 | 171 | J.O. Wheeler | | cold | wood |
| 2 | GSC-977 | 1,270±140* | 51°21'00" | 124°56'30" | 13 | - | R.J. Fulton | | cold | peat |
| 3 | GSC-948 | 2,250±130* | 51°21'00" | 124°56'30" | 13 | - | R.J. Fulton | | cold | peat |
| 4 | GSC-938 | 2,940±130* | 51°21'00" | 124°56'30" | 13 | - | R.J. Fulton | | cold | peat |
| 5 | GSC-169 | 3,760±140 | 51°19' | 118°01' | 6 | 170 | J.O. Wheeler | warm | | wood |
| 6 | Y-140 bis | 5,260±200 | 49°52' | 122°59' | 2 | 58 | W.H. Mathews | warm | | wood |
| 7 | GSC-197 | 5,470±140 | 51°46'30" | 118°54' | 8 | 109 | E.D. Dodson | warm | | wood |
| 8 | GSC-760 | 5,950±140 | 49°44' | 121°57' | 10 | 226 | E.D. Dodson | warm | | wood |
| 9 | GSC-1390 | 9,120±540 | 49°03'36" | 120°08'28" | 13 | - | A.L. van Ryswyk | warm | | charcoal |

*Dates corrected for $C^{13}/C^{12}$ ratio

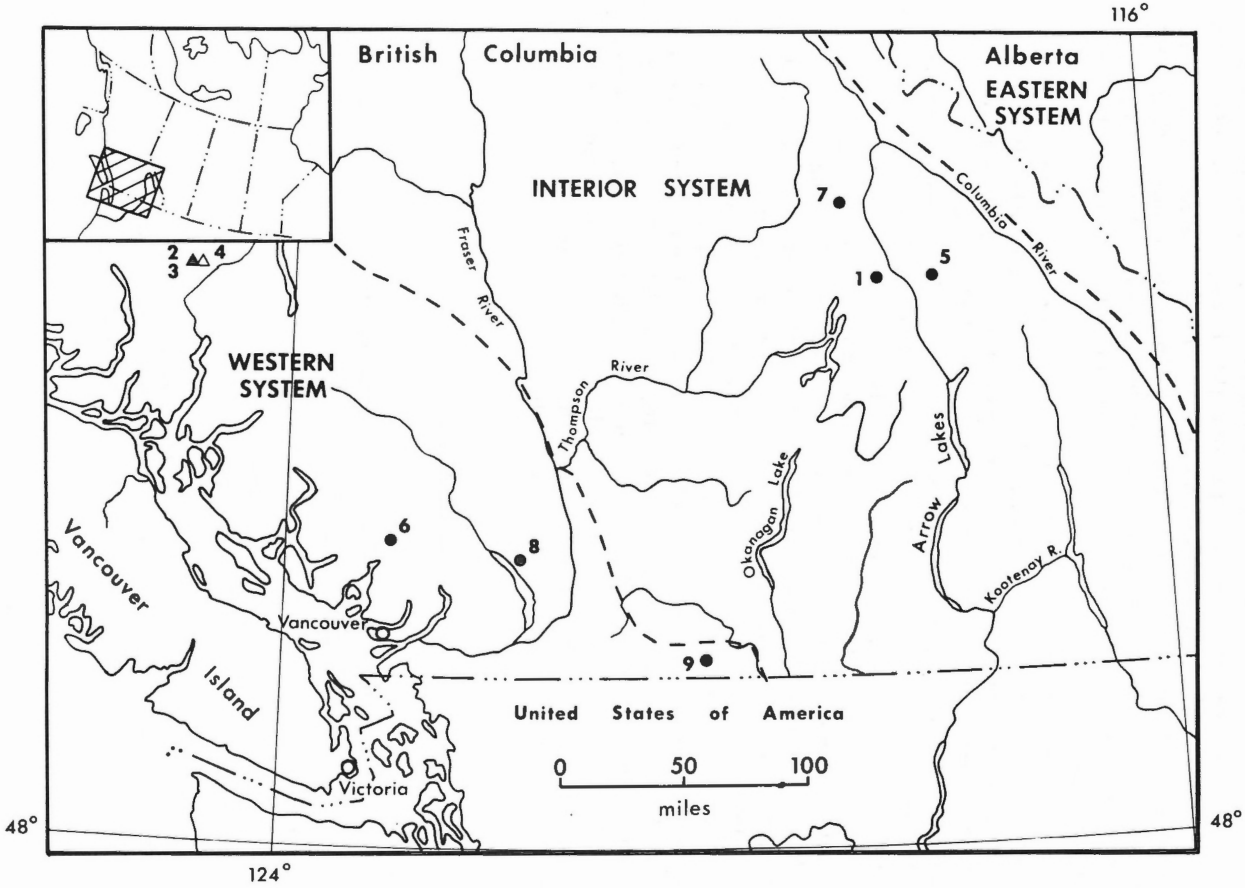

Figure 7. Distribution of radiocarbon dates connected with evidence of postglacial climate significantly different from present climate. Date on higher tree-line ● . Date on glacial advance, minimum age △ ; maximum age ▲ . Numbers refer to dates listed in Table VI.

shown that this ash was Mazama from Crater Lake. Hansen's age was based on the position of the ash in peat deposits and hence the age assigned was essentially correct even though the ash source was incorrectly named.

Several dates have been obtained for wood collected from snow, ice or glacial deposits which lie well above the present treeline (Lowdon and Blake, 1968, p. 226, Table VI). This wood indicates that, at the time of growth, the climate was warmer than present (Mathews, 1951, p. 366). The dates do not necessarily indicate the time when climate changed from warm to colder as dead wood can exist a long time in an alpine environment (Lamarche and Mooney, 1967). The dates on the wood (5,950 ± 140, 5,470 ± 140, 5,260 ± 200; GSC-760, GSC-197, Y-140 bis, Table VI) are close to Hansen's thermal maximum.

Throughout Alaska and the Yukon a well documented glacial advance took place between 3,000 and 2,500 years B.P. (Goldthwait, 1963, Porter, 1964, Borns and Goldthwait, 1966, Haselton, 1966, Denton and Stuiver, 1966, Porter and Denton, 1967, Rampton, 1970). In most parts of southern British Columbia, alpine glaciers reached their post-Wisconsin maximum in the past few centuries (Mathews, 1951, Munday, 1947) destroying or burying evidence of earlier, less extensive, advances. Several glaciers, however, have older moraine ridges outside the moraines built during the 18th and 19th centuries (Sherzer, 1907, Munday, 1936) indicating that earlier advances had taken place. Tiedemann Glacier, on the east flank of Mount Waddington, has several moraine ridges that lie outside the moraines built during the past few centuries. Dates from a bog into which Tiedemann Glacier advanced indicate that the glacier reached its maximum position 2,940 ± 130 years B.P. (GSC-938, Table VI) and had retreated from the oldest moraine 2,250 ± 130 years B.P. (GSC-948, Table VI). It appears, therefore, that the effect of climatic deterioration about 3,000 years ago was felt in southern British Columbia but that the coldest period (at least the time of greatest glacial advance) did not occur until the last few hundred years (Mathews, 1951, and 450 ± 130, GSC-571, Table VI).

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